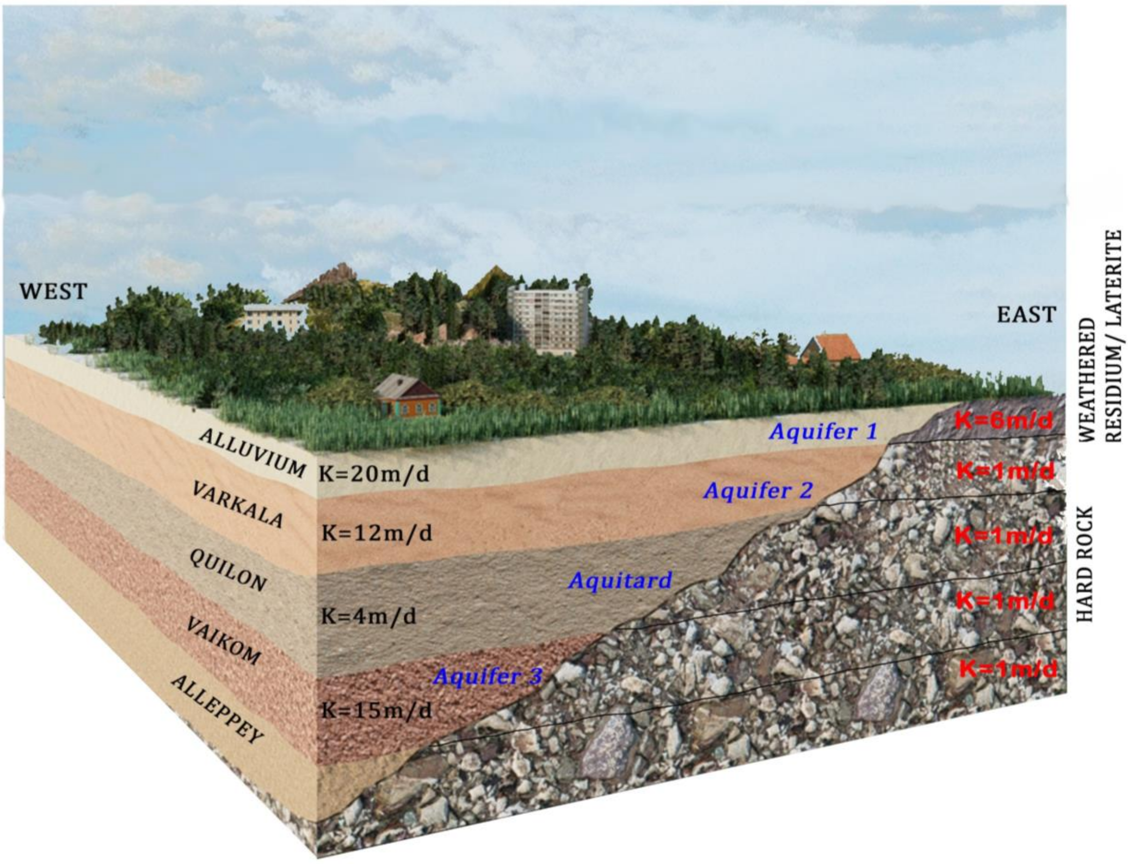
Report on

GROUND WATER FLOW MODELING OF MUVATTUPUZHA BASIN, CENTRAL KERALA



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CONTENTS

CHAPTERS			PAGE NO
1		**INTRODUCTION**	1
	1.1	Objectives of the study	1
	1.2	Previous studies	2
	1.3	Scope of the present study	3
2		**BACKGROUND INFORMATION**	4
	2.1	Location	4
	2.2	Rainfall & Climate	6
	2.3	Soil	7
	2.4	Geomorphology	6
	2.5	Drainage	9
	2.6	Geology	11
	2.7	Hydrogeology	13
3		**GROUND WATER FLOW MODELING**	24
	3.1	Flow equation	16
	3.2	Conceptual model	28
	3.3	Grid design and software	31
	3.4	Initial Condition	34
	3.5	Hydraulic Properties	35
	3.6	Recharge	37
	3.7	Ground Water Draft	39
	3.8	Evapotranspiration	42
	3.9	Model geometry and boundary conditions	43
4	4.0	Steady State calibration	44
		4.0.1 Zone Budget	47
		4.0.2 Cumulative zone budget	49
	4.1	Transient State	51

		4.1.1 Parameters	51
		4.1.2 Transient state calibration	53
		4.1.3 Data Validation	60
		4.1.4 Zone Budget	61
		4.1.5 Cumulative budget for transient state	63
	4.2	Sensitivity Analyses	67
	4.3	Inferences from modeling studies	69
5	5.0	**SUMMARY AND CONCLUSIONS**	72
	5.1	Limitations of the modelling study	74
		REFERENCES	75
		ANNEXURES	78

LIST OF FIGURES

Fig.No	Title	Page No
1	Administrative set up of study area	5
2	Monthly average rainfall distribution during 2014-2019	6
3	Geomorphology map of Muvattupuzha basin	8
4	Landform distribution of Muvattupuzha basin	9
5	River view at Perumuttam and Ramamangalam	10
6	Drainage network of Muvattupuzha River	11
7	Geological map of Muvattupuzha basin	12
8	Representative Elementary Volume (REV) used in the derivation of governing equation	24
9	Model domain view of Muvattupuzha Basin	25
10	Subsurface disposition of aquifer system in Muvattupuzha basin	28
11	3D aquifer disposition	29
12	Cross section showing disposition of multi layered aquifer system	30
13	Grid design of the study area with location of observation wells	32
14	Different zones in the study area	32
15	Distribution of Initial head 9top layer)	33
16	Zonal distribution of hydraulic conductivity	35
17	Hydraulic conductivity in different layers	35
18	Zonal distribution of recharge rates	37
19	Distribution of draft for steady state	40
20	Pictorial representation of draft for various aquifers	40
21	Distribution of Evapotranspiration values	41
22	Boundary conditions in the study area	43

23	Scatter plot of computed vs observed head for steady state	45
24	Distribution of Zone wise inflow and outflow components in steady state	48
25	Cumulative mass balance for steady state	49
26	Scatter plot of computed vs observed head during 1st stress period (31 days)	53
27	Scatter plot of computed vs observed head during end of third year (12 th stress period)	53
28	Scatter plot of computed vs observed head during end of fifth year (36 th stress period)	54
29	Scatter plot of computed vs observed head during end of fifth year (61 st stress period)	54
30	Transient state calibration -Well hydrograph showing comparison of computed and observed water levels of selected wells	55
31	Normalised RMS vs Time graph for the Transient state	57
32	Calibration Errors vs Time graph for the Transient state	57
33	Computed water levels with flow directions during different stress periods	58
34	Vertical view of water level contour during 48 th stress period and 60 th stress period	59
35	Zone budget for Transient State	62

LIST OF TABLES

Table No	Title	Page No
1	Landform units in Muvattupuzha Basin	8
2	General geological settings of Muvattupuzha Basin	13
3	Details of Exploratory wells in Muvattupuzha Basin (BW)	16
4	Details of Exploratory wells in Muvattupuzha Basin (TW)	18
5	Salient features Observation Wells	21
6	Temporal distribution of water level data of observation wells (m bgl) during 2014-2019	22
7	Zonal distribution of hydraulic properties	34
8	Zonal distribution of recharge rate for Steady State	37
9	Block wise details of draft applied in the model	39
10	Zone wise distribution of derived model parameters	46
11	Zone Budget-Steady State	47
12	Cumulative Zone Budget for Steady State	48
13	Error statistics (model residual statistics) at different periods of Transient State	56
14	Data validation for Transient State	60
15	Cumulative budget for Transient State	66
16	Sensitivity analyses for change in Hydraulic conductivity values	67
17	Sensitivity analyses for change in ET	68

LIST OF ANNEXURES

Annexure No	Title	Page No.
1A	Zone wise distribution of recharge rate (m^3/d) for Transient State	77-78
1B	Ground water pumping schedule(m^3/d) for Transient State	79-81
1C	River stage data for Transient State	82-99
1D	Evapotranspiration rate for Transient State	100-102
1E	Constant Head variations for Transient State	103-104
1F	General Head variations for transient State	105-106

INTRODUCTION

1.1 Objectives of the study

Ground water flow modeling of Muvattupuzha river basin was taken up during AAP 2019-20 and the same basin area was selected in consultation with CHQ guidelines for four weeks customized Training Programme at IHE Delft,Netherlands during the period of 08th July to 02th August, 2019.The aim of the assignment is to integrate various hydrogeological and hydrological data synthesized during National Aquifer Mapping Program (Naquim) and develop management plans to various future scenarios. This basin is best suited to quantify the effects of urbanization as it form the southern part of Kochi urban conglomeration which now extends upto the industrial belt of Aroor and Cherthala. The broad objectives of the present work are listed below.

(i) Simulate hydrodynamics of the ground water system in the Muvattupuzha Basin.

(ii) Evaluate recharge, discharge and storage components to reduce the ground water development at the existing rate of 73.8 % to safe limit in case of Elamdesam block which is categorised as Semi-critical block as per GEC-2017.

(iii) Study the aquifer response for different ground water development plans to evolve a sustainable ground water development strategy.

(iv) Provide background work for sea water intrusion/solute transport modeling in the future

1.2 Previous studies

Central Ground Water Board has carried out Systematic Hydrogeological Survey in the district during 1969-70,1970-71 ,1983,1984-85 ,1984,1987,1988, 1980-81(CGWB,1983a & b,1984,1985) Exploration for groundwater in the area (Ernakulam dist) was taken up during the FSP 1965 – 66, 74 – 75, 83 – 87, 89 – 90, 98 – 2001, 02, and again in 2011-12 (CGWB,1989,2018). Systematic hydrogeological surveys were carried out in different parts of the basin by S/Sh. S.V.N.S Rao (77-78, 82 – 83), GV.V.R.G.S.V. Rao (80 – 81), K.Md. Najeeb (81 – 82, 87 – 88), V. Dhinagaran (95 - 96) (CGWB,1988 a &b,1993,1994).

The first attempt to simulate a river basin of Kerala was carried out by Sri.D Shivane (CGWB,1987) under SIDA Project and later on solute transport modelling study in Kuttanad Alluvium was attempted during 2002 under HP(CGWB,2002). Aquifer Mapping studies along the coastal tracts of Alapuzha, Ernakulam and Kottayam districts particularly the area underlain by sedimentary formation has been taken up during 2014-15 and hard rocks during 2019-20. Exploratory drilling activities carried out during 2000-01, 2002-03 helped to bring out the subsurface disposition of hard rock more effectively in the eastern part of the basin. No of short term investigations were carried out out by the Scientist’s of Central Ground Water Board for various Govt.organisation in Ernakulam and Trichur district to augumenting the water resource to meet the demand.

1.3 Scope of the present study

The western part of the basin is bestowed with abundant water but owing to the peculiar geomorphic setting the water is either brackish due to tidal influence or unusable due to anthropogenic activities. The bottom confined aquifers are relatively safer and has good potential but least explored. Presently few industries are tapping the confined aquifers for their various industrial operations in the Kochi-Cherthala industrial corridor. Simulation of these confined aquifers may be used as a tool in formulating management plans/demand-supply requirements for the fastest growing industrial corridor in the state.

One block coming under Muvattupuzha Basin (Elamdesam) is classified as Semi-critical category as per GEC -2017 report (CGWB,2018). Normally in semi-critical/over exploited area, the emphasis is how to reduce the ground water development rate and find out which component will have substantial contribution to convert the area from semi critical to safe category. The role of Malankara dam using Moolamattam tail water (Idukki Dam) and its canal network system on surface water groundwater interaction needs to be investigated for better understanding of groundwater budget by simulating the hydrodynamics of the ground water system in the study area through numerical modeling techniques. It also aims to study the aquifer response for different ground water development plans to evolve a sustainable ground water development strategy.

2.0 BACKGROUND INFORMATION

2.1 Location

The Muvattupuzha River is the lifeline of central Kerala which spread over Ernakulam (47%), and Idukki (23%),Kottayam (17%) and

Alapuzha (13%) districts. It's a perennial river and third largest river systems in Kerala. The southern part of Kochi Urban conglomeration rests on this basin which experience fastest rate of urbanization in Kerala. It debouches into Vembanad lake which is a hub of backwater tourism in Kerala and finally reach Arabian sea through Fort Kochi/Mattancherry. The complex network of numerous Kayals, Canals and Lakes are attracting people from India and outside. It lies between $09^{o}30'45''$N to 10^{o} $07'46''$N latitudes and 76^{o} $14'$ $14''$ E to 76^{o} $56'$ $24''$E longitudes. It starts from Tharamgamkanam hill located at an elevation of about 1094 m above msl in Western Ghats and flows westerly through the three physiographic regions and ultimately debouch into the Lakshadweep sea at Kochi, covering a length of 76.8 km. Muvattupuzha Basin has a total catchment area of 2686 sq. km covering twenty blocks in four districts. Periyar river and Meenachil river form northern and southern boundary respectively and Arabian sea constitute the western boundary. Major tributaries of Muvattupuzha river are Thodupuzha Ar,Kaliyar Ar and Kothamangalam Ar which confluences at Muvattupuzha. The tail-race water (19.83-78.5 m3 /sec) released from 780MW Idukki Hydroelectric Project at Moolamattam is collected at Malankara Dam at Muttam near Thodupuzha and partly released to Thodupuzha Ar and partly through different canal system constructed under Muvattupuzha Valley Irrigation Project (MVIP). This has affected the geomorphological and hydrological signatures of the river basin after commissioning of Idukki Hydroelectric project in 1975.This is the only river basin in Kerala having inter basin water transfer. The old Muvattupuzha bridge built over the Muvattupuzha river was the first concrete bridge in Asia. It was completed in 1914. The administrative set up the basin is shown in Fig.1

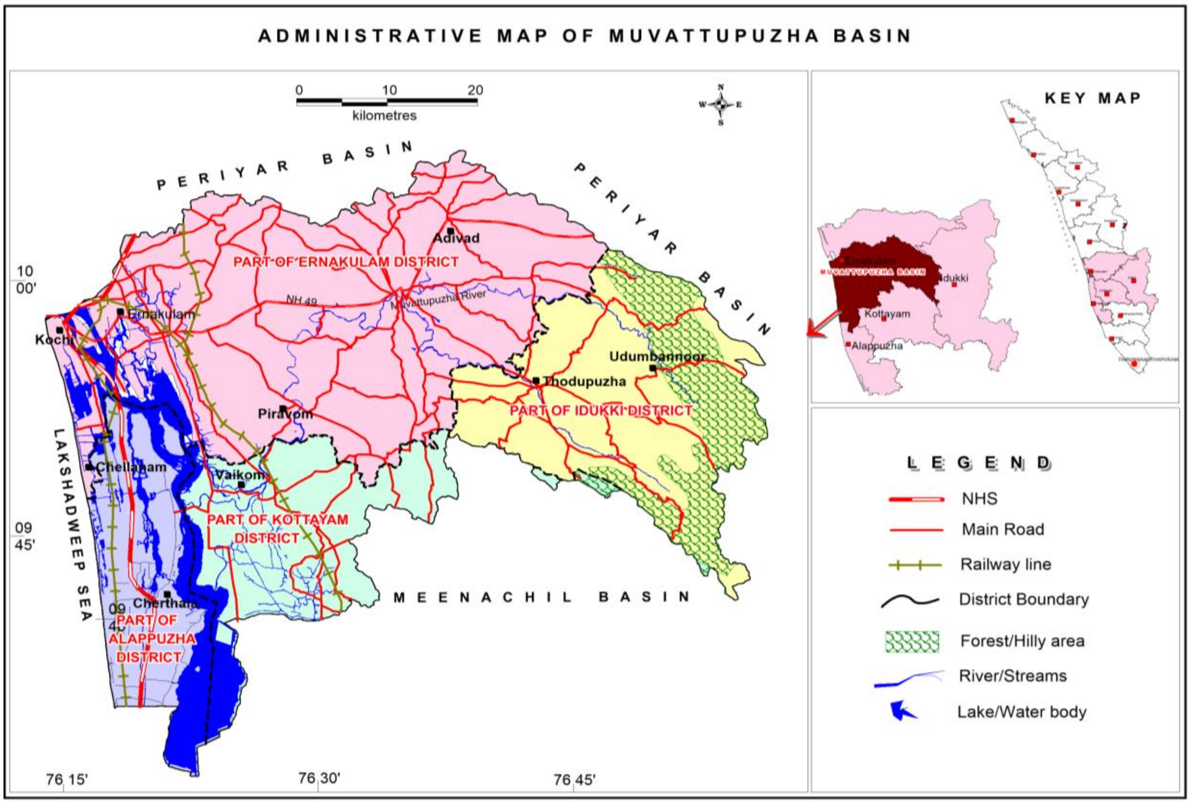


Fig 1. Administrative set up of the study area

Pineapple and Rubber plantations are the common agrarian engagements. Match box industries, saw mills, paper, plastic and wood carton making are the main industries in this area. In Kochi urban area, port and software parks are main employment provider. Hindustan News Print factory ,Piravam is major industry which uses surface water for their industrial activity. Other major industrial player is Kochin Refinery at Ambalamugal.

2.2 Rainfall & Climate

The Muvattupuzha basin and its environs enjoy a tropical humid climate with an average annual rainfall of 3100 mm. Temperate climate exists in the highland region throughout the year while the rest of the region has temperate climate with a high humid climate in the plains. The basin area experiences two monsoons, viz., the southwest (June to September) and northeast monsoons (October to December). The southwest monsoon accounts for 45% of total rainfall, followed by northeast monsoon (28.5%). June and August months have experienced maximum rain fall (>600 mm) and January has minimum rainfall (Fig.2). Occurrence of rainfall is slightly more in eastern part compared to west side. The forest area in the eastern part of the basin control the climate and influence the occurrence of more rainfall in the basin.

Fig.2 Monthly Average Rainfall distribution during 2014-2019 at site- Cherthala and Vannapuram (Souce: IDRB,Irrigation Dept, Govt of Kerala).

Mean annual temperature of the basin is 27.5^0C. The mean monthly temperature varies from a maximum value of 33^0 C during the moths of March to May and to a minimum of 26^0 C during June to November. The dry period of the basin starts from January and lasts till the month of April. Wet period of the basin starts from the month of April and extends upto November with a transitional period. Temperature, humidity and wind vary slightly with the influence of South-West and North-East monsoons.

2.3 Soil

In Muvattupuzha Basin different soils are encountered viz.forest loam in the hilly tracts, laterite soil in the mid land, riverine alluvium along river sections and its tributaries, alluvium in near sea/beaches and red loamy soil in between laterite and coastal alluvium. Lateritic soil which is reddish brown to yellowish brown in colour is the most widely spreaded soil. Red loamy soils are characterized by its reddish colour which is highly porous and friable. The major crops supported by the soil are coconut, tapioca, rubber, arecanut, pepper, cashew and spices.

2.4 Geomorphology

Geomorphological units of Muvattupuzha river basin includes thirteen classes such as Lower plateau , Piedimont zone, Residual hill, Residual mount, Denudational hill, Denudational structural hill, Linear ridge (lower plateau), Water body, Valley fill, and Alluvial plain (Fig.3 & Table-1). Substantial area of the basin is covered under water body including Muvattupuzha river with complex network of kayals, canals and backwater bodies. North-South trending linear mud flats are protecting the coastal plain which is peculiar to this basin. Structural hill is predominant in the eastern margin of the basin. Coastal plain is another geomorphic feature seen in the southeastern part of the basin which is reclaimed part of Vembanad lake (R & H Block of Kuttanad).

The areal distribution of various landform units present in Muvattupuzha basin is tabulated in Table-1 and Fig.4. It is observed that dissected lateritic lower plateau is the dominant landform (35%) followed by coastal plain (12%) and structural hill (11%). Piedmont zone and water body constitute 9 % and 8 % respectively. The topography varied from 1095 m to 0 m and the elevation gradually dips from west towards the coast.

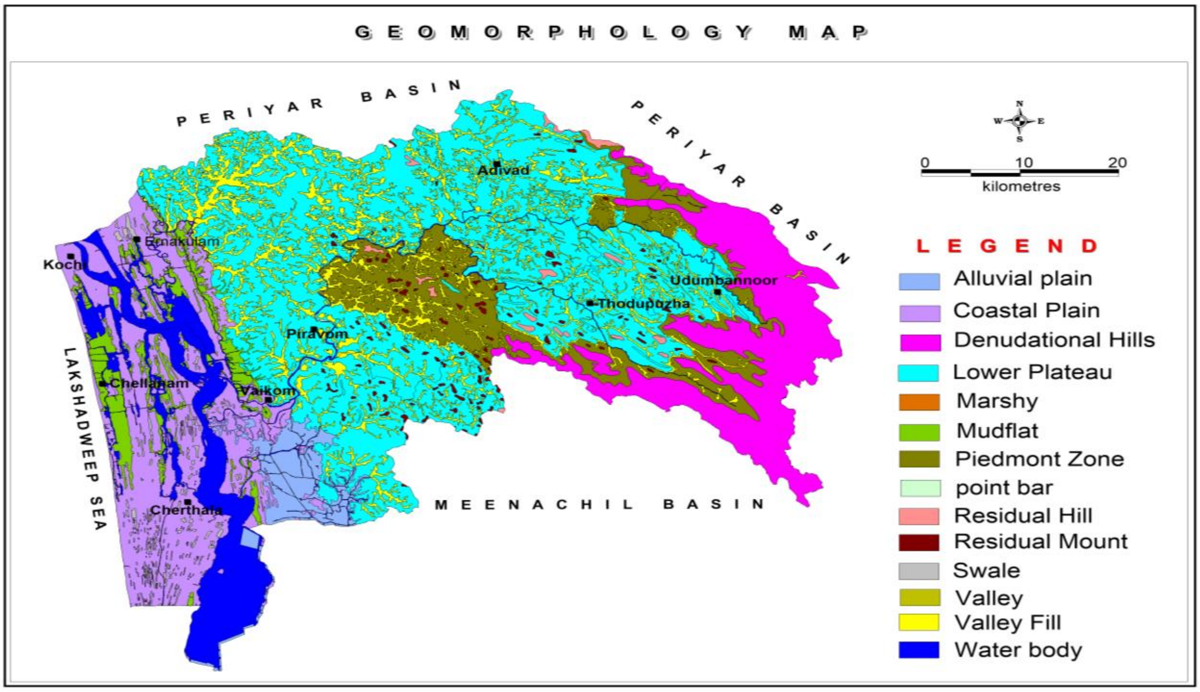


Fig.3 Geomorphology map of Muvattupuzha basin

Sl No	Landform Unit	Area (sq.km)
1	Lower Plateau (laterititic)-Dissected	925.02
2	Coastal Plain	320.7
3	Denudational Structural Hills	292
4	Piedmont zone	225.48
5	Water Body	218.96
6	Mud flat (coastal plain)	190
7	Valley Fill	171
8	Denudational Structural Hills	135.1
9	Linear Ridge (lower Plateau)	95.16
10	Alluvial Plain	85.45
11	Residual Mount	10.43
12	Residual Hill	9.2
13	Denudational Hills	7.5

Table-1 Landform units in Muvattupuzha Basin.

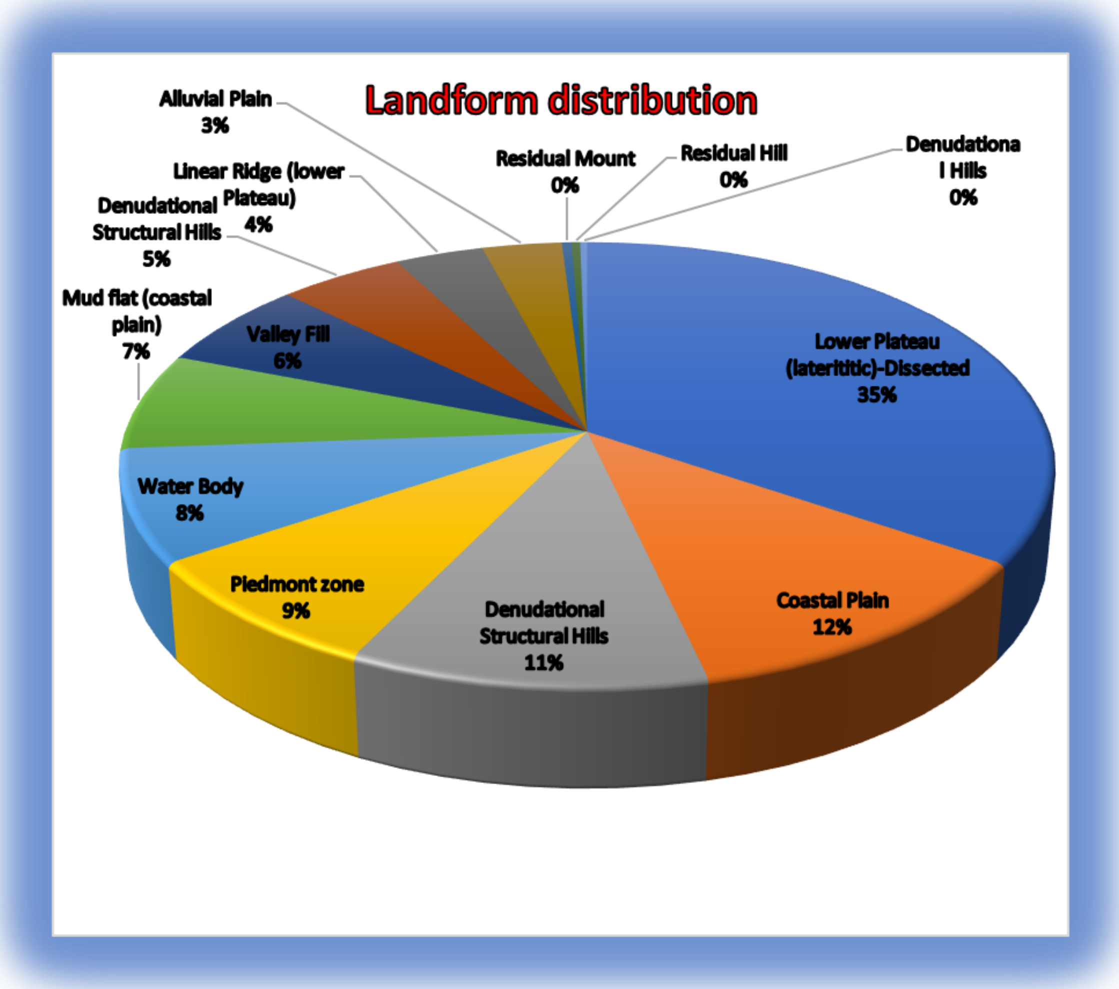


Fig.4. Landform distribution in Muvattupuzha basin

2.5 Drainage

Muvattupuzha river is a perennial river characterized by dendritic drainage pattern. Muvattupuzha river (means joining of three rivers) is formed by the confluence of three tributaries, viz. Kothamangalam, Kaliyar and Thodupuzha rivers. The Kothamangalam river originates from Vanchimala, flows in a WNW direction and Kaliyar river originates near Painavu in Idukki district and flows in a NW direction and Thodupuzha river originates from Thangakkanam hills and flows in a NW direction. Both Kothamangalam and Kaliyar rivers join near Perumuttam which is located east of Muvattupuzha town (Fig.4)and forms the Muvattupuzha river and later on confluence with Thodupuzha river at Puzhakarakavu known as Thriveni Sangamam and the river flow is known as Muvattupuzha (Fig.5).

Muvattupuzha river flows on an undulating topography with different soil types and an average with of 100 m is attained from Muvattupuzha to Velloor stretch. Measurement of river width, river stage during different seasons, river bed thickness and nature of river sand are essential in making River Boundary conditions effectively.

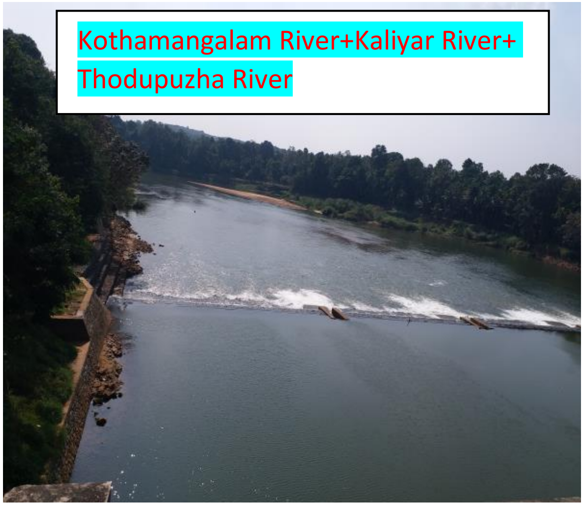


Fig.5 River view at Perumuttam (left) and Ramamangalam (Right)

Muvattupuzha river is dendritic in nature (Fig.6). The dendritic pattern is insequent in origin and is characterized by the presence of irregular branching of the streams in all directions. The drainage pattern is very closely spaced in high lands and widely spaced in low lands which indicate that drainage pattern developed in a region of highly homogenous rock type of uniform resistance such as crystalline rocks of Charnockite and Gneiss. (Fig.6).

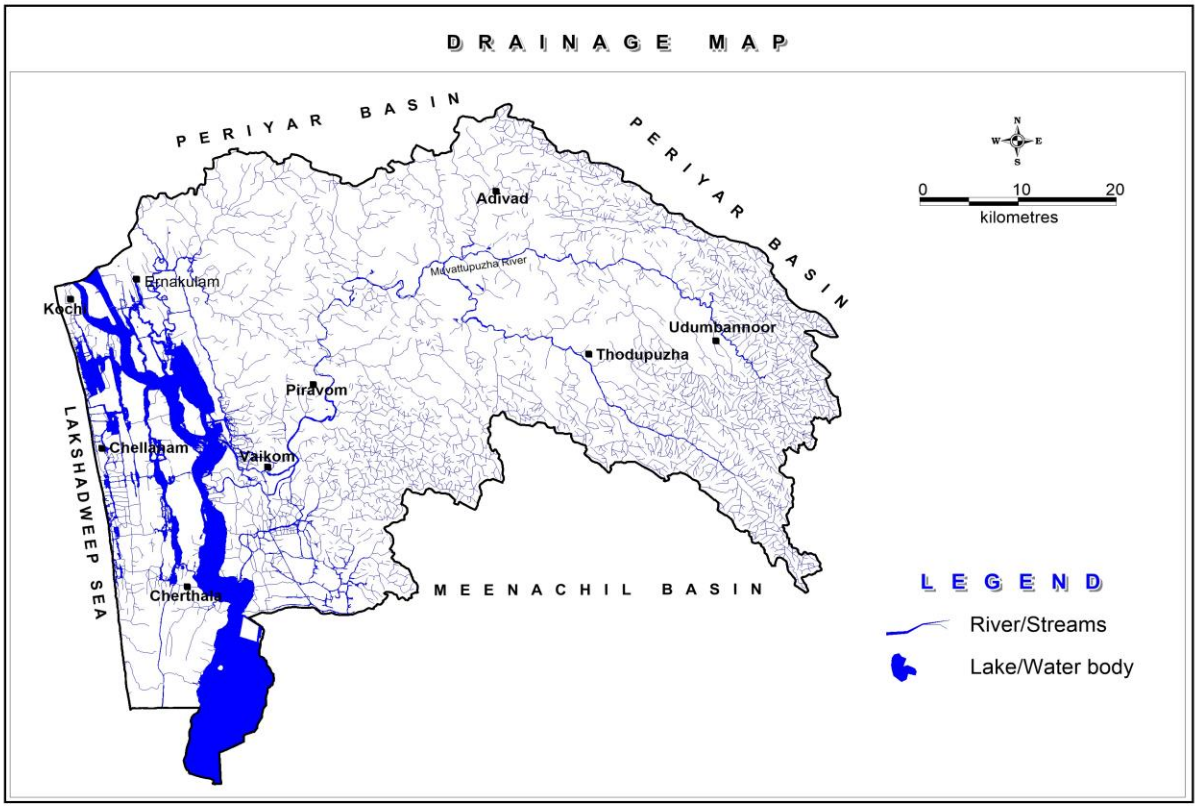


Fig.6 Drainage network of Muvattupuzha River.

2.6 Geology

Major part of Muvattupuzha basin is underlain by crystalline rocks of Archean age, consists of gneisses of Charnockite,Garnet biotite Gneiss,Calc granulites and Granites with a blanket of lateritic layer. In eastern part fresh crystalline rocks are exposed with thin layer of weathered mantle. In the western part adjoining sea, lithology becomes Tertiary formation (Vaikom/QuilonWarkalai Bed) with recent alluvium overlying on it (Fig.7). Here the thickness of laterite is increases towards west. The geology is varying in different region such as upper, middle and lower regions. In the upper reaches gneissic rocks form the major geology and in middle region occurrence of Charnockite is dominant.In the lower reaches coastal alluvium is the main composition.

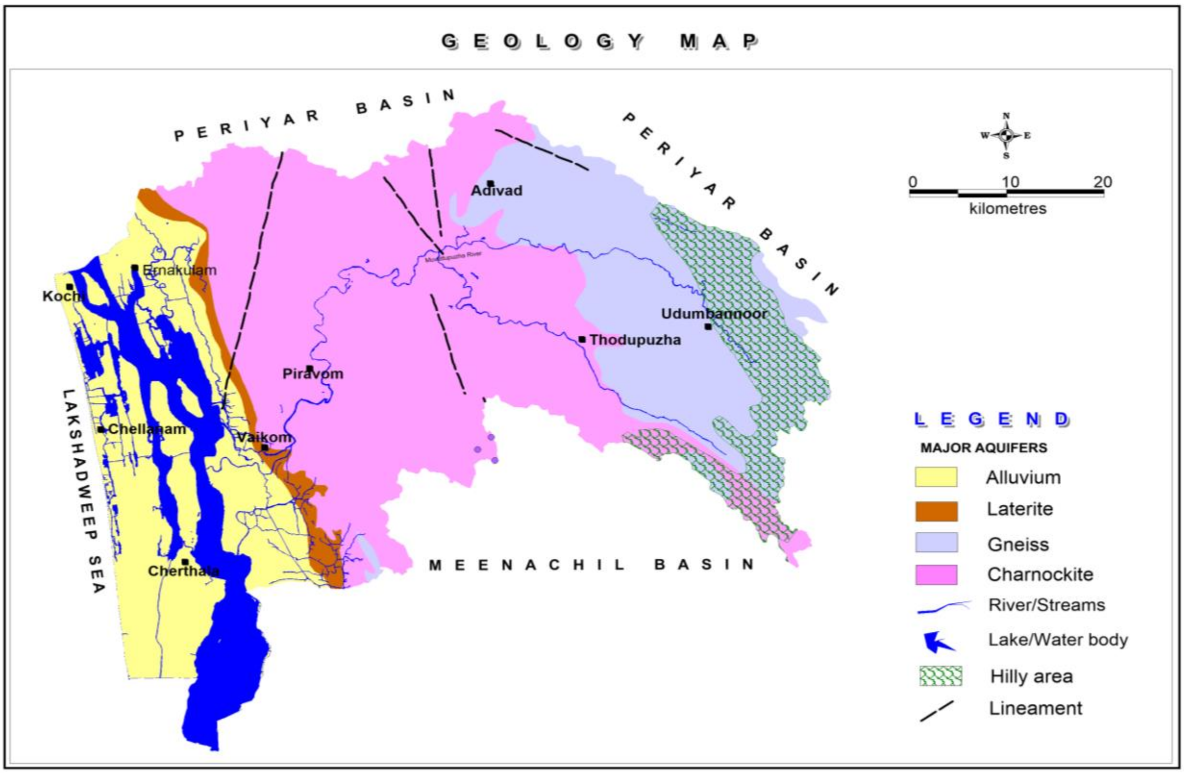


Fig.7 Geological map of Muvattupuzha Basin.

Presence of NNW-SSE trending Gabbro dyke is a prominent feature of this basin and is almost continuous. Quilon bed which is overlying the Vaikom beds are composed of ash,grey hard compact limestone, calcareous clay and marl and is considered as Aquitard.

Alleppey beds are the oldest Tertiary formation unconformably overlying the crystalline Archaean basement, which mainly composed of carbonaceous clay with minor lenses of sand. The maximum thickness of the formation is not known since no bore hole has encountered the entire thickness of the formation and it is only encountered in the deeper bore holes drilled between Kattur and Nallanikkal section in Alapuzha area.

ERA	AGE	FORMATION	LITHOLOGY
Quaternary	Recent	Alluvium	Sand and clay along the coast, flood plain deposits, riverine alluvium and valley fill deposits.
	Sub-recent	Laterites	Laterites and lateritic clays derived from Tertiary sediments and crystalline rocks.
Tertiary	Lower Miocene	Warkalai beds	Sandstone and clay with thin bands of lignite.
	Lower Miocene	Quilon Beds	Limestone and clay
	Oligocene to Eocene	Vaikom Beds	Sandstone, clay and thin bands of lignite
	Eocene	Alleppy Beds	Carbonaceous clay with minor lenses of fine sand
Precambrian	Proterozoic	Intrusives	Dolerite,Gabbro,Pegmatites and Quartz veins.
	Archaean	Migmatite Group	Granite gneiss, Hornblende biotite gneiss, Biotite gneisses and Garnet biotite gneiss.

Table-2 General geological settings of Muvattupuzha Basin

2.7 Hydrogeology

Ground water occurs under phreatic conditions in the weathered zone and recent Alluvium and under semi confined to confined conditions in the deeper fracture zones and sedimentary aquifers (Warkalai/Quilon/Vaikom).In case of shallow crystalline formations, groundwater occurs in the highly weathered residuum and well-jointed and interconnected fracture zones within shallow depth . In deeper crystalline formations, deep seated fractures in Charnockite/gneissic rocks form major potential aquifers. When exposed to surface, Charnockite rocks are less prone to weathering but characterised with less proportion of clay content result in development of a good aquifer.

Dug wells/filter point wells are the main source for tapping phreatic aquifer and bore wells meet the water requirement from deeper aquifers. Few tube wells are tapping Vaikom aquifer in coastal area.

Based on exploration data of 21 bore wells drilled by CGWB in Muvattupuzha basin tapping Charnockite/Hornblende biotite gneiss aquifer with depth range of 101-233 m bgl have discharge at the rate of 0.1 to 22 lps. T value ranges from 1.5 m^2/d to 69.3 m^2/d (Table- 3).

In the sedimentary formation 29 tube wells were constructed and very good yield have been encountered from the granular zones of Tertiary formations (mainly Vaikom) down to maximum depth of 444.9 m bgl (Table-4). The wells drilled in the sedimentary formation were in the depth range of 37.5 to 444.9 m bgl tapping multiple potential zones. The discharge of the wells is in the range of 0.5 to 91 lps and transmissivity value is 7 to 818 m^2/day. Wells tapping Recent alluvium formation is extensively developed in the coastal stretch with average width of 15 km to east.

The depth to water level during Premonsoon ranges from 0.65 to 3.48 m bgl in case of Alluvium and 2.2 to 12.4 in case of Weathered Residuum and during postmonsoon it is 0.34 to 4.02 m bgl for Alluvium and 2.2 to 12.4 for Weathered Residuum. Details of observation wells and water level data are given in Table-5 &6.

Sl No	Location	District	Long	Lat	Type	Year	Depth drilled	Lithology	Casing depth (m)	Fracture zones	SWL(mbgl)	Discharge (lps)	T (m2/vvday)
1	Chelad	Ernakulam	76.64	10.11	BW	2014-15	200	Charnockite	4.6	117-118	4.3	0.5	
2	Ilanji	Ernakulam	76.54	9.83	BW	1986-87	201	Charnockite	6.6	27-35,111-114,	0.81	7.6	31.9
3	Kadalikad	Ernakulam	76.68	9.92	BW	1986-87	201	Charnockite	6.46	15.6,38,95	1.2	10	69.3
4	Kizhakambalam	Ernakulam	76.41	10.03	BW	1987-88	131	Charnockite	8.5	19-23,34-38,126	2.39	22	
5	Kothamangalam	Ernakulam	76.61	10.05	BW	2014-15	200	Charnockite	7	28.5-30	7.4	5	14.5
6	Kozhipalli	Ernakulam	76.61	9.87	BW	1986-87	188	Charnockite	4.25	12.03,65,145	2.12	10	35.9
7	Nadukani	Ernakulam	76.67	10.09	BW	1986-87	201	Garnet biotite gneiss	4.4	15.65	1.1	0.1	NA
8	Onakkur	Ernakulam	76.52	9.89	BW	1987-88	201	Charnockite	9.1	28	dry	Nil	NA
9	Palakuzha	Ernakulam	76.61	9.88	BW	2014-15	200	Charnockite	5.4	62-63		0.25	
10	Pallarimangalam	Ernakulam	76.66	10.03	BW	2011-12	101	Hb Bio gneiss	8.5	10 to 11	12	0.2	
11	Pezhakapilly	Ernakulam	76.56	10.02	BW	2014-15	136	Charnockite	20	63-65	8.95	10	41.88
12	Puthencruz	Ernakulam	76.45	9.975	BW	2014-15	200	Charnockite	8.4				
13	Vadakkumaradi	Ernakulam	76.56	9.95	BW	1986-87	237	Charnockite	6.5	24-38,73-80,180-183,191-192	4.46	1.12	Nil
14	Ramamangalam	Ernakulam	76.63	9.95	BW	2014-15	200	Charnockite	8				
15	Muvattupuzha	Ernakulam	76.48	9.88	BW	2014-15	153	Charnockite	7	12 to 13			
16	Muttam	Idki	76.74	9.85	BW	2003-04	37.1	Hornblende Biotite Gneiss	6.2	16.7-17.7, 23.9-24.9,32.33-35.37	2.4	14	49
17	Padikodikulam	Idki	76.75	9.94	BW	2003-04	110.5	Hornblende Biotite Gneiss	10.85	25 - 26, 45.5- 46.5	6.5	1.2	1.5
18	Arikuzha	Idki	76.64	9.91	BW	2003-04	110.4	Hornblende Biotite Gneiss	10.3	17-18,22-23	4.5	3	7.1
19	Moolamattom	Idki	76.86	9.79	BW	2004-	114	Garnet biotite gneiss	17.5	38.4 - 41.4,48.8-	11.58	12	14.2

						05				51.8,57-68,85-90,110-114			
20	Vannapuram	Idki	76.79	9.99	BW	2004-05	233.2	Hornblende biotite gneiss	17.7	38.0 - 42.0,78-78,124-128,150-154,220-228	26.7	1	10.6
21	Thodupuzha	Idki	76.72	9.88	BW	2016-17	200						

Table-3 Details of exploratory wells drilled in Muvattupuzha Basin (Bore wells)

SL No	District	Location	Long	Lat	Type	Year	Depth drilled	Depth constructed	Lithology	Depth to bed rock encountered	Zones encountered	Zones tapped	SWL (mbgl)	Discharge (lps)	T (m2/day)
1	Ernakulam	Chellanum	76.28	9.81	TW	1973	295.6		sand, clay, laterite, limestone, gravel	223	65-71,122-169,190-205,211-217	149.6-175.4			
2	Ernakulam	Kandakadavu	76.27	9.85	TW	1973	240.8	186.8	sand, clay, gravel	207	64.72-72,77-103,106-114,177-185,193-207	177.4-185.1	4.41	101	818
3	Ernakulam	Kumbalangi	76.28	9.88	TW	1973	150.8	110.7	sand, clay, calay with lignite, gravel	140	70.1-71.9,90.2-94.8,100.6-104.8,106.7-109	70.1-71.9,90.2-94.8,100.6-104.8,106.7-109.0	0.04	8.5	143
4	Ernakulam	Panangad	76.32	9.90	TW	1984	69.2	60	clay, sand	60	29-39, 50-60	29-38, 50-58.0(Vaik om)	1.06	6	193.6
5	Ernakulam	Welligdon Island	76.28	9.94	TW	1998	116.5	105	clay, sand	116		97-103	5.18	1.2	NA
6	Ernakulam	Vaittla	76.30	9.97	TW	1999	54.66	48	clay, sand	48	52	42-45	0.34	2.5	NA
7	Ernakulam	Palluuthy-EW-I	76.27	9.92	TW	1999	144	100	Clay, sand			95.5-96.5	2.16	3.3	4.7
8	Ernakula	Palluuthy-	76.27	9.92	TW	1999	146.2	143	Clay, sand			122.5-140.5	1.2	3.3	16

	m	EW-II					5								
9	Ernakulam	WelligTon Port Trust qtrs	76.28	9.95	TW	2000	133.5	105	Clay, sand			96.0-102.0	1.7	3.1	
10	Ernakulam	Subash Park	76.28	9.97	TW	2000	200	96	Clay, sand			81.0-84.0, 90-93	4.25	3	
11	Ernakulam	Thevaa	76.30	9.94	TW	2000	127	99	Clay, sand			85.0-97.0	5.5	3.7	7
12	Ernakulam	Kannaali-EW1	76.27	9.87	TW	2001	222	199	Clay, sand			181.0- 196	0.6	1.2	
13	Ernakulam	Kannaali-EW2	76.27	9.87	TW	2001	100	100	Clay, sand			85.0-97.0	5.82	3.7	
14	Ernakulam	Mundaveli	76.26	9.93	TW	2001	207	122	Clay, sand			109.0- 118	1.2	3.1	89
15	Ernakulam	INS Dronacharya Fort Kochi	76.25	9.95	TW	2001	198	181	Clay, sand			166.0- 178	9.18	0.5	
16	Ernakulam	Fort ochi - Veli	76.25	9.96	TW	2002	202	186	Clay, sand			174-180			
17	Alapuzha	Mannacherry	76.37	9.58	TW	1997	202.73	199	clay, laterite, sand ,gravel			193-196	5.58		
18	Alapuzha	North Mararikolam	76.33	9.63	TW	1991	357.4	96	sand, clay, laterite		64-74, 78-82,88-84,118-124	70-74, 78-82,88-92			
19	Alapuzha	Shertallai	76.33	9.63	TW	1957	237	Nil	sand, clay, laterite, gravel, calcareous clay	NA	33-39, 67-73,83-89,172-178,197-203,215-221	33-39, 67- 73,83-89,172-178,197-203,215-221			
20	Alapuzha	Arthugal	76.30	9.66	TW	1986	444.9	103	sand, clay, laterite, carbonaceo us clay, limestone		90-100, 139-145	91-100	1.98	91-100	221
21	Alapuzha	Kottaram	76.32	9.70	TW	1989	326.4	172.5	sand, clay, carbonaceo us clay, limestone	322	17-23, 148-, 151,156-160,162.5-167.5,169.5-202-208,235-245,254-261	148-151,156-160,162.5-165.5,167.5-169.5	1.26		

22	Alapuzha	Pattanakad	76.3	9.74	TW	1973	274.3	214.3	sand, clay, clay with lignite, limestone, gravel	268	71-80, 82-92,178-188,191.4,194.5,197.4-211.2	178-188, 191.4-194.5,197.4-211.2	3.43 magl	26.55	98
23	Alapuzha	Thuravur	76.32	9.76	TW	1989	222.8	Nil	sand, clay, laterite, carbonaceo us clay, limestone, gravel	222	54.62, 88-96,98-105	87-93, 98- 101	1.55		
24	Alapuzha	Thakatusseri	76.36	9.77	TW	1973	127.4	Nil 86 m hole.	sand, clay, laterite, limestone	123	24.3-32.9,37.8-42.6,66.45-69.5,89-90.83,93.88-115.22		NA	NA	NA
25	Alapuzha	Chandrur	76.3	9.85	TW	1973	180.41	Nil	sand, clay, clay with lignite, limestone, gravel	146	49.99-54.16,62.18-73.15,77.42-79.25,89-90.22,92.66-95.71,96.62-103.02,107.9-112.78.123.53-135.94				
26	Kottayam	Kallaa	76.48	9.70	TW	1974	37.5	Nil	laterite, sand	36.6	7.62-12.19,15.85-25.38				
27	Kottayam	Payarttubagam	76.4	9.71	TW	1974	91.44	Nil	sand, clay	76.2	54-60, 70-76				
28	Kottayam	Udayanapuram	76.40	9.78	TW	1974	69.5	67.97	laterite, clay, sand, clay with lignite	66.8	6.7-12.1, 54.9-59.7,64-66.5	54.9-59.7, 64.6-66.5			
29	Kottayam	Kulasekaramangalam	76.4	9.79	TW	1974	54.86	Nil	clay, sand, clay with lignite	45.7	13-17, 30-33, 39-45				

Table-4 Details of exploratory wells drilled in Muvattupuzha Basin (Tube wells)

Sl No	SITE_NAME	District	Long	Lat	Well #	MP (m)	Depth(mbgl)	Dia (m)	Lithology	Aquifer	Structure	Use
1	Cherthalai	ALAPPUZHA	76.350	9.700	Hobs-1	0.80	2.10	1.50	Alluvium	Unconfined	Dug well	Domestic
2	Arukutti	ALAPPUZHA	76.317	9.850	Hobs-9	0.58	3.35	1.90	Alluvium	Unconfined	Dug well	Domestic
3	Arur	ALAPPUZHA	76.305	9.870	Hobs-6	0.70	3.00	1.80	Alluvium	Unconfined	Dug well	Domestic
4	Chandirur (R1)	ALAPPUZHA	76.300	9.833	Hobs-7	0.86	3.80	1.05	Alluvium	Unconfined	Dug well	Domestic
5	Kanichukulangara	ALAPPUZHA	76.314	9.633	Hobs-3	1.10	4.10	1.80	Alluvium	Unconfined	Dug well	Domestic
6	Panavally	ALAPPUZHA	76.352	9.814	Hobs-2	0.90	2.90	1.75	Alluvium	Unconfined	Dug well	Domestic
7	Pattanakad	ALAPPUZHA	76.292	9.733	Hobs-8	0.90	2.90	1.75	Alluvium	Unconfined	Dug well	Domestic
8	Thaikattusseri (R1)	ALAPPUZHA	76.342	9.783	Hobs-10	1.20	3.80	1.60	Alluvium	Unconfined	Dug well	Domestic
9	Thaneermukkam DW	ALAPPUZHA	76.390	9.678	Hobs-4	0.60	2.70	2.40	Alluvium	Unconfined	Dug well	Domestic
10	Thuravur	ALAPPUZHA	76.317	9.770	Hobs-5	1.07	5.00	1.20	Alluvium	Unconfined	Dug well	Domestic
11	Arakunnam	ERNAKULAM	76.435	9.886	Hobs-12	0.85	14.15	2.50	Weathered Residuum	Unconfined	Dug well	Domestic
12	Arakuzha	ERNAKULAM	76.596	9.929	Hobs-13	0.85	7.70	2.00	Weathered Residuum	Unconfined	Dug well	Domestic
13	East Marady	ERNAKULAM	76.576	9.951	Hobs-14	0.70	10.10	3.00	Weathered Residuum	Unconfined	Dug well	Domestic
14	Fort cochin	ERNAKULAM	76.246	9.950	Hobs-15	0.85	4.40	2.50	Alluvium	Unconfined	Dug well	Domestic
15	Kalur	ERNAKULAM	76.700	9.983	Hobs-17	0.50	7.88	2.50	Weathered Residuum	Unconfined	Dug well	Domestic
16	Kothamangalam (R3)	ERNAKULAM	76.628	10.067	Hobs-20	0.80	7.00	2.70	Weathered Residuum	Unconfined	Dug well	Domestic
17	Mulanthuruthi	ERNAKULAM	76.392	9.892	Hobs-21	0.90	12.20	1.90	Weathered Residuum	Unconfined	Dug well	Domestic
18	Muvattupuzha	ERNAKULAM	76.579	9.985	Hobs-22	0.70	10.18	2.54	Weathered Residuum	Unconfined	Dug well	Domestic
19	Chellanum	ERNAKULAM	76.285	9.807	Hobs-23	0.59	2.14	1.56	Alluvium	Unconfined	Dug well	Domestic
20	Paingottur	ERNAKULAM	76.710	10.005	Hobs-24	0.70	8.50	2.45	Weathered Residuum	Unconfined	Dug well	Domestic
21	Pambakuda	ERNAKULAM	76.517	9.917	Hobs-26	0.90	9.30	2.00	Weathered Residuum	Unconfined	Dug well	Domestic
22	Piravom	ERNAKULAM	76.483	9.867	Hobs-27	0.50	7.30	2.50	Weathered Residuum	Unconfined	Dug well	Domestic

23	Poothotta	ERNAKULAM	76.385	9.850	Hobs-28	0.82	5.20	2.85	Alluvium	Unconfined	Dug well	Domestic
24	Punithura	ERNAKULAM	76.333	9.933	Hobs-29	0.45	3.35	2.25	Alluvium	Unconfined	Dug well	Domestic
25	Thirumaradi	ERNAKULAM	76.555	9.887	Hobs-30	1.2	8.5	3.50	Weathered Residuum	Unconfined	Dug well	Domestic
26	Tripunithura	ERNAKULAM	76.343	9.943	Hobs-32	0.85	5.00	1.60	Alluvium	Unconfined	Dug well	Domestic
27	Udayamperoor	ERNAKULAM	76.370	9.883	Hobs-33	1.00	6.00	1.80	Alluvium	Unconfined	Dug well	Domestic
28	Veliyanad	ERNAKULAM	76.455	9.870	Hobs-35	1	10	4.00	Weathered Residuum	Unconfined	Dug well	Domestic
29	Edapally	ERNAKULAM	76.308	10.022	Hobs-55	0.38	3.40	1.53	Alluvium	Unconfined	Dug well	Domestic
30	Irumbanam	ERNAKULAM	76.350	9.950	Hobs-4	0.50	4.25	1.00	Alluvium	Unconfined	Dug well	Domestic
31	Namakuzhi	ERNAKULAM	76.275	9.919	Hobs-33	1.2	9.1	1.70	Weathered Residuum	Unconfined	Dug well	Domestic
32	Kaliyar	IDUKKI	76.782	9.975	Hobs-36	0.80	8.37	2.50	Weathered Residuum	Unconfined	Dug well	Domestic
33	Kodikulam east	IDUKKI	76.765	9.948	Hobs-37	0.80	10.00	2.75	Weathered Residuum	Unconfined	Dug well	Domestic
34	Pannimattom	IDUKKI	76.828	9.848	Hobs-38	0.80	5.27	3.00	Weathered Residuum	Unconfined	Dug well	Domestic
35	Udumbannur	IDUKKI	76.821	9.907	Hobs-39	0.71	8.90	2.42	Weathered Residuum	Unconfined	Dug well	Domestic
36	Arikuzha	IDUKKI	76.645	9.914	Hobs-41	0.75	6.15	2.75	Weathered Residuum	Unconfined	Dug well	Domestic
37	Karimkunnam (R1)	IDUKKI	76.688	9.854	Hobs-42	0.70	6.10	2.74	Weathered Residuum	Unconfined	Dug well	Domestic
38	Kumaramangalam	IDUKKI	76.708	9.936	Hobs-43	0.60	5.44	2.50	Weathered Residuum	Unconfined	Dug well	Domestic
39	Thodupuzha	IDUKKI	76.713	9.898	Hobs-44	1.00	13.51	2.65	Weathered Residuum	Unconfined	Dug well	Domestic
40	Arunuttimangalam	KOTTAYAM	76.498	9.801	Hobs-45	0.63	8.50	2.34	Weathered Residuum	Unconfined	Dug well	Domestic
41	Ayamkudi	KOTTAYAM	76.473	9.753	Hobs-46	0.70	14.70	2.25	Weathered Residuum	Unconfined	Dug well	Domestic
42	Kaduthuruthi	KOTTAYAM	76.492	9.761	Hobs-47	0.53	8.55	2.85	Weathered Residuum	Unconfined	Dug well	Domestic
43	Thalayolaparambu (R1)	KOTTAYAM	76.437	9.783	Hobs-48	0.80	9.50	2.50	Weathered Residuum	Unconfined	Dug well	Domestic
44	Chempu	KOTTAYAM	76.396	9.810	Hobs-51	0.65	4.1	1.00	Weathered Residuum	Unconfined	Dug well	Domestic
45	Kudavechur	KOTTAYAM	76.421	9.678	Hobs-52	0.70	4.15	1.75	Alluvium	Unconfined	Dug well	Domestic

46	Palamkadavu	KOTTAYAM	76.441	9.793	Hobs-53	0.70	4.90	1.80	Alluvium	Unconfined	Dug well	Domestic
47	Vaikom	KOTTAYAM	76.393	9.750	Hobs-54	1.15	5.65	1.80	Alluvium	Unconfined	Dug well	Domestic

Table - 5. Salient features of Observation Wells (Water level in m bgl)

SL No	Well #	Location	2014		2015				2016				2017				2018				2019		
			Aug	Nov	Jan	April	Aug	Nov	Jan	April	Aug	Nov	Jan	April	Aug	Nov	Jan	April	Aug	Nov	Jan	April	Aug
1	Hobs-1	Cherthalai	0.54	0.75	0.80	0.91	0.90	0.84	0.73	1.05	0.70	0.89	0.75	1.20	0.80	0.60	0.71	0.65	0.95	1.03	0.84	1.05	0.9
2	Hobs-9	Arukutti	0.92	1.42	2.07	2.62	1.42	1.82	2.04	2.42	1.47	1.61	2.02	2.57	1.02	1.27	2	2.35	1.51	1.09	1.90	2.69	1.15
3	Hobs-6	Arur	0.30	1.00	1.45	2.20	0.90	0.65	0.80	2	0.90	1.22	1.60	2.28	0.40	0.84	1.30	1.83	0.91	0.50	1.70	1.87	0.3
4	Hobs-7	Chandirur (R1)	0.49	1.34	1.84	2.29	1.14	2.01	1.69	2.34	1.27	1.66	2.04	2.69	0.64	1.11	1.64	2.04	1.36	1.14	1.79	2.64	0.46
5	Hobs-3	Kanichukulangara	2.10	2.00	2.20	2.70	1.85	1.79	2.11	2.22	1.85	1.84	2.30	2.90	1.70	1.75	2.01	2.40	1.87	1.8	2.35	2.86	1.6
6	Hobs-2	Panavally	0.50	1.00	1.30	1.85	1.00	0.60	1.20	1.75	1.05	1.13	1.60	2.16	0.70	0.93	1.05	1.65	1.08	0.82	1.65	2.00	0.55
7	Hobs-8	Pattanakad	0.95	0.95	1.25	1.55	0.70	0.59	0.91	1.50	0.70	0.85	1.35	2.00	0.45	0.51	1.20	1.60	0.65	0.34	1.17	1.85	0.38
8	Hobs-10	Thaikattusseri (R1)	0.50	1.00	1.30	2.00	0.90	1.05	1.67	1.45	0.50	1	1.45	1.80	0.6	0.60	1.65	1.25	1.05	0.65	1.70	2.10	0.64
9	Hobs-4	Thaneermukkam	0.40	0.9	1.30	0.80	1.00	1.09	1.07	1.10	1.15	1.05	1.10	1.40	0.90	0.71	1.10	0.93	1.14	0.77	1.22	1.33	0.51
10	Hobs-5	Thuravur	2.12	1.5	2.20	2.55	2.00	1.53	2.04	2.80	1.65	1.98	2.50	3.30	1.50	1.8	2.2	3	1.56	1	1.67	2.63	0.79
11	Hobs-12	Arakunnam	8.8	8.95	10.55	11.90	8.95	9.25	9.45	12.15	8.65	10.20	11.39	12.93	8.89	8.85	9.46	11.90	8.90	8.73	14.16	10.96	8.49
12	Hobs-13	Arakuzha	5	6	6.15	6.45	4.97	5.80	6.25	5.15	5.97	6.27	6.59	4.95	5.53	5.90	6.29	6.25	6.15	5.90	6.36	6.24	5.27
13	Hobs-14	East Marady	5	5.20	5.90	6.10	4.55	5.50	6.10	6.85	5.24	5.84	6.22	6.40	4.42	5.58	5.72	5.95	5.78	5.70	5.92	6.38	4.6
14	Hobs-15	Fort cochin	1.45	1.65	2.25	2.05	1.85	1.6	2.13	2.35	1.81	1.77	2	2.45	1.16	1.61	1.99	2.10	2.38	1.43	2.28	1.85	0.95
15	Hobs-17	Kalur	4.00	2.90	6.00	6.90	4.30	4.40	5.80	6.95	4.55	5.72	6.46	6.75	3.60	5.11	6.10	6.85	5.15	5.10	6.11	6.80	2.88
16	Hobs-20	Kothamangalam (R3)	4.3	4	4	5	4.20	3.80	3.90	5.90	4.06	4.38	4.40	4.55	3.82	4.35	4.39	4.55	4.32	4.28	3.95	3.96	2.6
17	Hobs-21	Mulanthuruthi	4.30	8.00	8.90	8.80	5.20	5.40	8.70	8.85	7.03	8.31	10.21	9.45	6.96	7.82	8.69	8.60	8.19	8.38	8.51	8.65	4.9
18	Hobs-22	Muvattupuzha	4.00	3.80	5.85	6.60	4.86	4.15	5.57	6.60	5.04	6.61	7.25	7.65	4.94	5.78	7.54	7.30	6.86	5.82	6.40	7.25	3.89
19	Hobs-23	Chellanum	0.91	0.81	1.11	0.96	0.66	0.39	1.01	1.21	0.33	0.87	1.18	1.16	0.67	0.83	1.08	1.01	1.13	0.83	1.06	1.08	0.58
20	Hobs-24	Paingottur	3.85	2.70	5.20	5.40	4.32	3.82	5.20	5.60	4.41	3.85	5.50	5.35	3.64	4.62	6.14	5.25	4.78	4.55	5.51	5.40	2.69
21	Hobs-26	Pambakuda	4.20	4.90	6.90	5.00	4.00	4.70	5.70	4.10	5.45	6.42	6.74	6.15	3.62	4.10	6.34	4.95	5.95	5.20	6.41	4.00	3.61

22	Hobs-27	Piravom	5.00	5.15	5.70	5.90	5.00	4.82	5.30	6.40	4.40	6.58	6.30	6.35	3.78	4.91	5.44	5.75	5.82	5.85	5.95	6.03	5.5
23	Hobs-28	Poothotta	0.78	1.98	2.58	3.48	2.28	1.88	2.28	3.38	1.62	2.56	2.83	3.53	1.66	2.03	2.48	2.18	1.62	2.11	2.56	3.31	0.8
24	Hobs-29	Punithura	2.85	1.25	2.25	2.45	1.10	0.45	0.95	1.00	0.73	0.97	1.62	3.30	1.15	1.20	1.75	1.90	1.37	1.10	2.97	2.93	0.54
25	Hobs-30	Thirumaradi	3.40	3.40	5.40	4.40	2.35	3.50	3.98	4.20	3.78	4.69	5.56	5.55	2.90	3.44	5.24	4.50	4.75	4.05	5.28	4.00	2.57
26	Hobs-32	Tripunithura	1.70	1.70	2.50	3.15	2.10	2.10	2.25	3.20	1.85	2.42	3.19	2.65	1.66	2.14	2.49	3.30	1.84	2.07	2.62	3.58	1.52
27	Hobs-33	Udayamperoor	3.4	4	6.94	7.89	3.43	3.29	5.73	7.70	3.49	2.49	6.29	4.29	3.29	4.02	6.60	7.39	4.37	4.39	5.31	5.79	0.99
28	Hobs-35	Veliyanad	2.45	3.95	4.05	4.45	3.70	3.25	3.93	5.15	3.60	4.34	4.05	4.75	2.91	3.25	3.65	4.45	4.59	3.45	4.33	4.5	4.4
29	Hobs-55	Edapally	1.12	1.32	1.62	2.62	1.12	1.37	1.60	2.12	1.26	1.53	1.85	2.07	1.15	1.47	1.84	1.92	1.62	1.51	1.87	2.11	1.15
30	Hobs-34	Irumbanam	0.50	1.20	2.65	3.40	1.00	0.90	1.60	4.00	0.88	1.56	2.59	4.45	0.85	1.14	2.00	4.11	1.49	1.06	1.89	3.32	0.5
31	Hobs-33	Namakuzhi	3.04	5.05	9.40	8.25	6.53	7.25	9.95	10.60	4.40	10.72	11.54	9.90	3.40	3.90	9.70	8.40	7.55	6.00	8.73	5.83	2.9
32	Hobs-36	Kaliyar	3.77	4.75	5.30	4.95	4.44	4.10	5.30	5.88	4.32	4.98	5.51	5.45	4.00	4.48	5.59	5.45	4.82	4.73	5.23	5.73	2.52
33	Hobs-37	Kodikulam east	2.50	4.00	4.90	8.20	3.55	3.10	4.52	5.02	3.51	4.60	5.50	5.03	2.52	3.91	5.00	5.51	4.24	4.05	4.36	6.25	2.1
34	Hobs-38	Pannimattom	2.66	3.10	3.65	4.00	2.90	3.02	3.46	3.90	3.04	3.34	3.93	3.76	2.69	2.89	4.20	4.00	2.76	3.10	3.38	4.05	2.7
35	Hobs-39	Udumbannur	3.4	4	6.94	7.89	3.43	3.29	5.73	7.70	3.49	2.49	6.29	4.29	3.29	4.02	6.60	7.39	4.37	4.39	5.31	5.79	0.99
36	Hobs-41	Arikuzha	2.30	4.70	5.20	5.25	3.98	1.55	3.56	4.42	3.25	2.89	4.23	4.35	2.43	4.23	4.5	4.4	2.71	4.85	5.06	4.90	1.89
37	Hobs-42	Karimkunnam (R1)	2.80	3.25	3.40	3.50	3.34	2.80	2.80	3.30	2.10	2.70	3.52	3.22	2.10	3.22	4.06	2.20	2.89	3.10	3.34	3.20	2.65
38	Hobs-43	Kumaramangalam	3.15	3.70	4.35	4.70	3.44	3.20	3.80	4.40	3.52	3.82	4.50	4.35	3.22	3.54	4.10	3.90	2.78	3.70	4.25	4.22	2.86
39	Hobs-44	Thodupuzha	6.27	8.10	8.55	7.60	7.02	6.24	9.20	10.60	6.92	7.31	10.46	11.17	6.00	7.38	11.00	11.08	7.18	7.65	7.87	7.60	5.88
40	Hobs-45	Arunuttimangalam	5.75	5.82	5.77	6.67	5.83	6.21	5.87	6.73	5.95	5.97	5.87	6.5	5.62	5.77	6.34	6.6	6.07	5.92	5.97	6.47	5.37
41	Hobs-46	Ayamkudi	6.05	7.25	9.45	12.40	6.79	7.44	9.50	11.25	8.50	10.30	11.50	12.20	5.49	6.97	10.15	9.62	8.78	7.68	10.30	10.70	5.33
42	Hobs-47	Kaduthuruthi	5.97	5.37	5.87	6.67	5.15	5.27	5.07	6.01	5.47	5.97	7.25	6	4.82	3.32	6.59	6.47	5.37	5.87	5.72	6.55	4.32
43	Hobs-48	Thalayolaparambu (R1)	2.59	1.95	2.85	3.10	2.14	2.68	3.10	3.45	2.30	2.70	3.36	3	1.66	2.35	3.20	2.90	2.50	2.50	2.80	3.35	1.54
44	Hobs-51	Chempu	1.13	1.80	2.45	3.20	1.66	1.50	2.05	2.25	1.55	2.65	3.15	2.2	1.95	1.70	2.64	2.07	1.36	1.93	2.38	3.35	0.71
45	Hobs-52	Kudavechur	0.90	0.40	1.80	2.57	1.38	1.30	2.10	2.46	1.50	1.54	2.44	2.2	0.72	1.60	1.84	2.15	1.50	1.78	1.90	3.38	0.95
46	Hobs-53	Palamkadavu	1.21	1.56	2.20	2.80	1.79	1.90	2.00	3.05	1.80	2.10	2.81	3.51	1.55	1.43	2.50	2.63	1.95	1.51	1.80	2.85	1.38
47	Hobs-54	Vaikom	0.99	3.95	2.75	1.53	1.55	1.31	2.25	4.17	1.65	2.45	2.18	1.09	0.45	0.62	2.50	3.25	3.59	2.83	3.00	1.95	0.64

Table-6 Temporal distribution of water level data of observation wells (m bgl) during 2014-2019.

3.0 GROUND WATER FLOW MODELING

3.1 Flow equation

Ground water flow and change in water levels can be analysed and described mathematically using partial differential equations (PDE) , provided with adequate hydrogeological data. These equations are based on certain simplifying assumptions which involve : the direction of flow, geometry of the aquifer ,the heterogeneity or anisotropy of bedrock or sediments within the aquifer, the contaminant transport mechanism and chemical reactions. With these assumptions mixed with uncertainties in the values of data required by the model , that a model must be viewed as an approximation and not an exact duplication of field conditions.

Groundwater flow in three dimensions in a porous medium of constant density through porous earth material may be expressed by the following partial differential equation (Rushton and Redshaw, 1979, Mc Donald and Harbough,1984 and Anderson and Woessner,1992) based on conservation of Mass and Darcy's law:

$$\frac{\delta}{\delta x}\left(K_{xx}\frac{\delta h}{\delta x}\right)+\frac{\delta}{\delta y}\left(K_{yy}\frac{\delta h}{\delta y}\right)+\frac{\delta}{\delta z}\left(K_{zz}\frac{\delta h}{\delta z}\right)\pm W=S_s\frac{\delta h}{\delta t} \quad \text{...........(1)}$$

where,

K_{xx} K_{yy} K_{zz}	=	the hydraulic conductivity along x, y, and z coordinates that are assumed to be parallel to the major axes of hydraulic conductivity (LT^{-1})
h	=	potentiometric head (L)
$\pm$ W	=	volumetric flux per unit volume and represents sources

and/or sinks of water (T^{-1})

S_s = the specific storage of the porous material (L^{-1})

t = time (T)

In general S_S, K_{xx} K_{yy} K_{zz} may be functions of space (independent variable) and h and W may be functions of space and time (dependent variable) so that equation-1 describes three dimensional (3-D) transient ground water flow under non equilibrium, anisotropic and saturated porous medium provided the principal axes of hydraulic conductivity are aligned with the x-y Cartesian coordinate axes (Mc Donald and Harbough,1984) (Fig.8).

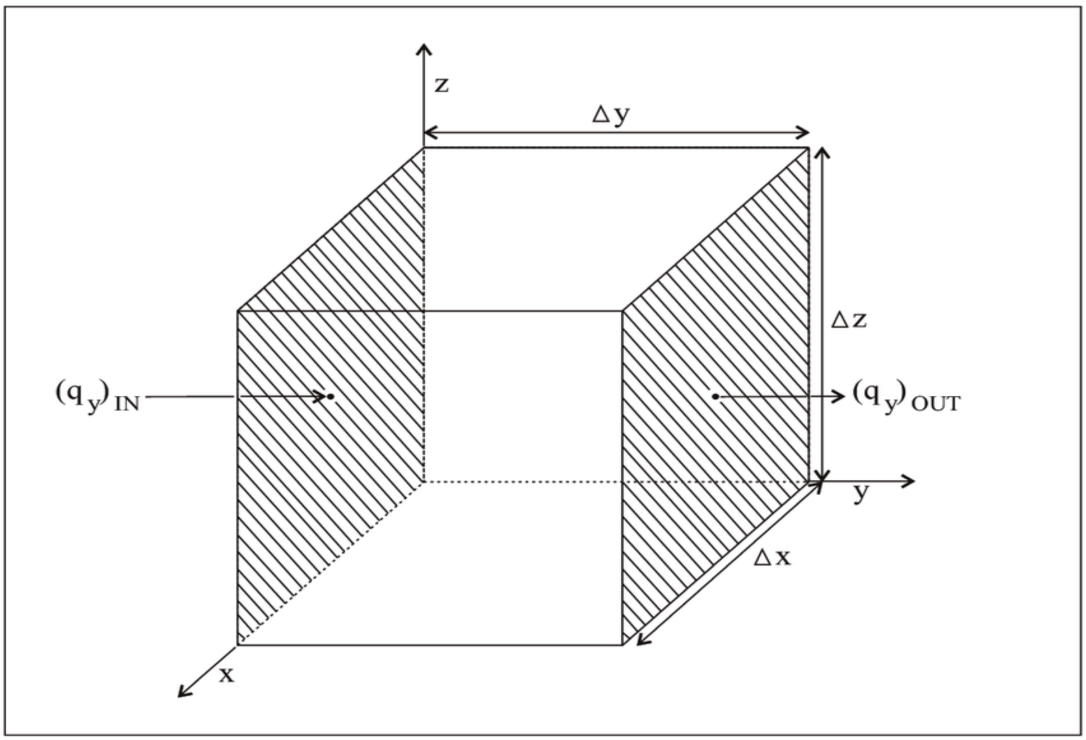


Fig.8. Representative Elementary Volume (REV) used in the derivation of governing equation.(Anderson and Woessner,1992, and Anderson et al,2015).

Visual Modflow software, a graphical user interface (GUI) using the algorithm called “Modular Finite-Difference Groundwater Flow” code (MODFLOW) developed by USGS (McDonald and Harbaugh, 1988), was used to simulate groundwater flow in the Muvattupuzha Basin.Visual MODFLOW uses block centered finite difference method where the aquifer system is divided into rectangular block by a grid.The grid of blocks is arranged by rows, columns and layers and each block is commonly called a cell. For each cell within the volume of aquifer system, aquifer properties and information related to wells, rivers, lake/dams, boundaries and other inflow and outflow components are specified. MODFLOW uses the input to construct and solve equations of ground water flow in the aquifer system. The discretised model domain prepared for Muvattupuzha Basin is shown below (Fig.9).

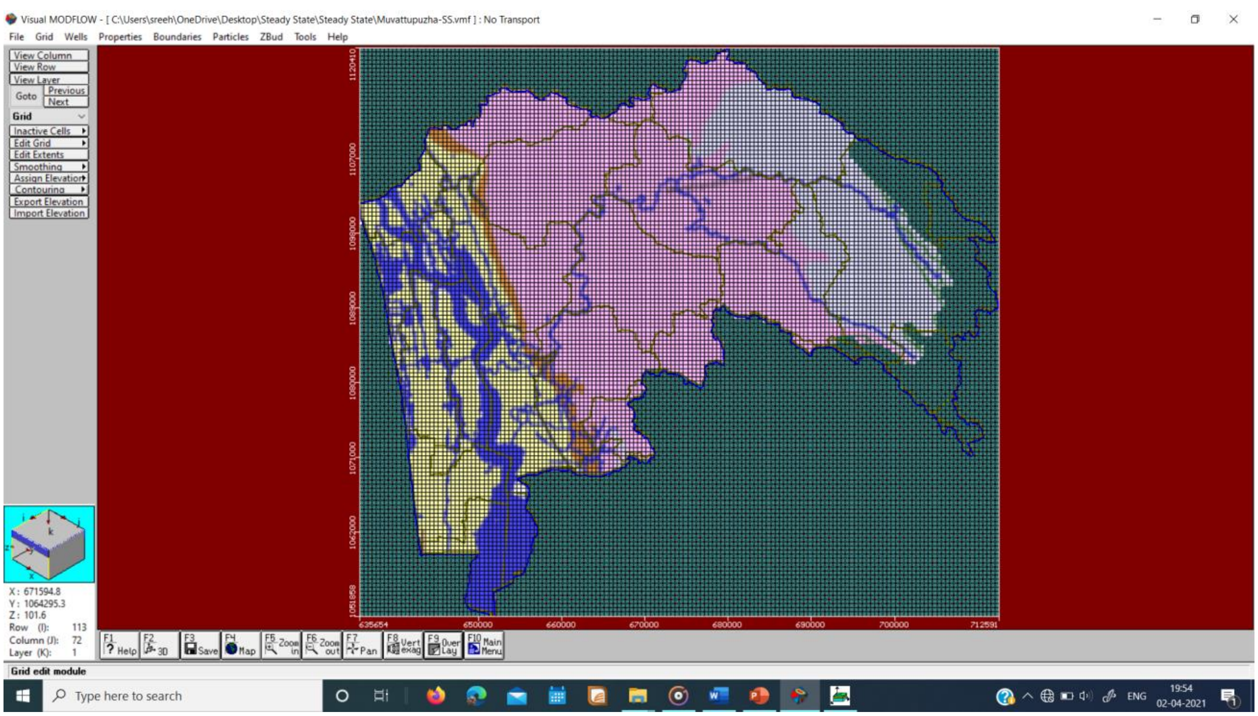


Fig.9 Model domain view of Muvattupuzha Basin .

The assumptions used in the model are

(i) Equation (1) is used in the present model to simulate groundwater flow and computer software Visual Modflow Flex(Classic Interface) is used for the purpose.

(ii) The weathered part of aquifer is considered as a porous and homogenous one and as such it represents an equivalent porous medium (EPM).

(iii) Top aquifer (layer-1) is only simulated and other bottom layers are kept as dummy layers as no separate head value available for these confining layers.

(iv) Simulation has to be carried out for weathered-fractured coupled media for first layer to accommodate the existence of shallow fracture system within the depth of 40 m .

(v) The hydraulic conductivity (K) values in the x and y co-ordinate directions are the same and for z coordinates it is 10% of x direction.

(vi) Zone wise recharge and pumping rate were assigned.

(vii) The interaction between the surface water body like River/lake and aquifer is considered.

(viii) The Evapotranspiration package is applied to substantiate the water loss due to shallow aquifer system in the coastal part.

Modeling involves integration of multiple data sets of different hydraulic and hydrogeologic properties and listed below are the sources of data against the input values and different properties.

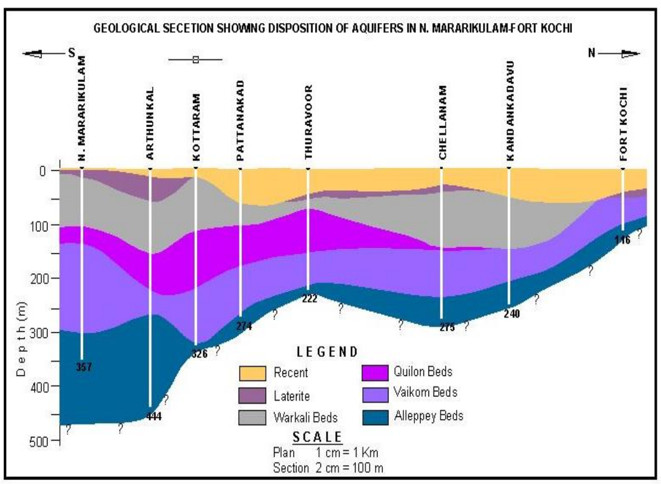
Hydraulic conductivity values were used instead of Transmissivity values because the aquifer is a water table one and whose saturated thickness will be varying due to input and output stress changes.

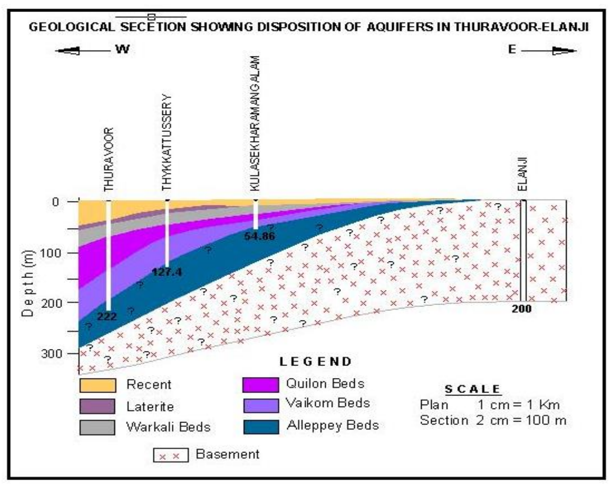
Sl No	Input data/Packages	Sources
1	Elevation	USGS earth explorer SRTM (30* 30m)
2	Rainfall-station wise	MI Dept, Govt of Kerala and IMD
3	Draft	Dynamic GW Resources ,KR-2017 Report
4	Recharge	Rainfall and Draft data
5	Hydraulic parameters	SIDA and other reports of CGWB
6	River, Dam & Canal Network	MI data- Govt of Kerala
7	Evapotranspiration	WRIS portal, MOWR (www.indiawris.gov.in)
8	Water level/Piezometric head	WL data retrieved from GEMS (CGWB).

3.2 Conceptual model

A conceptual model is a simplified representation of the groundwater flow system, frequently in pictorial form that defines the hydro stratigraphic units of interest and all system boundaries. Based on the subsurface geology and synthesis of exploration data and field data (Fig.10 (A) & (B)), a five layer ground water model was conceptualized (Fig.11).The study area is characterized by both hard rock in the major part (69%) and soft rock adjoining coastal side (31%).

In the hard rock area, the top weathered part forms the phreatic aquifer and the bottom one is the fractured aquifer system. The weathered thickness varies from 7 m in the hills in the east to about 50 m in the down west. In sedimentary area, the aquifers are divided into (i)recent alluvium with laterite (ii) Warkalai beds (iii) Quilon beds (Aquitard) (iv) Vaikom beds and (v) Alleppey Beds at the bottom. Of these five aquifers the bottom one - Alleppey beds are not considered due to little explored beds. Wherever a small patch of laterite is present , it is combined with alluvium as first layer due to their vertical continuity. In the western part of the basin there is three aquifer system Viz, Alluvium, Warkalai and Vaikom Beds. Quilon beds are considered as Aquitard due to presence of hard limestone. The first top layer (Alluvium) is in phreatic condition and deeper layers are in confined condition where Warkalai and Quilon beds rest on Vaikom Beds. The aquifers have maximum thickness in the west and pinching out towards east (Fig.10 A &B).





(A) (B)

Fig.10 Subsurface disposition of aquifer system in Muvattupuzha Basin (A) 2D section along N-S direction (B) 2D section E-W direction

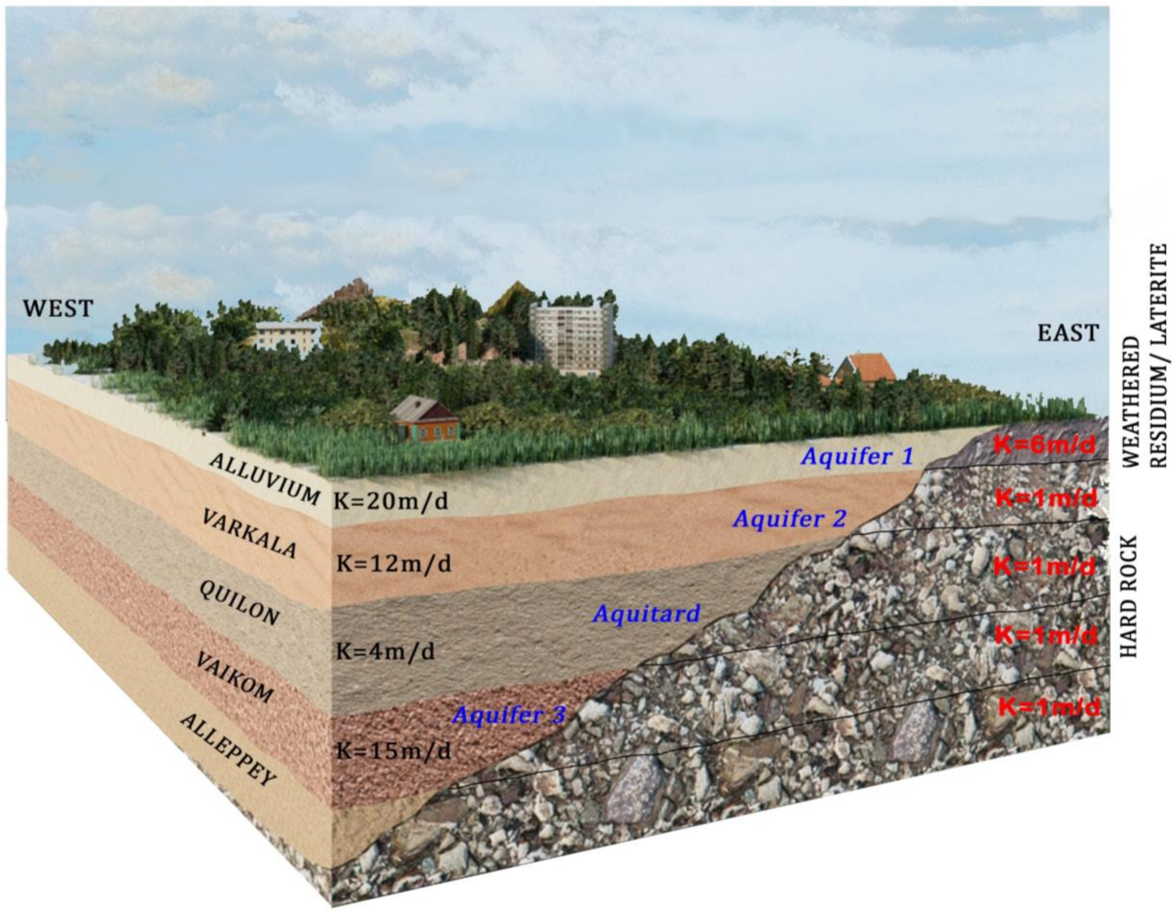


Fig.11 3D aquifer disposition

Fig.10 (A &B) shows that the highly undulated nature of the confined aquifer system indicating the structural disturbances. The hardrock -softrock combination of multi-layered aquifer system was introduced into the model domain through K values.

The absence of individual piezometric head for each confined aquifer (Warkalai & Vaikom) has created major hindrance to simulate the bottom layers and as such the top layer is simulated and kept the bottom confined layers as dummy layers for the time being. Once the piezometric head of confined layers generated, it can be incorporated in the model domain and simulate the aquifer system as a whole.

The surface elevation data with respect to Datum (MSL) for each cell has been generated using standard SRTM data set of USGS to avoid interpolation errors due to lack of sufficient ground control points. The ground elevation data has been taken as top of layer 1. The exploration data has been used to demarcate the bottom of layer 1,2,3,4 which completely defined the four layer system in the model (Fig.12).

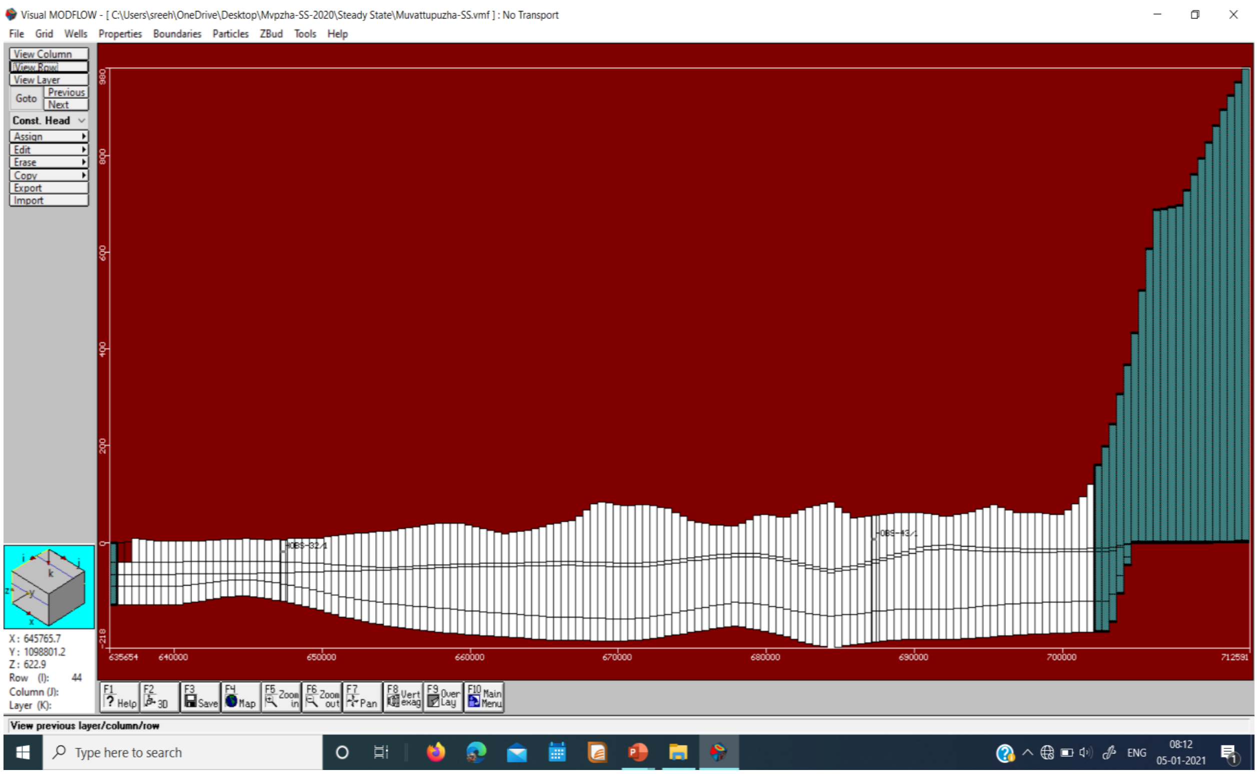


Fig.12 Cross section showing disposition of multi layered aquifer system (Col # 42, Row-17)

3.3 Grid design and software

The study area was discretized to 9816 active cells of 500 m by 500 m dimension (Fig.13). Each cell represents an area of 0.125 sq.km. Cells outside the study area were treated as inactive cells. In W-E direction (X axis) model coordinates range from 635654m to 712591 m and in S-N direction (Y axis) the model coordinates start from 1052054 m and end at 1113525 m. The length of Muvattupuzha river was taken as the criterion to decide the Y directional grid size. The northern and southern boundary are considered as no flow boundary being the drainage divide and western side bordering with Arabian sea was taken as Constant Head boundary. A General Head Boundary (GHB) was assumed as the river system is in continuation with Periyar River system in north west and Pamba River system in the southwest. Based on geology and water holding structures, the top layer has been divided in to three separate zones (Fig.14).

The finite difference groundwater model Visual Modflow Flex 2014.2 (Classic Interface) was used in the present study to simulate the single layer hydrodynamics of Muvattupuzha basin. The model was initially simulated for first stress period with 30 days to run steady state and then extended for five years starting from August 2014 to August 2019 for transient state having 61 stress periods/ time steps where each stress period comprises of 30 days. A stress period is defined as a time period in which all the stresses (boundary conditions, pumping rates, etc.) on the system are constant.

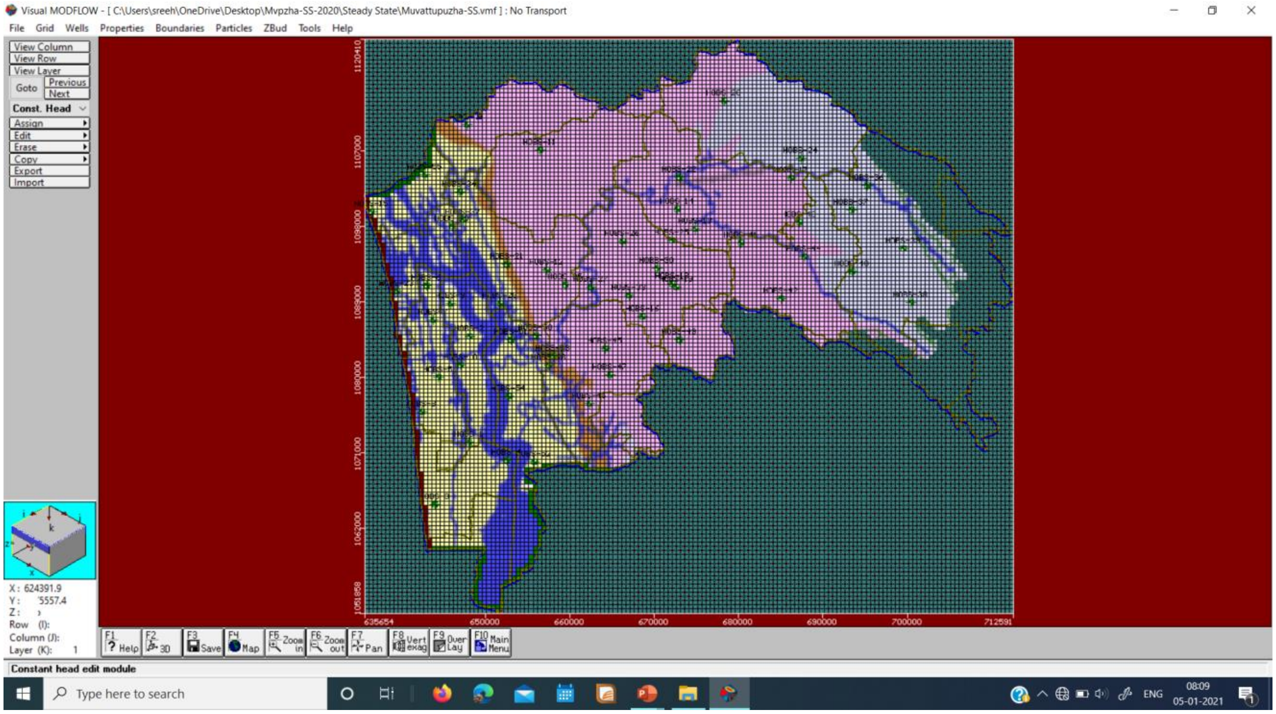


Fig. 13 Grid design of the study area with location of observation wells

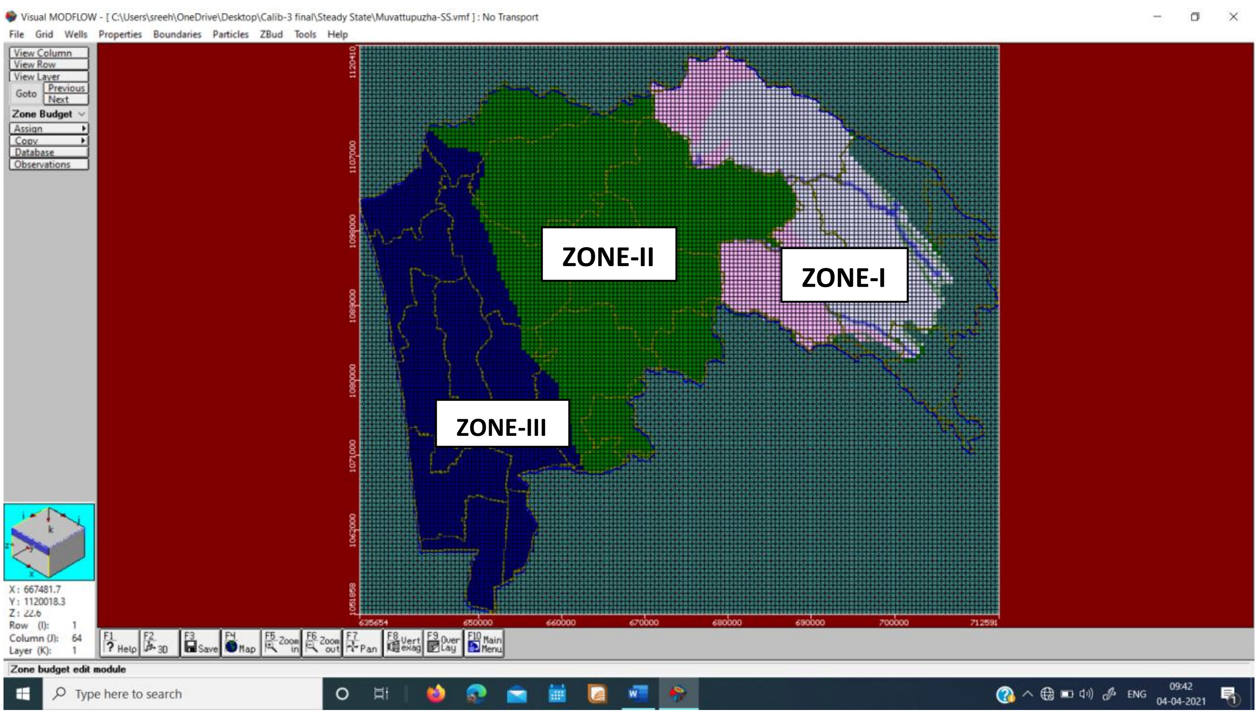


Fig.14 Different zones in the study area

3.4 Initial Condition

The water level data of August-2014 was taken as the initial water table condition for simulation of the flow model (layer-1) as the aquifer is saturated after monsoon season. Due to lack of separate water level data of confined aquifer no initial condition was applied to Layer-II (Warkalai)and layer- IV (Vaikom). The water level elevation with respect to MSL is imported and interpolated into the model. The distributed initial head in the domain varied between 6.5 to 153.78m (amsl) for unconfined condition of top unconfined layer (Fig.15).The calibrated head of steady state will be the initial condition of transient state.

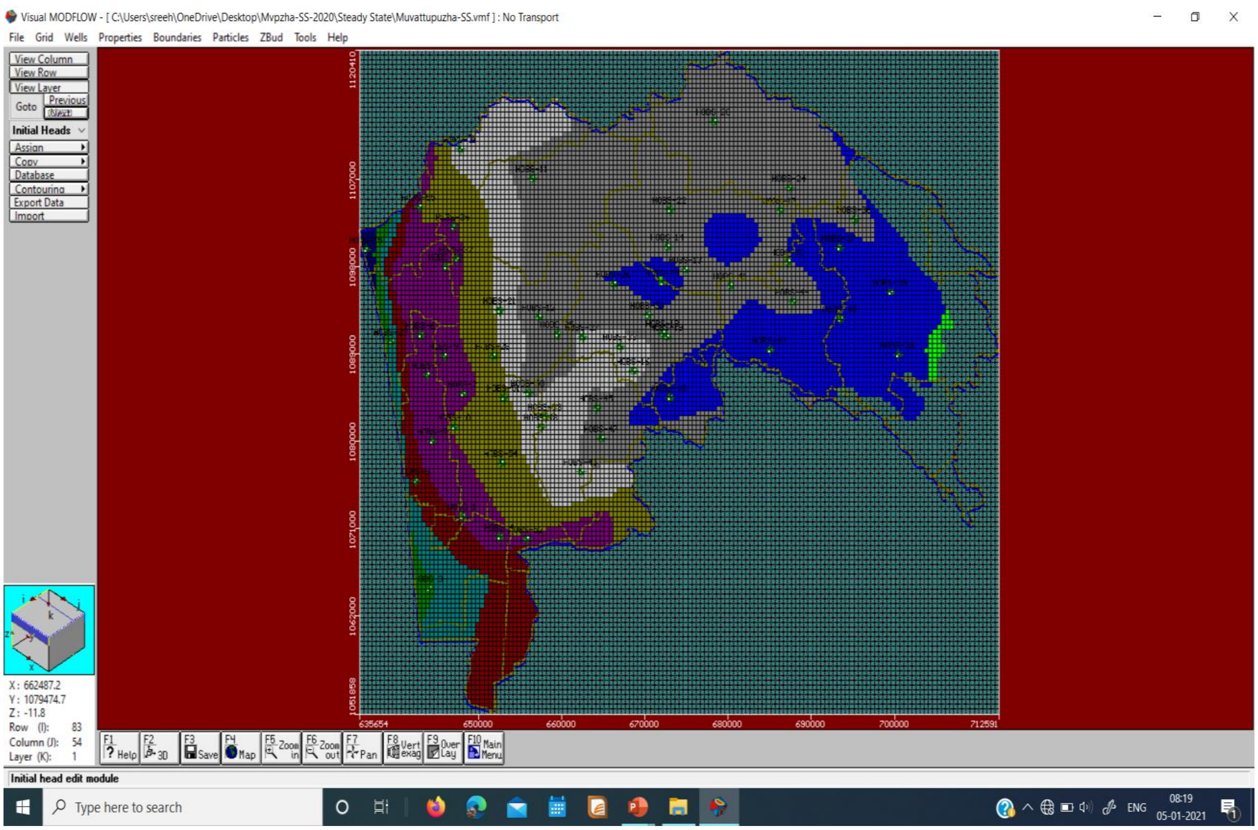


Fig.15 Distribution of Initial head (top layer)

3.5 Hydraulic Properties

The distributed values of hydraulic conductivity and specific storage values were available based on pump test values of transmissivity and storativity values. Therefore these values were assigned to start the steady state and then fine tuned during calibration. The initial values assigned for hydraulic conductivity and specific storage values on different layers are listed below in Table- 7.

Layer	Zone	Kx (m/day)	Ky (m/day)	Kz (m/day)	Sy	Ss (l/m)
Layer-I	Zone-I (Alluvium)	15	15	1.5	0.06	0.003
Layer-I	Zone II (Weatered Residuum)	8	8	0.8	0.04	0.0025
Layer-II	Zone III(Warkalai)	12	12	1.2	0.2	0.0031
Layer-II	Zone IV (Hard rock)	2	2	0.2	0.02	0.00001
Layer-III	Zone V (Quilon) Aquitard	4	4	0.4	0.04	0.0065
Layer-III	Zone-VI (Hardrock)	2	2	0.2	0.02	0.00001
Layer-IV	Zone-VII (Vaikom)	20	20	2	0.22	0.001
Layer-IV	Zone-VIII(Hardrock)	1	1	0.1	0.02	0.00001

Table-7 Zonal distribution of hydraulic properties

Same trend has followed for Storage parameter. K and S values were assigned as zones rather than point values (Fig.16).Two zones were assigned for top aquifer and other bottom confining layers (Fig.17) resulted in eight zones in the model for K and S values.

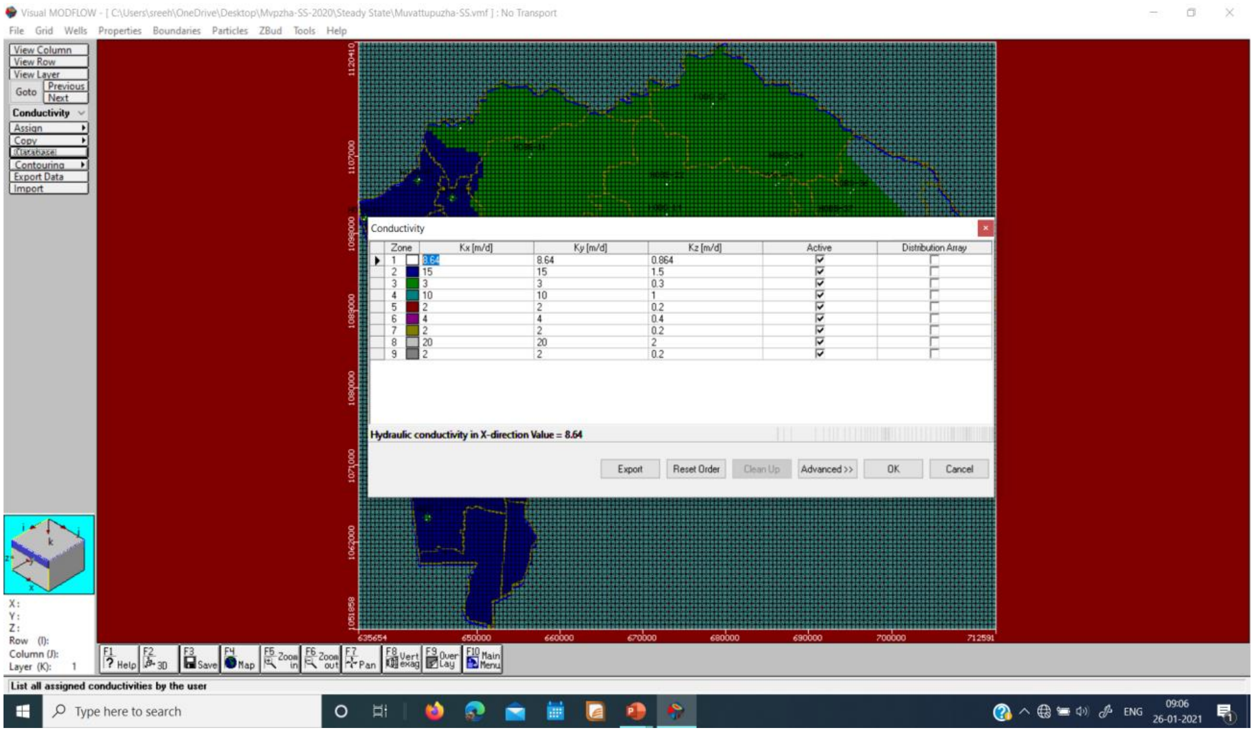


Fig.16 Zonal distribution of Hydraulic conductivity

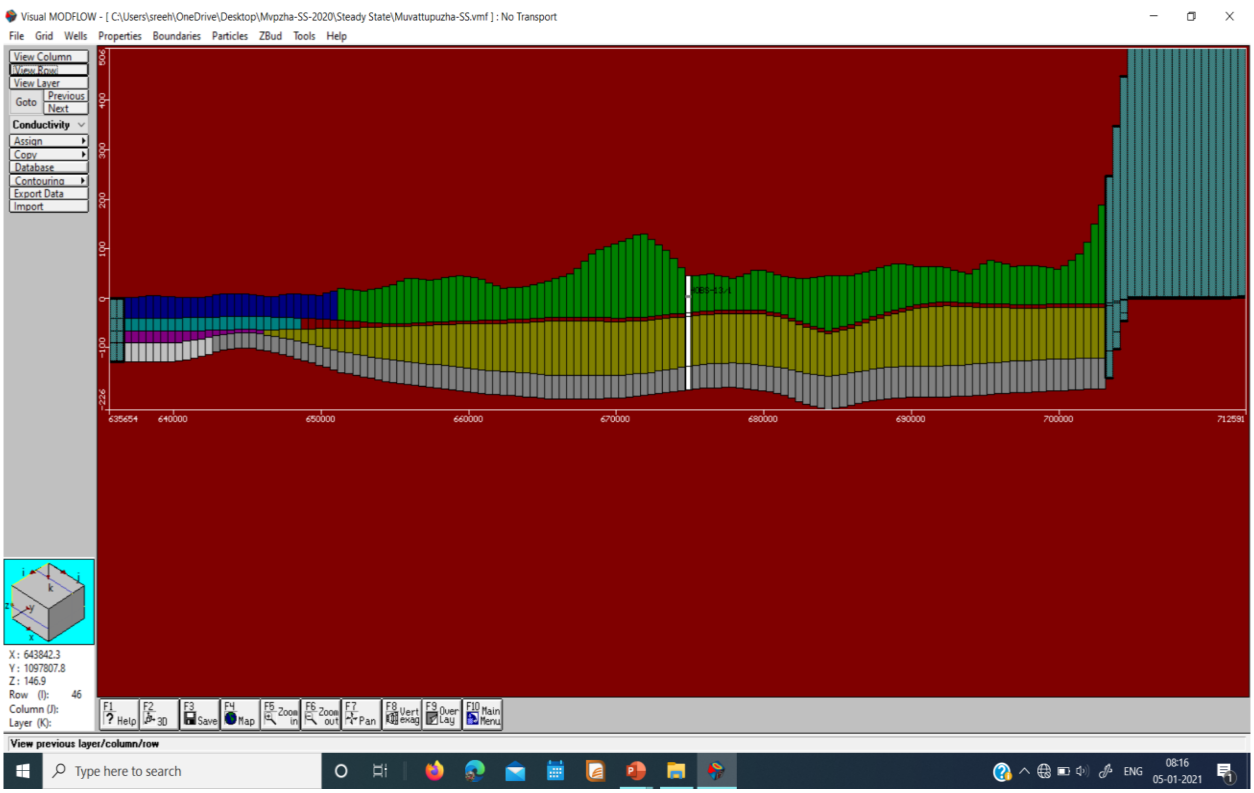


Fig.17 Hydraulic conductivity in different layers

3.6 Recharge

Based on GEC-2015 methodology (CGWB,2017), RIF method (Recharge Infiltration factor) was adopted for calculating monsoon and non monsoon recharge and is estimated using the following equation.

Rrf = f x A x Normal rainfall in monsoon season
Where f = rainfall infiltration factor A = area for computation of recharge

Other components used in the recharge calculation are (i)recharge due to canal,(ii) recharge due to applied ground water irrigation and (iii) canal irrigation. Canal irrigation plays a significant role as the area is networked with MVIP canals and augmenting recharge during lean periods

The five year daily rainfall data from Muvattupuzha Basin area (Aroor, Cherthala, Piravam and Vannapuram sites) was considered and applied for the whole basin as different zones due to variability of rainfall occurrence in the basin. Based on the variability, the recharge was worked out for each block. The recharge rate of each block is considered as single zone. The zonal distribution of recharge component is given in table-8 and Fig.18.

Sl No	Block	Zone	Recharge (m/d)
1	Idukki	1	0.004185
2	Elamdesam	2	0.004915
3	Kothamangalam	3	0.004538
4	Muvattupuzha	4	0.005125
5	Tdpzha	6	0.015571
6	Uzhavoor	6	0.005146
7	Pambakuda	7	0.005547
8	Vadavukode	8	0.005223
9	Koovapadi	9	0.005537
10	Vazhakulam	10	0.005901
11	Mulanthuruthy	11	0.00351

12	Kaduthuruthy	12	0.005582
13	Ettumanoor	13	0.002885
14	Vaikom	14	0.002685
15	Aryad	15	0.003057
16	Kanjikuzhi	16	0.003251
17	Thykattussery	17	0.002297
18	Pattanakkad	18	0.002681
19	Palluruthy	19	0.002756
20	Edappally	20	0.002554

Table- 8 Zonal distribution of Recharge rate for steady state.

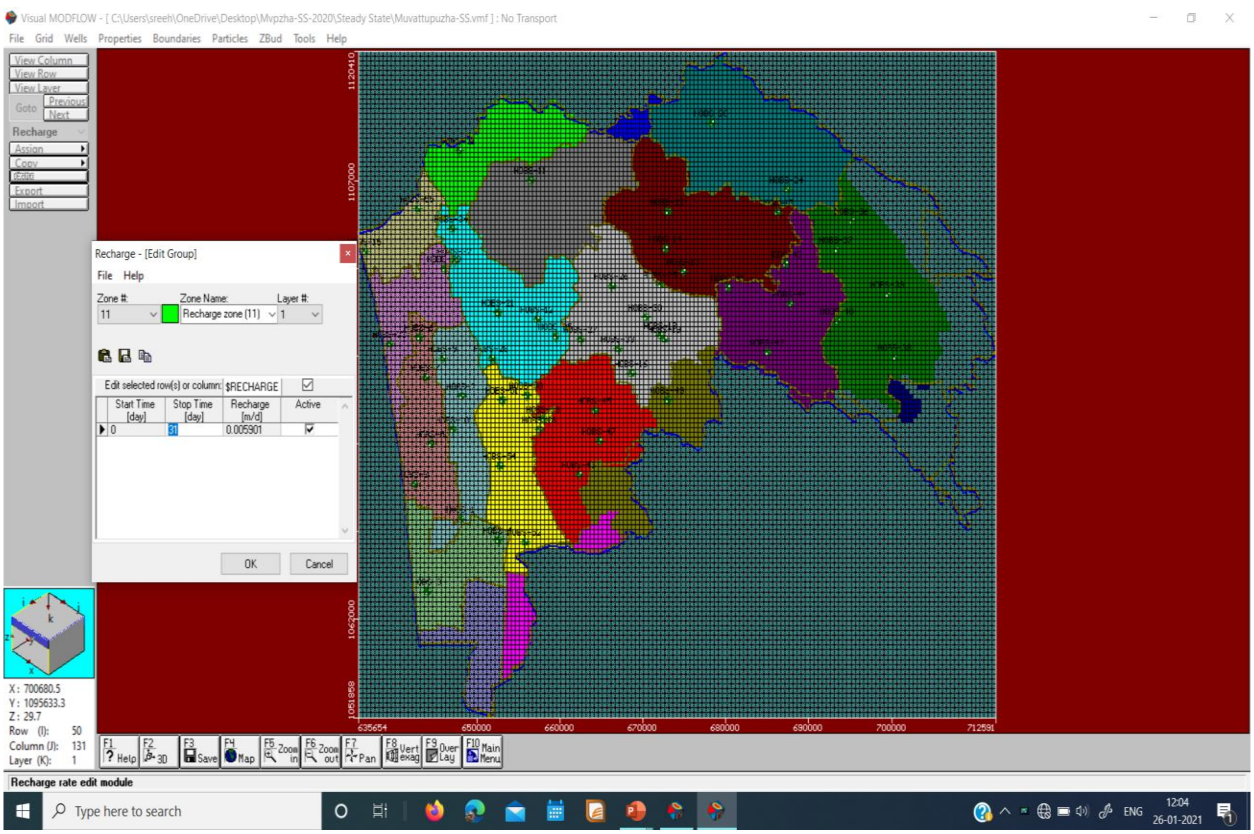


Fig.18. Zonal distribution of Recharge rate.

3.7 Ground Water Draft

Different types of ground water abstraction structures (irrigation dug well, tube well, filter point wells,domestic dug well, bore well) exist in the study area and used mainly for irrigation and domestic purpose. Small scale farming activity using domestic dug well or bore well is common in the study area. A complete data base on ground water abstraction are not available. Therefore the well census data of GEC-2017 was taken as base data for the preparation of draft component.

Seasonal draft based on cropping pattern and domestic requirement was worked out considering the fact that there is no existence of major drinking water supply scheme of either Kerala Water Authority or Local Self Govt Departments. Major industries such as Mc Dowels Distillery at Cherthala,Pallipuram Industrial hub, ice plants/fish processing units at Aroor area are tapping ground water from Warkalai and Vaikom aquifers for their various industrial operations and the draft of these industries were worked out as per the daily pumping rates. The draft data worked out for the basin is distributed throughout the model domain using 388 no of bore wells (layer-1) where one cell represent one well as shown in Fig.19. 14 wells were assigned for Warkalai,27 wells for Vaikom , and 13 wells tappng hard rock aquifers are provided (Fig.20).The block wise distribution of wells is shown in Table-9. Negative sign indicate that wells are discharging.

Sl No	**Block**	**No of wells**	**Draft (m3/d) per well**
1	Aryad	5	-217.78
2	Edappally	5	-251.86
3	Elamdesam	35	-25.85

4	Ettumanoor	5	-78.86
5	Idukki	5	-71.77
6	Kaduthuruthy	30	-62.65
7	Kanjikuzhi	15	-94.15
8	Koovapadi	3	-57.14
9	Kothamangalam	40	-66.13
10	Mulanthuruthy	30	-85.2
11	Muvattupuzha	40	-59.9
12	Palluruthy	10	-42.65
13	Pambakuda	35	-55.33
14	Pattanakkad	15	-106.13
15	Thodupuzha	30	-59.08
16	Thykattussery	15	-118.35
17	Uzhavoor	10	-75.54
18	Vadavukode	30	-62.21
19	Vaikom	20	-58.33
20	Vazhakulam	10	-192.42
	Total wells	388	

Table-9. Block wise details of draft rate applied in the model.

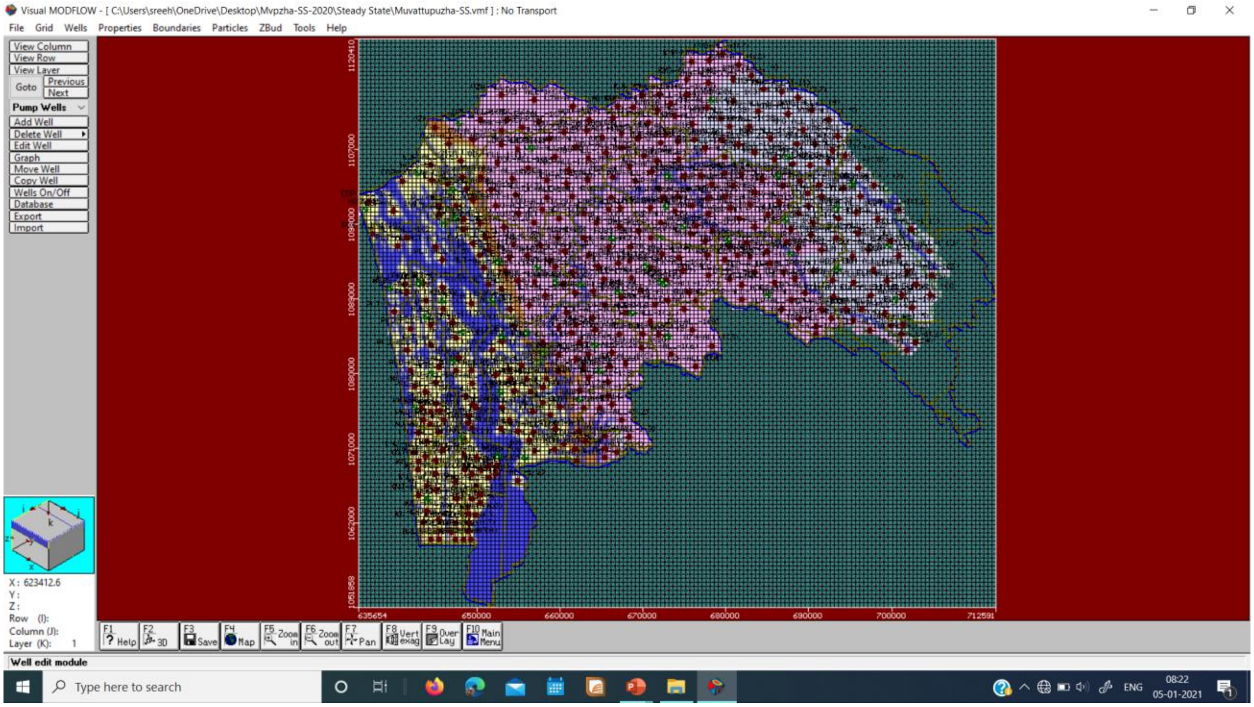


Fig.19 Distribution of draft for steady state

Fig.20 Pictorial representation of draft for various aquifers.

3.8 Evapotranspiration (ET)

Evapotranspiration (ET) values considered for steady state are given below and three zones were assigned considering homogeneous crops/trees and extinction depth. (Fig.21).ET rate and Extinction Depth (ED) kept for different zones are listed below

Zone	ET rate (m/d)	ED (m)
Zone -I	0.00233	2.5
Zone-II	0.00243	1.8
Zone-III	0.00207	1

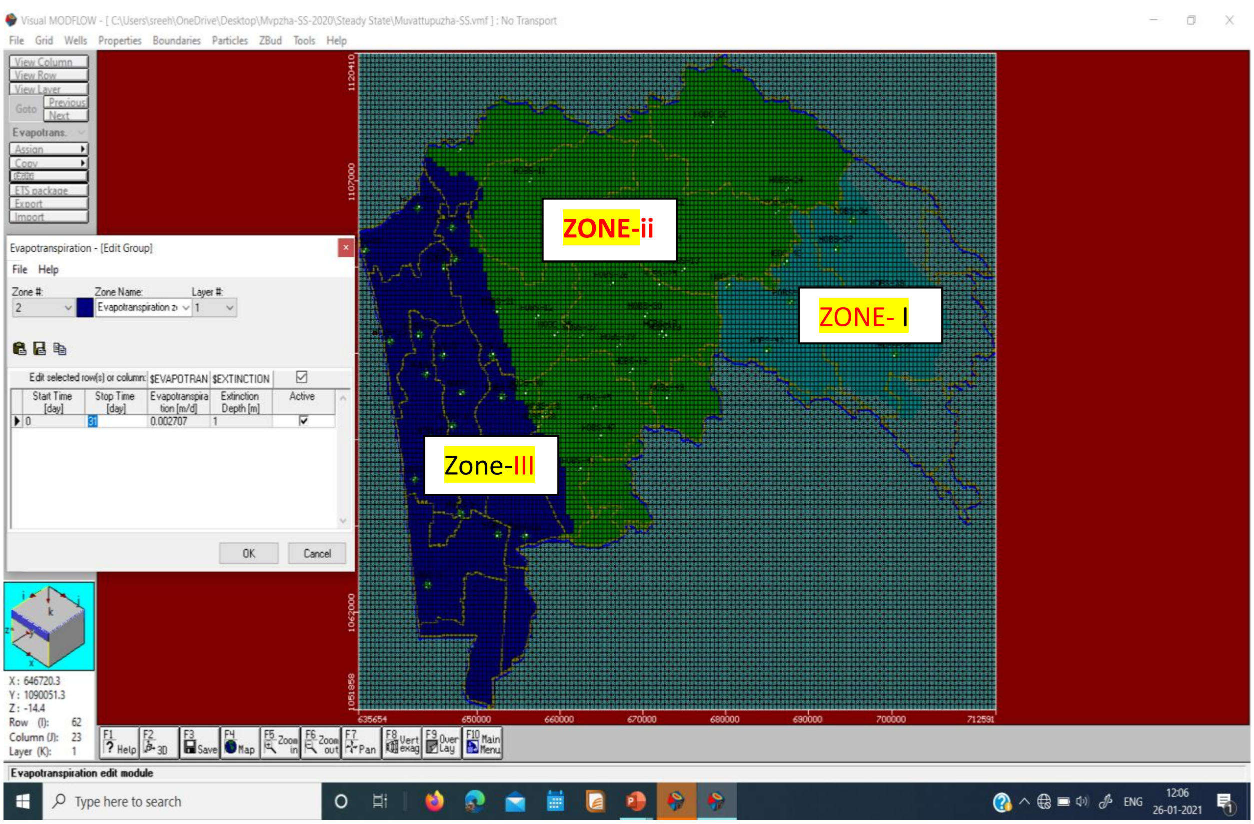


Fig.21 Distribution of Evapotranspiration values

3.9 Model geometry and boundary conditions

Muvattupuzha Basin is a natural ground water basin characterised by distinct drainage divide and well established river drainage network system. Four layers were considered for modeling purpose but simulation is restricted to single top layer consists of Alluvium in the western part and weathered residuum in the eastern part. The river Muvattupuzha is simulated as head dependent flow and River Package of MODFLOW is used to simulate the river flow. In the north and south, model boundary was taken as no flow boundary due to drainage divide. More over east of Muvattupuzha river is characterised with hilly area with steep slope. This area is also set as no flow boundary (inactive cell). Another boundary existed in the model is constant head boundary at the western side where Muvattupuzha river debouch into Arabian Sea at Kochi back water. In the northwestern and southwestern side the model boundary is considered as General head Boundary due to the connectivity with Periyar and Pamba river systems. Major part of the ground water flow discharges towards Muvattupuzha River through streams. (Fig.22).

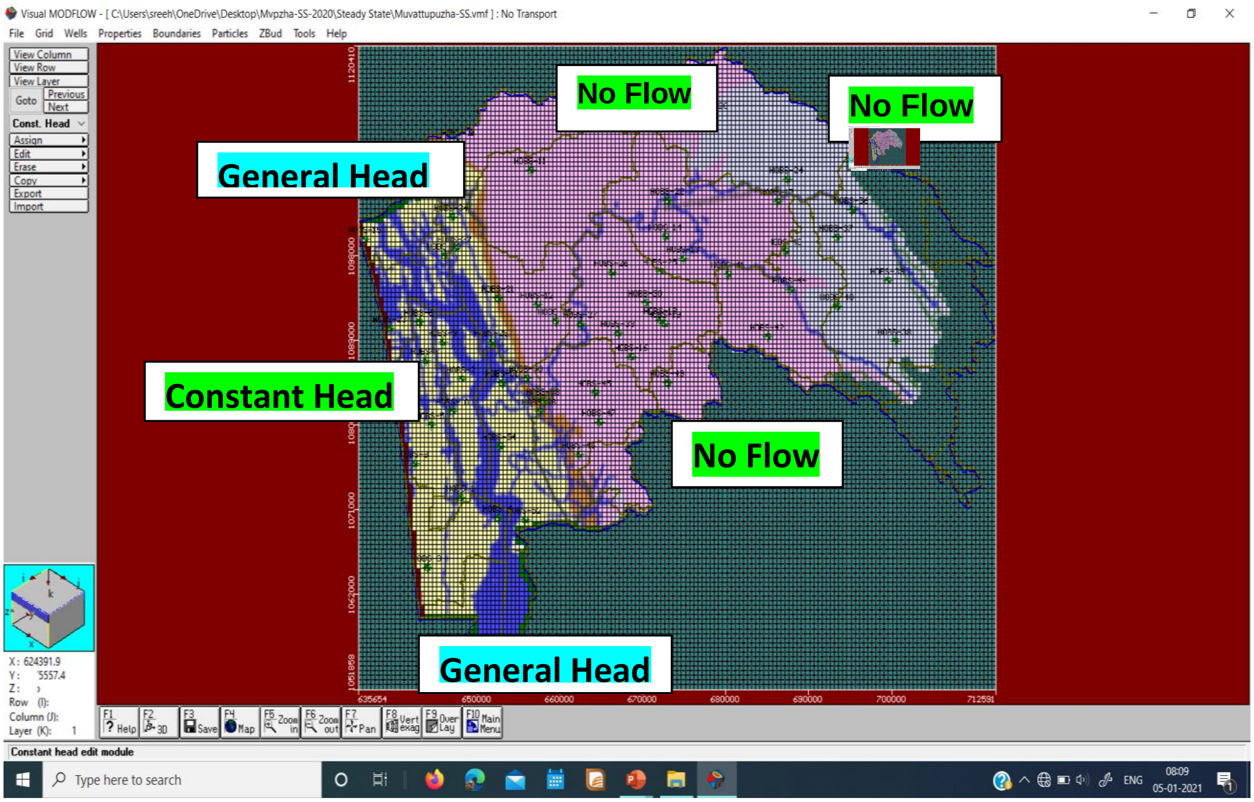


Fig.22 Boundary conditions in the study area

4.0 Steady State calibration

Steady state assumes that inflows are equal to outflow and there is no change in aquifer storage. In this model, calibration was carried out by matching of observed head in the aquifer with hydraulic head simulated by MODFLOW using solver viz. SIP or WHS. The calibration was made using 47 observation wells monitored during August 2014. By trial and error calibration , the conductivity values were increased/decreased during many sequential runs until the good match between observed and the simulated water level contours were obtained.

The accuracy of calibration is judged through statistical analysis by comparing the mean error, root mean square (RMS),normalised RMS etc (Andserson and Woessner,1992).The hydraulic conductivity values are varied iteratively so that Root Mean square (RMS) could kept as low as possible. The lowest RMS value observed was 9.76 m and normalised RMS is 10.27% (Fig.19).Normalised RMS is a more representative measure of the fit than the standard RMS, as it accounts for the scale of the potential range of data values. Normalised RMS value of 10.27 % is within the accepted limit but it is relatively high compared to the minimum and maximum observed head (-0.28 and 94.78 respectively).This needs to be reduced as low as possible through fine tuning of various hydraulic properties for making the transient state more accurate. The correlation coefficient is 0.95. The absolute residual mean is 6.91 m and residual mean is 5.07 m. The absolute residual mean measures the average magnitude of residuals and therefore provides a better indication of calibration than the residual mean (Waterloo Hydrogeologic Inc,2005).SEE or Standard Error of Estimate is 1.23 m which is the measure of the variability of the residual around the expected residual value,

From the scatter plot of calculated and observed heads it is inferred that the model is highly over predicting the calculated head. The scatter plot data analysis indicate that majority of wells (80%) have overpredicted head distribution compared to observed head.

	No of wells	**%**
Calc Head >Obs Head	38	80
Calc Head </= Obs Head	9	20
Calc Head= Obs Head	0	0
Total	47	100

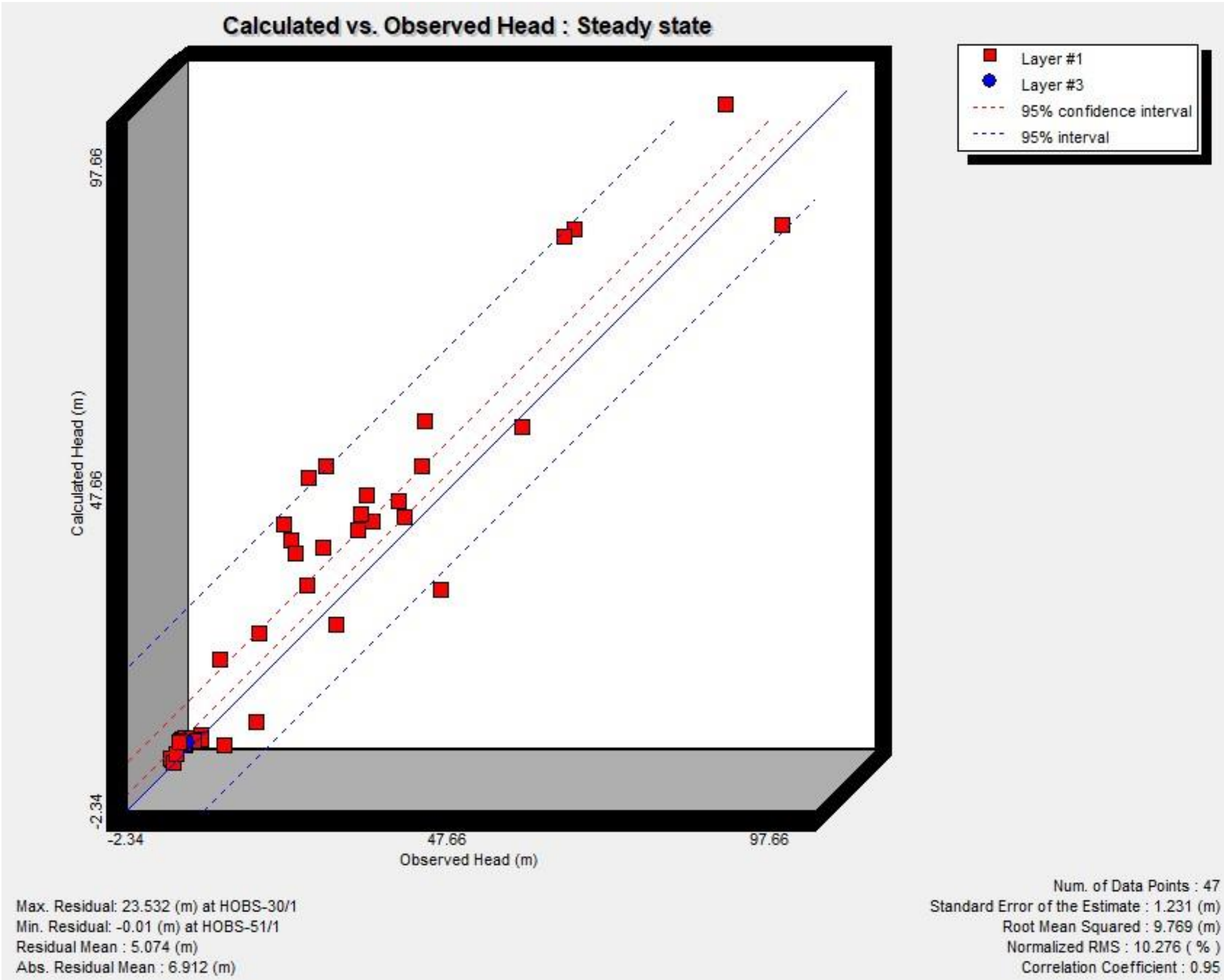


Fig.23 Scatter plot of computed vs observed head for steady state.

Hydraulic Conductivity (Kx,Ky,Kz), Specific yield (Sy), Specific Storage (Ss) values obtained from steady state calibration are given in Table 10.

Layer	Zone	Kx (m/day)	Ky (m/day)	Kz (m/day)	Sy	Ss (l/m)
Layer-I	Zone-I (Alluvium)	20	20	2	0.08	0.003
Layer-I	Zone II (Weatered Residuum)	10	10	1	0.04	0.0025
Layer-II	Zone III(Warkalai)	15	15	1.5	0.21	0.0031
Layer-II	Zone IV (Hard rock)	3	3	0.3	0.02	0.00001
Layer-III	Zone V (Quilon) Aquitard	6	6	0.6	0.04	0.0065
Layer-III	Zone-VI (Hardrock)	2	2	0.2	0.02	0.00001

Layer-IV	Zone-VII (Vaikom)	30	30	3	0.26	0.001
Layer-IV	Zone-VIII(Hardrock)	2	2	0.2	0.02	0.00001

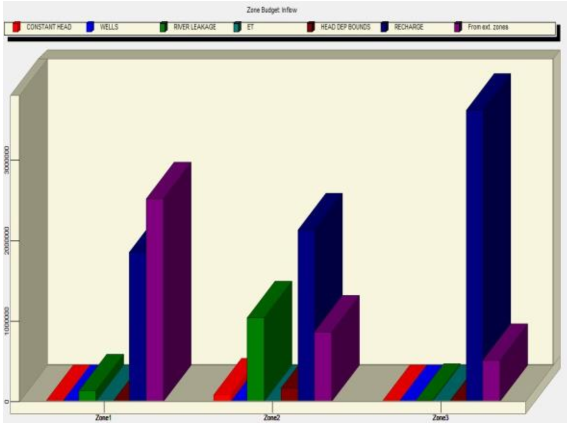
Table 10 Zone wise distribution of derived model parameters (Steady state)

4.0.1 Zone Budget

Visual Modflow incorporates ZONE BUDGET software developed by USGS, which calculates sub-regional water budgets using the results from the MODFLOW (Visual Modflow Manual,2006). It calculate budgets by tabulating the budget data that MODFLOW produces using the cell-by-cell flow option. A sub region of a model for which it calculates a water budget is termed a zone and is indicated by a zone number. Here top layer(aquifer-1) has been divided into three zones (Fig.14) based on geology and water holding structures (Canals) and for each zone a zone budget has been generated and calculated for steady state. The results are summarised in Table 11 & Fig.24. The inflow figure (A) indicate that each zone plays its role in total budget and recharge component is seen as dominant factor. For outflow component well draft and river are controlling Zone-1 whereas ET is playing dominant role in Zone-III.

Zone	Inflow	Outflow
Zone I	Storage = 0 [m^3/day] Constant Head = 0 [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 = 1857700 [m^3/day] ET = 0 [m^3/day] River Leakage = 133050 [m^3/day] Stream Leakage = 0 [m^3/day] Surface Leakage = 0.00 m^3/day General-Head = 0 [m^3/day] Zone 2 to 1 = 1835000 m^3/day Zone 3 to 1 = 688810 m^3/day Total IN = 4514600 m^3/day	Storage = 0 [m^3/day] Constant Head = 0 [m^3/day] Wells = 1525700 [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 = 577950 [m^3/day] River Leakage = 1475400 [m^3/day] Stream Leakage = 0 [m^3/day] Surface Leakage = 0.00 m^3/day General-Head = 0 [m^3/day] Zone 1 to 2 = 439940 m^3/day Zone 1 to 3 = 495650 m^3/day Total OUT = 4514600 m^3/day
Difference : **IN-OUT = -45.41 m^3/day** **Percentage Discrepancy = 0 %**		
Zone II	Storage = 0 [m^3/day] Constant Head = 87899 [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 = 2139400 [m^3/day] ET = 0 [m^3/day] River Leakage = 1046000 [m^3/day] Stream Leakage = 0 [m^3/day] Surface Leakage = 0.00 m^3/day General-Head = 164360 [m^3/day] Zone 1 to 2 = 439940 m^3/day Zone 3 to 2 = 427050 m^3/day Total IN = 4304600 m^3/day	Storage = 0 [m^3/day] Constant Head = 155550 [m^3/day] Wells = 11858 [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 = 718930 [m^3/day] River Leakage = 1475800 [m^3/day] Stream Leakage = 0 [m^3/day] Surface Leakage = 0.00 m^3/day General-Head = 89654 [m^3/day] Zone 2 to 1 = 1835000 m^3/day Zone 2 to 3 = 17780 m^3/day Total OUT = 4304600 m^3/day
Difference : **IN-OUT = 9.51 m^3/day** **Percentage Discrepancy = 0%**		
Zone III	Storage = 0 [m^3/day] Constant Head = 0 [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 = 3626800 [m^3/day] ET = 0 [m^3/day] River Leakage = 14752 [m^3/day] Stream Leakage = 0 [m^3/day] Surface Leakage = 0.00 m^3/day General-Head = 0 [m^3/day] Zone 1 to 3 = 495650 m^3/day Zone 2 to 3 = 17780 m^3/day Total IN = 4155000 m^3/day	Storage = 0 [m^3/day] Constant Head = 0 [m^3/day] Wells = 11051 [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 = 1570100 [m^3/day] River Leakage = 1430000 [m^3/day] Stream Leakage = 0 [m^3/day] Surface Leakage = 0.00 m^3/day General-Head = 27880 [m^3/day] Zone 3 to 1 = 688810 m^3/day Zone 3 to 2 = 427050 m^3/day Total OUT = 4154900 m^3/day
Difference : **IN-OUT = 9.51 m^3/day** **Percentage Discrepancy = 0%**		

Table-11 Zone budget- Steady state



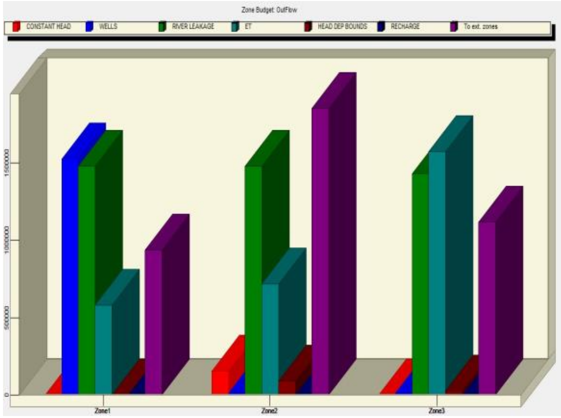


Fig.24 Distribution of Zone wise inflow (left) and outflow (right) components in steady state.

4.0.2 Cumulative Zone budget

The cumulative input and output have been summarised below in Table- 12 and Fig. 25 depicts the variation of each recharge and discharge components in the study area.

IN	**OUT**
Storage = 0 [m^3/day] Constant Head = 87899.4453 [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 = 7623830 [m^3/day] ET = 0 [m^3/day] River Leakage = 1193840.875 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 164356.9531 [m^3/day] Total IN = 9069927 [m^3/day]	Storage = 0 [m^3/day] Constant Head = 155548.4375 [m^3/day] Wells = 1548577.375 [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 = 2867008 [m^3/day] River Leakage = 4381253 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 117533.9297 [m^3/day] Total OUT = 9069921 [m^3/day]
Difference : **IN-OUT = 6 m^3/day** **Percentage Discrepancy = 0%**	

Table 12.Cumulative Zone budget for Steady State

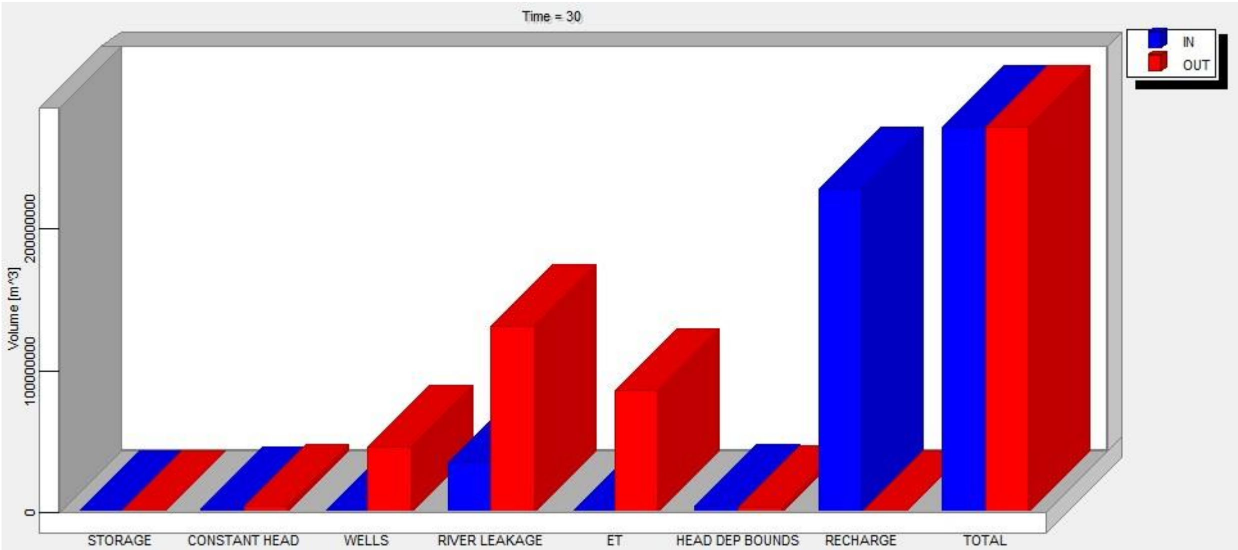


Fig.25 Cumulative mass balance for Steady State

The cumulative budget indicate that total recharge contributing to the basin is 7623830 m^3/day, river leakage is 1193840.87 m^3/day and from seepage inflows from other basin (GHB) is 164356.95 m^3/day and inflow from sea is about 87899.44 m^3/day. In case of outflows, an amount of 117533.92 m^3/day leaves the watershed through general head boundary and withdrawals from the wells is 1548577.37 m^3/day, ET accounts for 2867008 m^3/day ,river discharges about 4381253 m^3/day and other flows like constant head constitute 155548.43 m^3/day. Thus, the total volume of water entering the watershed is 9069927 m^3/day (3310 MCM) and leaving the watershed is 9069921 m^3/day (3310 MCM) with error percentage is zero.

The cumulative input and output results have been quantified in MCM and shown below indicate that in inflow budget, recharge component has major contribution whereas in outflow budget. River discharge and

Evapotranspiration (ET) indicate substantial role in maintaining the mass balance compared to wells (draft) and river flow.

Inflow (MCM)				Outflow (MCM)				
Recharge	River Leakage	General Head	Constant Head	River discharge	ET	Wells	Constant Head	General Head
2782.69	435.95	95.99	32	1599.15	1046.45	565.23	56.77	42.89

4.1 Transient State

4.1.1 Parameters

The duration of simulation is five years starting from August 2014 to August 2019 and monthly water level data for the study area were collected for the same period (Table-4&5). Based on water level data transient state modeling was planned for the said period comprising 61 monthly stress periods having 30-31 days at each stress period. In the absence of adequate field data recharge and discharge components were assumed wherever necessary. The initial hydraulic properties of steady state was carry forward for initial run of transient state. The steady state calibrated head at each node point will be the initial condition for transient state model.

(a) **Recharge:** Recharge figures include recharge from rainfall and return flow of irrigation. Zone/block wise recharge rate calculated used in the model are given in Annexure-1A

(b) **Draft** :Ground water draft was assumed to be equally distributed over each zone (block) in the study area. A constant draft schedule was used for all the pumping wells in each individual zone , given in Annexure-1B. The total number of pumping wells considered was

250.

(c)Water level: Seasonal water level data of 47 observations wells of CGWB was considered (Table-5) and Reduced Level (RL) was worked out for the entire period for Transient state.

(d)River Stage : The river stage variations of Muvattupuzha river were assumed and the data used for transient modeling are given in Annexure-1C.Due to highly undulating elevation and meandering river system the related river stage data was incorporated cell wise or rarely group of cells clubbed together where cell elevation is uniform. Since it is a huge data base the same could not be shown here, rather river stage is arranged in such a way to show the major river stage variations in three zones (upper ,middle and lower reaches) which is based on major change in elevation as shown in Annexure 1C.

(e)Evapotranspiration : Evapotranspiration data used for the transient state modeling are given in Annexure 1D.

(f) Constant Head: Western boundary of the basin is considered as Constant head boundary. The Constant Head is assumed as 0 m. A linear array of cells parallel to sea was selected and assigned constant head data which is more or less static head (Annexure-1E).

(g)General Head: As the boundary is interconnected to other basins (Periyar Pamba) in north and south, a General Head boundary is assigned to limited area to reflect the inflow and outflow from the study area to other basins (Annexure-1F)

4.1.2 Transient State calibration

In transient state model, total 1856 days starting from August 2014 to August 2019 were considered and total number of stress periods are 61. During each stress periods some changes in the pumping pattern were taken into consideration. The initial head values and boundary generated through steady state model calibration were used as the initial condition for the transient state. The storage coefficient /specific yield becomes effective in the transient state. The model was run in the transient with these values.

A number of trial runs have been made with changes in the input and output parameters until a correlation coefficient of 0.943 is arrived with RMS value of 7.85 m. The normalised RMS ranges from 10.03% at 1st stress period to 8.25 % at 36th stress period and finally 8.72 % at 61st stress period (1856 days) (Fig.26 to 29). Hydrographs are the best indicator of model behaviour in the field. The match between observed and calculated head variations are depicted in Fig.30 which are grouped as three categories viz. good, medium and poor match for ease of interpretation. This clearly indicate that at certain places there is good calibration and in other places there is poor calibration and in some other areas there is medium calibration. The medium to poor match in some wells may be reduced by further fine tuning of recharge and discharge components. Hydrographs representing wells of Alluvium are in general showing poor match indicate the minimal withdrawal compared to recharge resulted in shallow water level condition and rejected recharge.

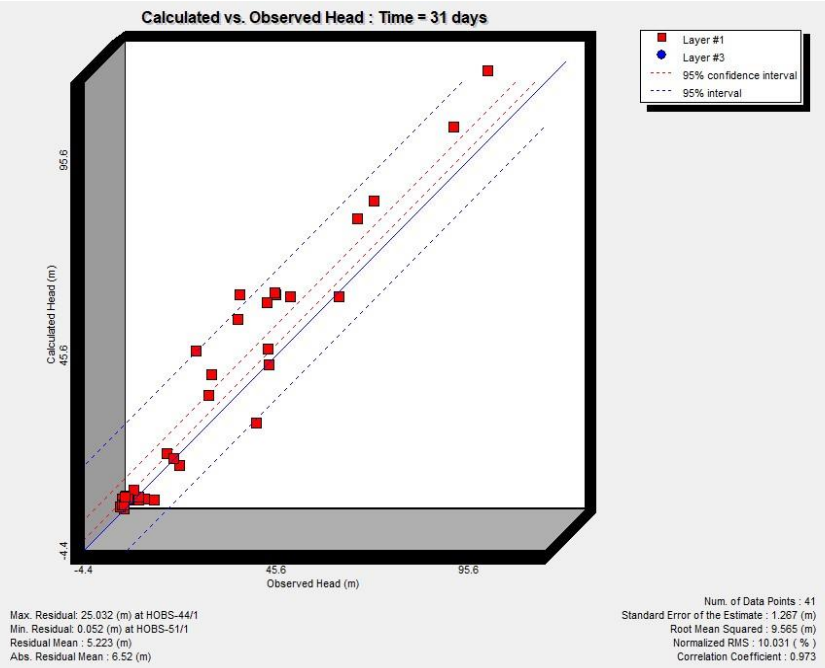


Fig 26 Scatter plot of observed and computed heads during 1st stress period (31 days)

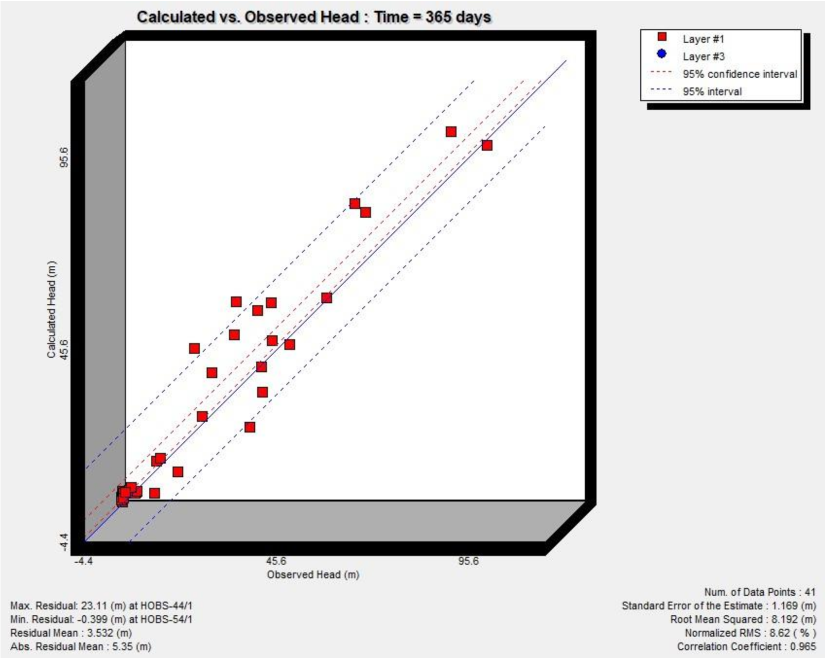


Fig.27 Scatter plot of observed and computed heads during end of first year (12th stress period).

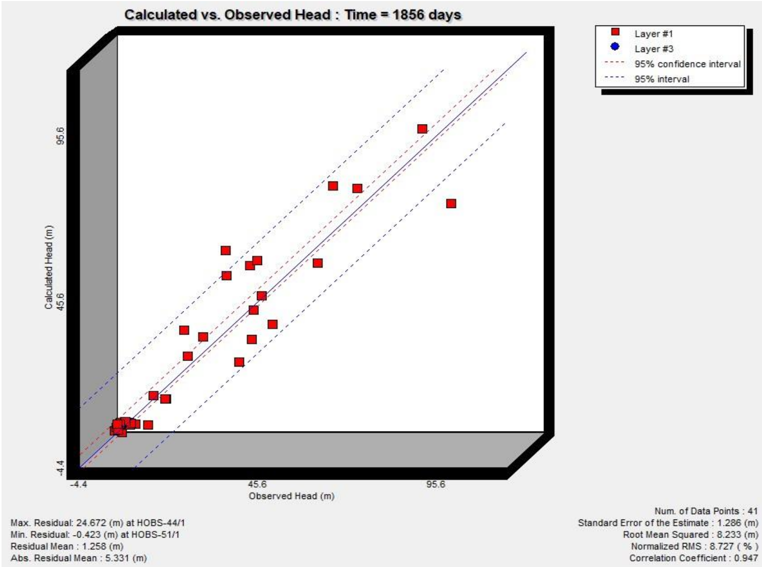


Fig.28 Scatter plot of observed and computed heads during end of third year (36th stress period).

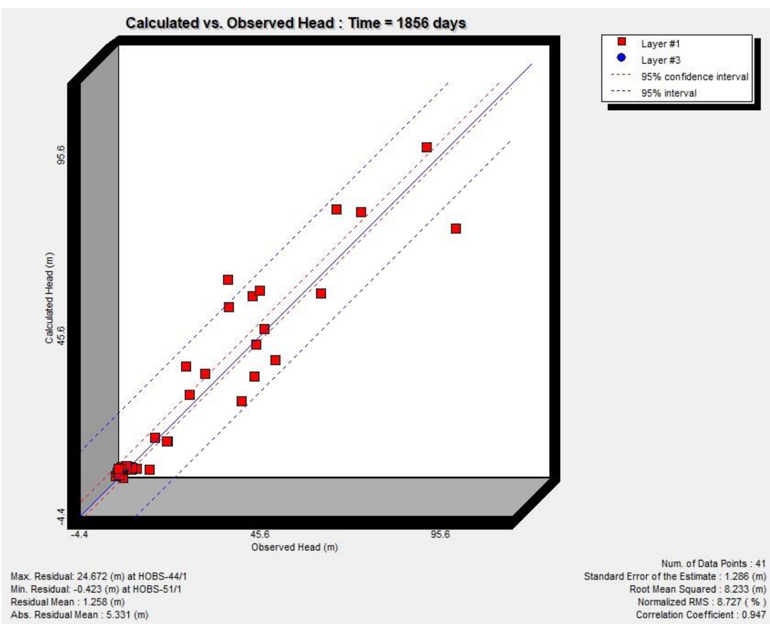


Fig.29. Scatter plot of observed and computed heads during end of fifth year (61st stress period).

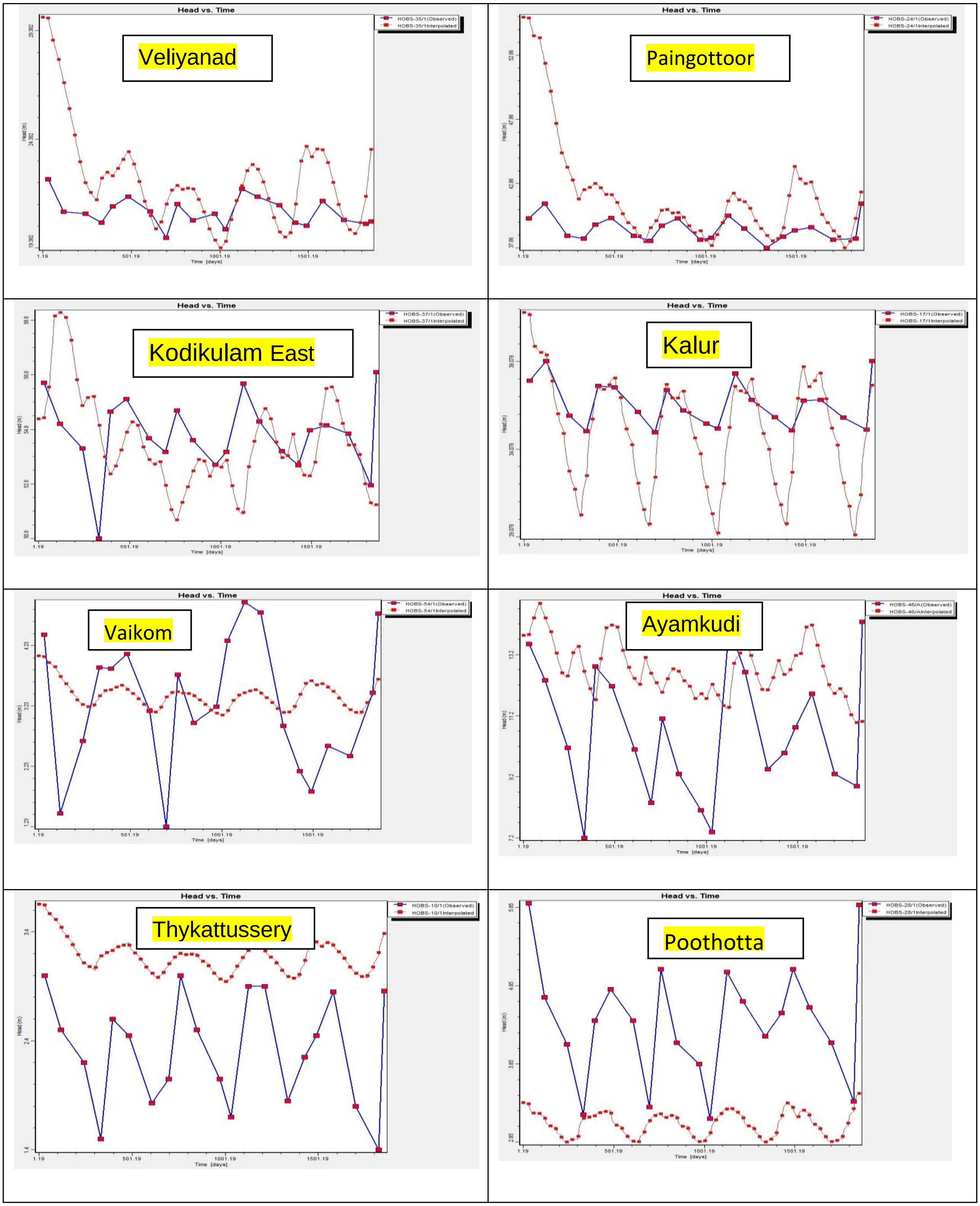


Fig.30 Transient State Calibration-Well Hydrograph showing comparison of computed and observed water levels of selected wells.

There are some generally accepted methods of evaluating and interpreting the model calibration using both qualitative and quantitative measures viz. residual mean (RM),absolute residual mean (ARM),standard error of the estimate (SEE), root mean squared error (RMSE),normalised root mean squared error (NRMSE),correlation coefficient (CE) etc. If the response of the model corresponding to the parameters assumed for calibration were found acceptable with these criteria, then the model's parameters and the setting of the model were said to be calibrated (Anderson,1992,Elango,2005,Ahmed and Umar,2009,IIT,2014).The above mentioned error statistics/model residual statistics of different periods of model run are tabulated in Table-13.

Stress Periods(days)	RM (m)	ARM (m)	SE	RMS (m)	NRMS (%)	CC
1 (30)	5.22	6.52	1.26	9.56	10.03	0.973
12 (365)	3.53	5.35	1.16	8.19	8.62	0.965
24 (730)	2.57	5.27	1.17	7.85	8.27	0.958
36 (1095)	1.47	5.18	1.21	7.84	8.25	0.952
48 (1460)	2.67	5.56	1.2	8.08	8.53	0.954
61(1856)	1.25	5.53	1.26	8.23	8.72	0.947

Table-13.Error statistics (model residual statistics) at different stress periods of Transient state.

The above table indicate the gradual reduction of error at various stress periods during transient state. The same is graphically shown in Fig.31 &32. The annual variation of reduced water level in Muvattupuzha basin is in the range of 0.05-94.38 (m amsl) and an average of Normalised RMS of 8% indicate better fit/accuracy of the model calibrated.

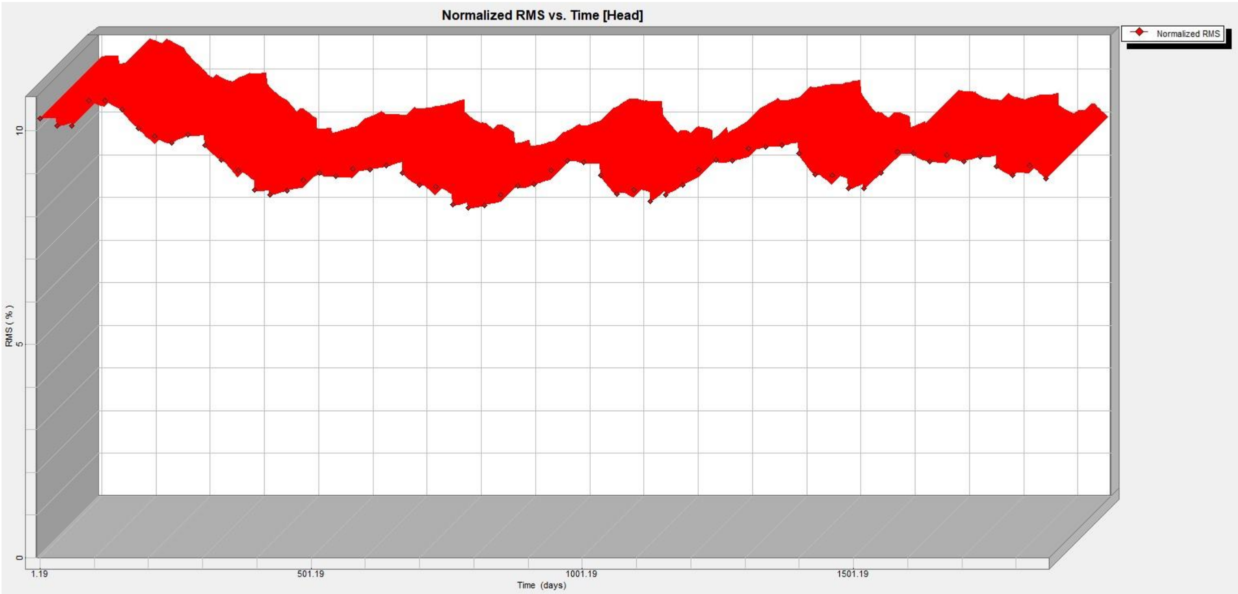


Fig.31. Normalised RMS vs Time graph for the Transient State

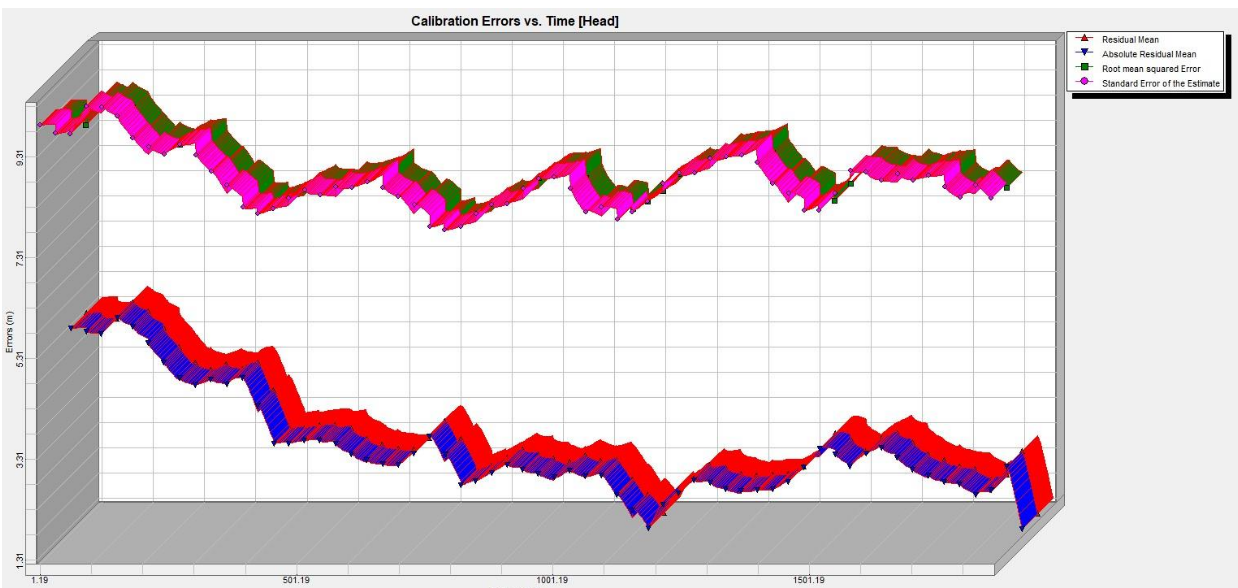
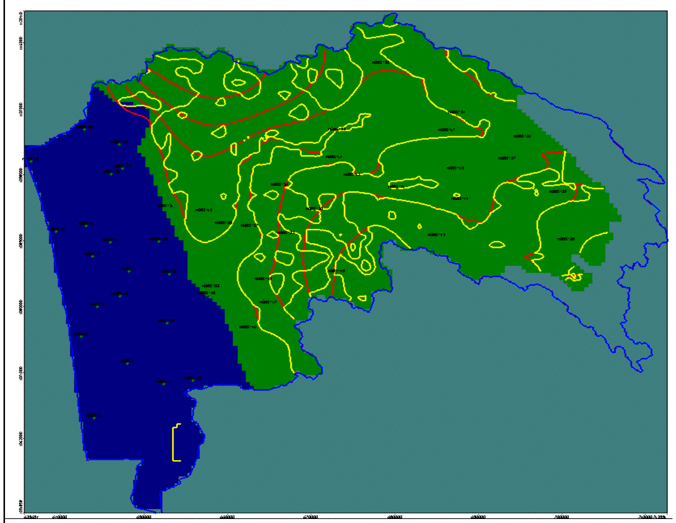


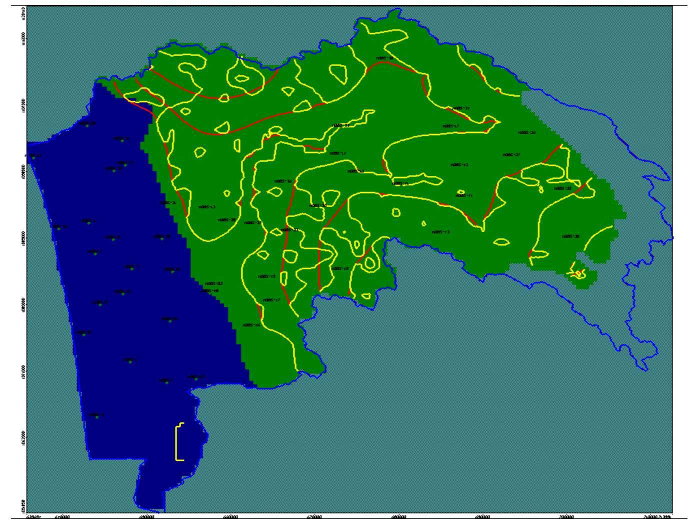
Fig.32 Calibration Errors vs Time graph for the Transient State

The ground water flow directions were calibrated during transient state calibration. The computed water levels and flow directions during different stress periods are shown in in Fig.33 & 34. A perusal of the figures indicate that contours are apparently close to each other in majority of the areas.

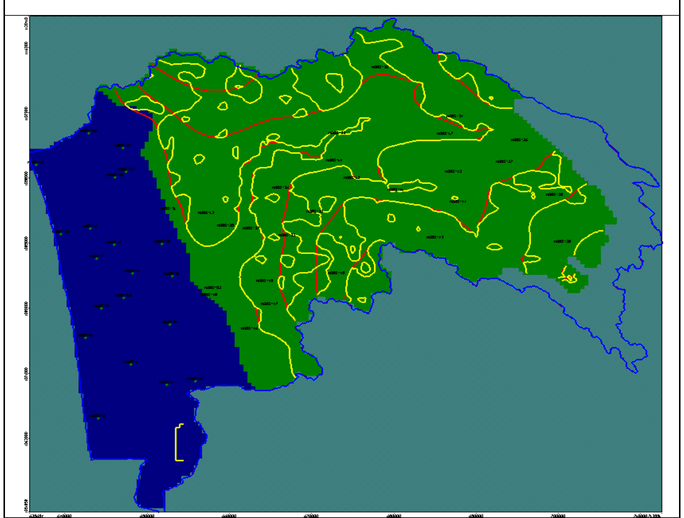
The general flow direction is either towards Muvattupuzha river or towards western sea side.In the western part where Alluvium is present, the water levels are not visible as the water level is below MSL.



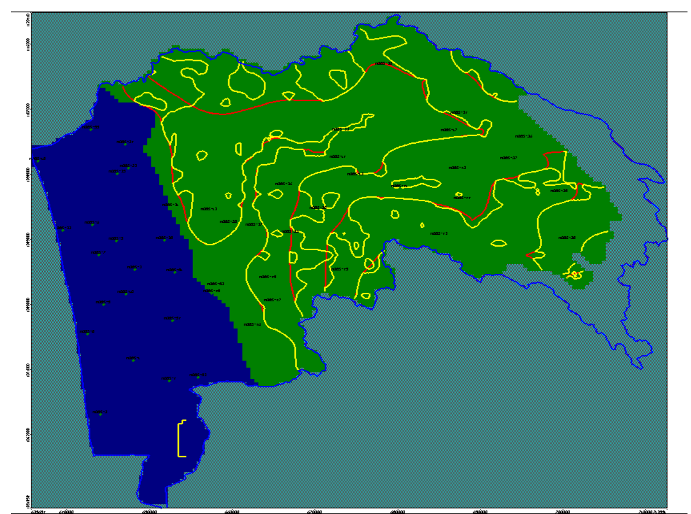
(a) 24th stress period (730 days)



(b) 36th stress period (1095 days)



(c) 48th stress period (1460 days)



(d) 61th stress period (1856 days)

Fig.33. Computed and observed water levels with flow directions during different stress periods (a-d).

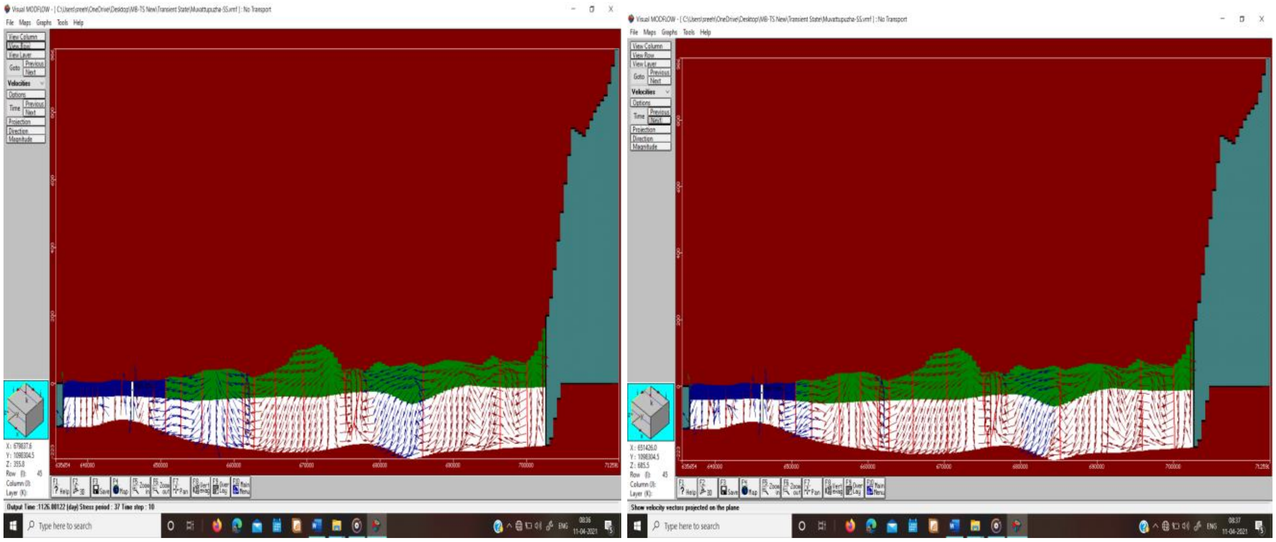


Fig.34. Vertical view of water level contour during 48th stress period (left) and 61th stress period (right) (R-45, C-10)

4.1.3 Data Validation

After successful completion of calibration of transient state, the model was used for validating the results obtained. The known observed value of water level for four wells in the unconfined aquifer (Layer-1) were matched with the computed water level and the same is presented below in Table-14.

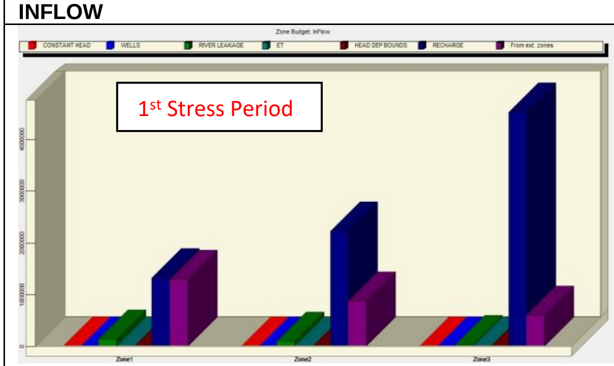
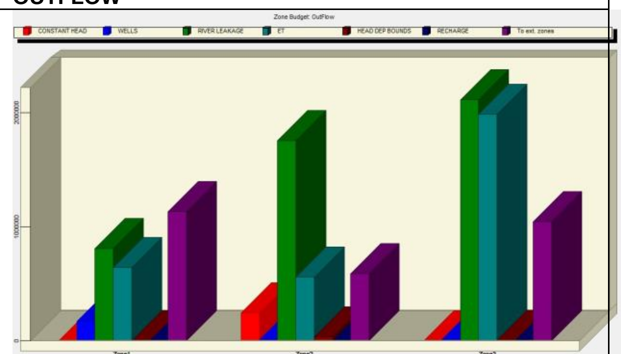
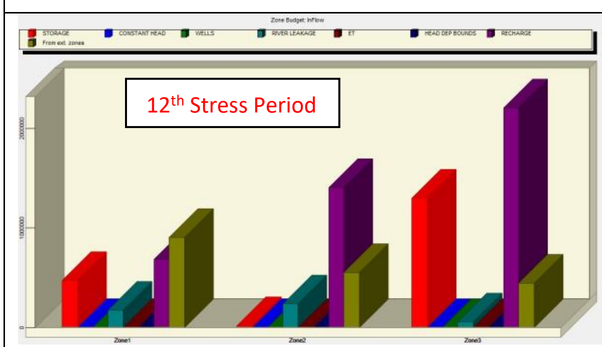
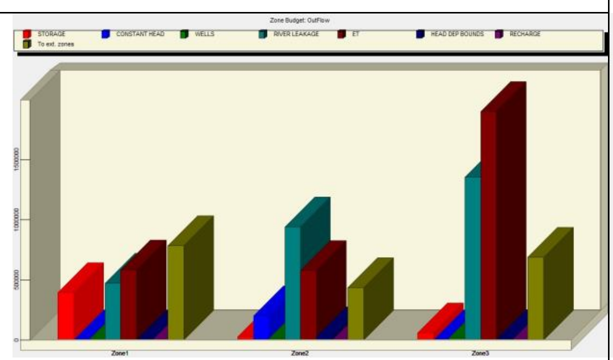
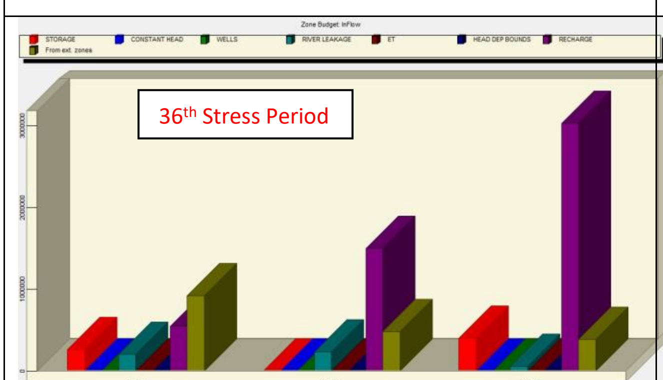
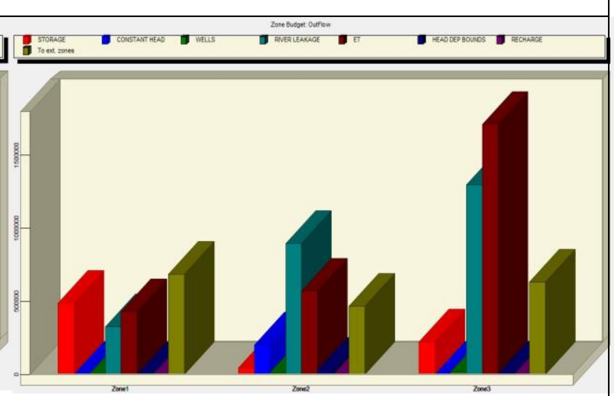
Sl No	Obs Well No	Observed Water Level (m) (Day1856)	Computed Water Level (m) (Day 1856)	Difference (m) (Calc-Obs)
1	HOBS-51	4.29	3.87	-0.42
2	HOBS-8	1.22	1.66	0.44
3	HOBS-4	2.73	3.23	0.50
4	HOBS-10	2.86	3.39	0.53
5	HOBS-32	3	3.68	0.68
6	HOBS-5	2.61	3.37	0.76
7	HOBS-24	41.31	42.20	0.89
8	HOBS-55	3.17	4.11	0.94
9	HOBS-21	11.1	12.04	0.94
10	HOBS-52	3.05	4.04	0.99
11	HOBS-29	2.46	3.47	1.01

12	HOBS-23	0.05	1.50	1.45
13	HOBS-6	1.7	3.33	1.63
14	HOBS-3	0.6	2.30	1.70
15	HOBS-2	1.55	3.64	2.09
16	HOBS-34	1.85	4.05	2.20
17	HOBS-1	1.1	3.55	2.45
18	HOBS-9	0.98	3.49	2.51
19	HOBS-35	20.6	23.93	3.33
20	HOBS-27	14.5	11.13	-3.37
21	HOBS-46	14.27	11.02	-3.25
22	HOBS-28	5.88	3.47	-2.41
23	HOBS-17	39.12	37.74	-1.38
24	HOBS-53	4.34	3.07	-1.27
25	HOBS-15	2.17	0.94	-1.23
26	HOBS-54	4.76	3.67	-1.09

Table-14 Data validation for Transient State

4.1.4 Zone Budget

Like steady state, zone wise water budget has been worked for different stress periods in transient state and shown in Fig.35. Zone -3 is playing a dominant role like steady state. In zone -3 recharge component is the major inflow factor whereas in outflow, river leakage , ET and storage are influencing the budget. This indicate that in zone-3 the ground water is depleting in higher rate along with river discharge and ET due to close proximity to sea and higher K value. The outflow component of zone -1during the last stress periods (48 and 61) indicate a sudden jump in storage which is attributed by very high rainfall occurred during 2018 (SP 48) and 2019 August (SP 61) and minimal weathered residuum with steep gradient.Therefore it is assumed that excess rainfall would not augment the recharge component reciprocally and flown out of the zone as storage. In such condition the efficacy of traditional artificial recharge structures is undermined. The necessity to arrest the ground water flow in this zone (zone-1) during excess rainfall may be developed by artificial water collecting structures such as roof top rainwater structures ,surface storage tanks. It is important to notice that Semi-critical block viz. Elamdesam is is falling in this zone and quantification of inflow-outflow components will help to design/implement various management strategies effectively in converting this block to safe category.

INFLOW	OUTFLOW
	
	
	

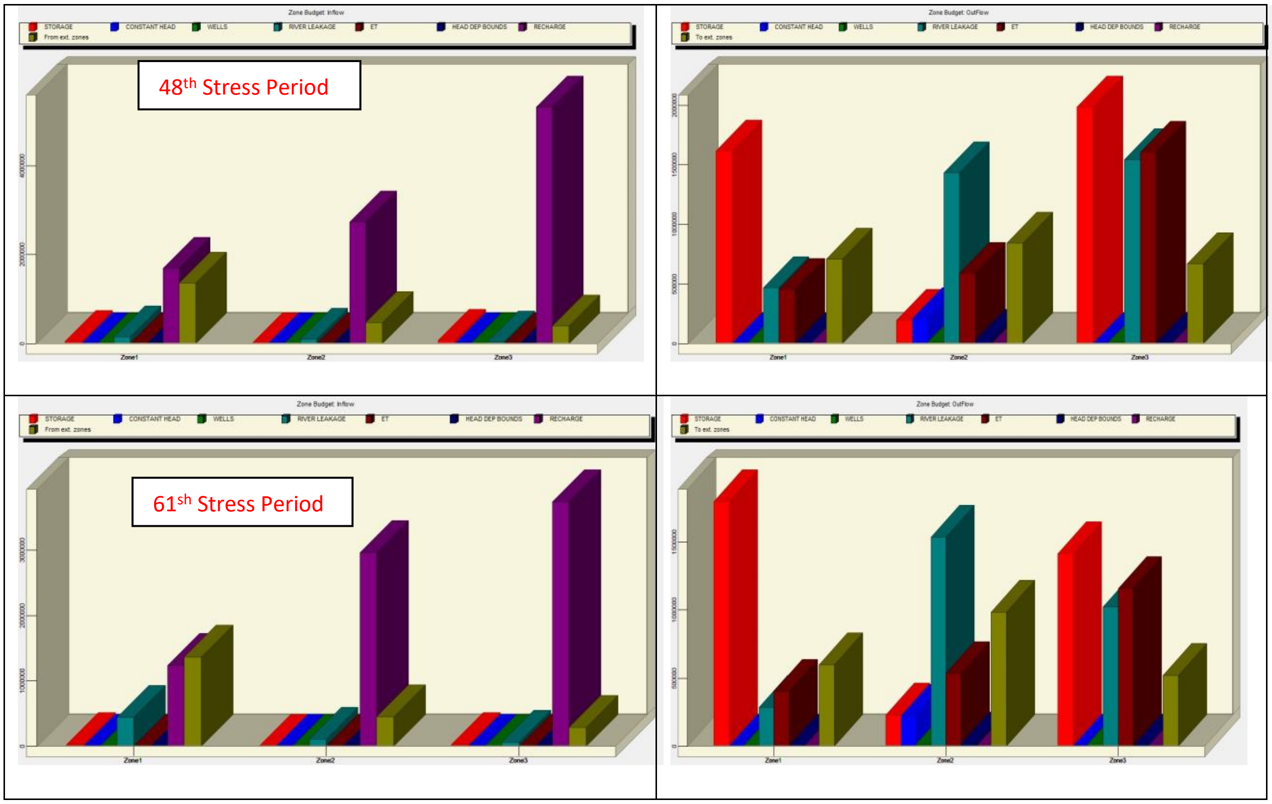


Fig.35 Zone budget for Transient State for various stress periods

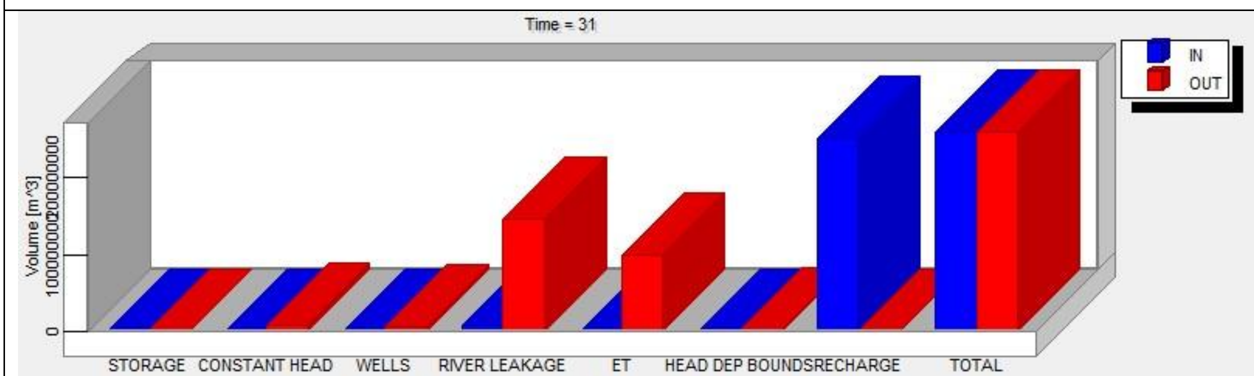
4.1.5 Cumulative budget- Transient state

The cumulative budget has been computed for transient period and presented in Table-15. A perusal of the cumulative budget of the study area indicate that % discrepancy varies from zero % in almost all stress periods to -0.03 %.

The mass balance is one of the key indicators of a successful simulation. If the mass balance error for a simulation is less than 2 %, the results of the simulation may generally be considered acceptable, provided the model is also calibrated (Visual Modflow Manual,2006).An acceptable range of 1% is recommended by Anderson and Woessner (1992).This strengthens the validity of overall model simulation.

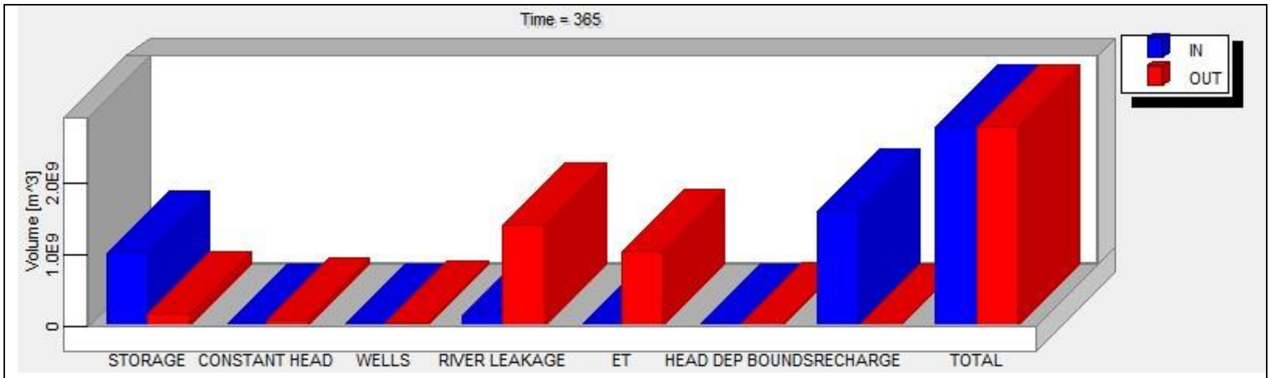
1. Time (days) : 30, Stress period :1 , Time step :10

IN	OUT
Storage = 0 [m^3/day] Constant Head = 155.677 [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 = 8088468 [m^3/day] ET = 0 [m^3/day] River Leakage = 258963.2344 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 1532.9479 [m^3/day] Total IN = 8349120 [m^3/day]	Storage = 0 [m^3/day] Constant Head = 244953.7188 [m^3/day] Wells = 201779.3125 [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 = 3183431.25 [m^3/day] River Leakage = 4680424.5 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 38560.3828 [m^3/day] Total OUT = 8349149.5 [m^3/day]
IN - OUT =-29.5 [m^3/day]	
Discrepancy = 0%	



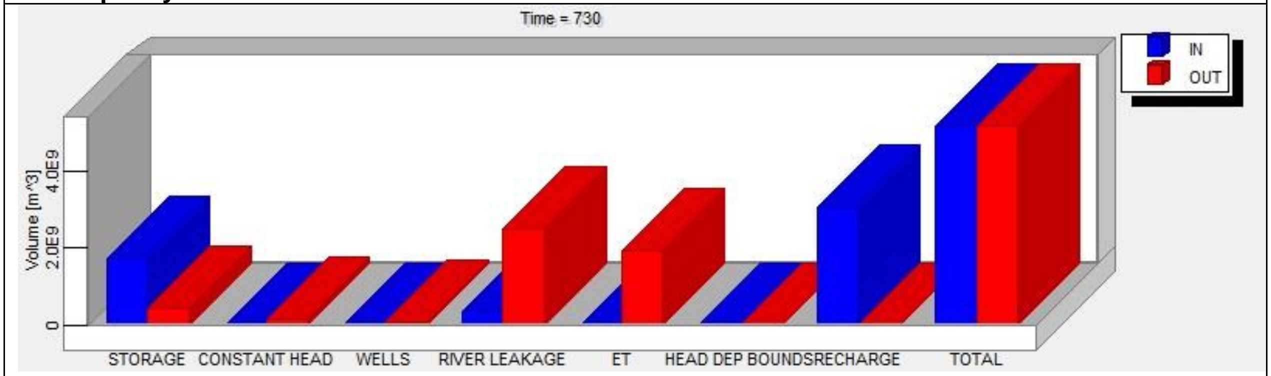
2. Time (days) : 365, Stress period : 12 , Time step :10

IN	OUT
Storage = 1799473.375 [m^3/day] Constant Head = 0 [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 = 4303685.5 [m^3/day] ET = 0 [m^3/day] River Leakage = 475301.0625 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 726.4911 [m^3/day] Total IN = 6579186.5 [m^3/day]	Storage = 480679.7812 [m^3/day] Constant Head = 203710.1562 [m^3/day] Wells = 33841.7578 [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 = 3062357.75 [m^3/day] River Leakage = 2766673.25 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 31879.2891 [m^3/day] Total OUT = 6579142.5 [m^3/day]
IN - OUT = 44 [m^3/day]	
Discrepancy = 0%	



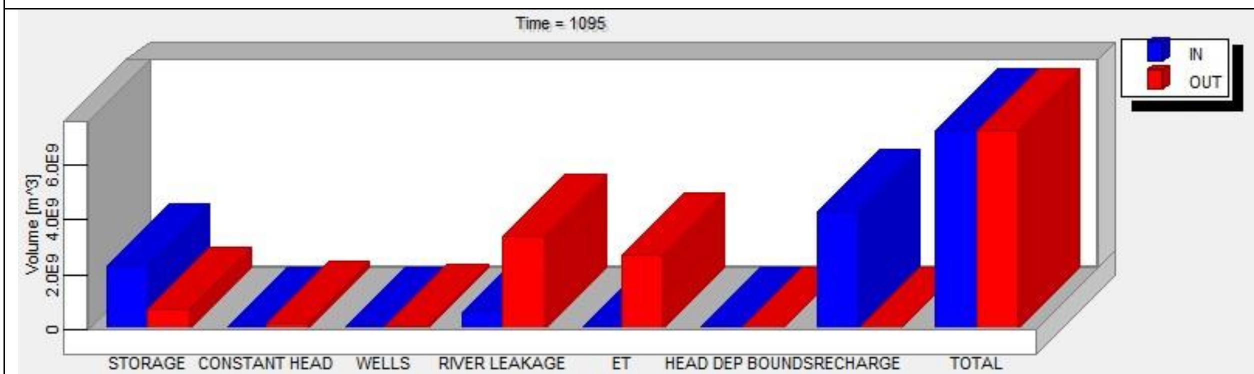
3. Time (days) : 730, Stress period :24 , Time step :10

IN	OUT
Storage = 668428.75 [m^3/day] Constant Head = 0 [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 = 5077898.5 [m^3/day] ET = 0 [m^3/day] River Leakage = 500102.8438 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 760.3937 [m^3/day] Total IN = 6247190.5 [m^3/day]	Storage = 754282.9375 [m^3/day] Constant Head = 201403.7031 [m^3/day] Wells = 33841.7578 [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 = 2710106.75 [m^3/day] River Leakage = 2518028 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 29460.75 [m^3/day] Total OUT = 6247124 [m^3/day]
IN - OUT = 66.5 [m^3/day]	
Discrepancy = 0%	



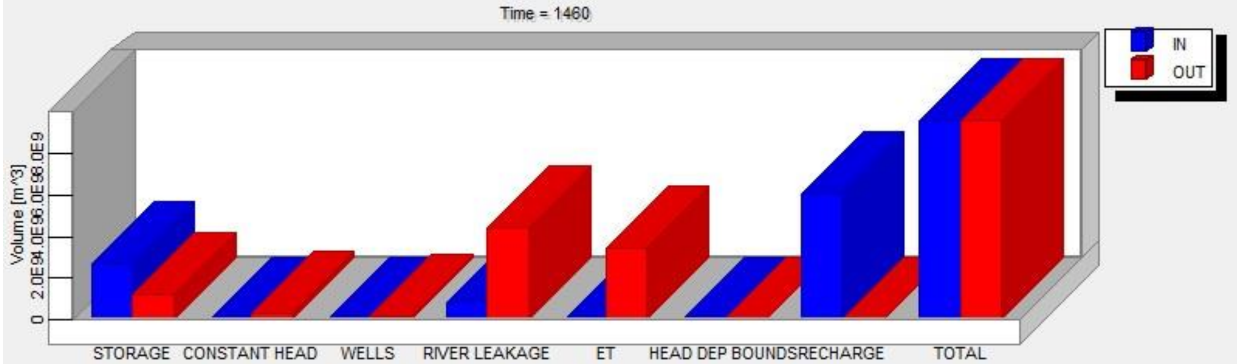
4. Time (days) : 1095, Stress period :36 , Time step :10

IN	OUT
Storage = 735894.5625 [m^3/day] Constant Head = 0 [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 = 4416819 [m^3/day] ET = 0 [m^3/day] River Leakage = 504279.8125 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 776.2697 [m^3/day] Total IN = 5657769.5 [m^3/day]	Storage = 794013.375 [m^3/day] Constant Head = 198226.2656 [m^3/day] Wells = 33841.7578 [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 = 2392589.5 [m^3/day] River Leakage = 2212705.25 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 26360.2227 [m^3/day] Total OUT = 5657736 [m^3/day]
IN - OUT = 33.5[m^3/day]	
Discrepancy = 0%	



5. Time (days) : 1460, Stress period : 48 , Time step :10

IN	OUT
Storage = 125460.4922 [m^3/day] Constant Head = 0 [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 = 9751434 [m^3/day] ET = 0 [m^3/day] River Leakage = 296433.875 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 627.5081 [m^3/day] Total IN = 10173956 [m^3/day]	Storage = 3800140 [m^3/day] Constant Head = 211409.1875 [m^3/day] Wells = 33841.7578 [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 = 2650004.5 [m^3/day] River Leakage = 3447023.75 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 31515.6035 [m^3/day] Total OUT = 10173936 [m^3/day]
IN - OUT = 20 [m^3/day]	
Discrepancy = 0%	



5. Time (days) : 1825, Stress period : 61 , Time step :10

IN	**OUT**
Storage = 58037.7773 [m^3/day] Constant Head = 0 [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 = 7963704 [m^3/day] ET = 0 [m^3/day] River Leakage = 613451.5625 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 2072.3171 [m^3/day] Total IN = 8637266 [m^3/day]	Storage = 3435282.75 [m^3/day] Constant Head = 220166.7344 [m^3/day] Wells = 33771.7656 [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 = 2091952.625 [m^3/day] River Leakage = 2838442.5 [m^3/day] Stream Leakage = 0 [m^3/day] General-Head = 17622.3887 [m^3/day] Total OUT = 8637239 [m^3/day]
IN - OUT = 27 [m^3/day]	
Discrepancy = 0%	

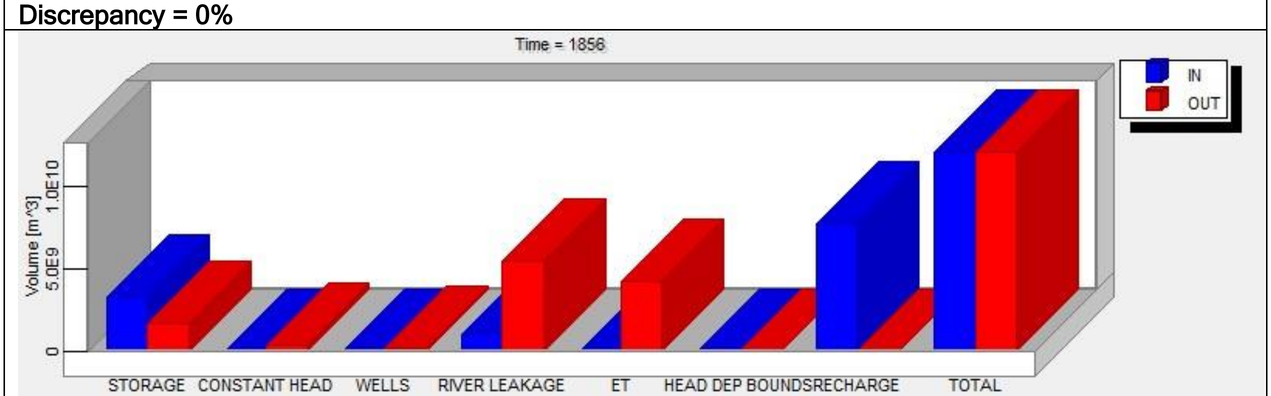


Table 15. Cumulative budget for transient state

4.2 Sensitivity Analysis

Sensitivity analyses is the process to identify the factors which affect the variation in the output components of model. Once the model is satisfactorily calibrated, sensitivity analyses were performed to determine the model's sensitivity to the variations (or uncertainties) in physical parameters. These techniques are typically applied iteratively. Sensitivity analysis were applied for hydraulic conductivity and ET values as these values are seem to be important in the model domain. The changes in hydraulic conductivity and its sensitivity to change in root mean square (RMS) error and normalised RMS (NRMS) error were studied. The input hydraulic conductivity values and are changed by +10%, -10%, +20% and - 20%. It is observed from the analysis that, the NRMS does not vary above 2% for increase or decrease of K value up to 20%. Hence, the model is not sensitive to aquifer parameter i.e., hydraulic conductivity (Table-16).

Stress Period	Change in K value	RMS error (m)	Normalised RMS (%)
12	0	8.19	8.62
	(+)10	8.02	8.44
	(-)10	8.43	8.87
	(+)20	7.91	8.22
	(-)20	8.79	9.25
24	0	7.64	8.26
	(+)10	7.81	8.23
	(-)10	7.92	8.34
	(+)20	7.81	8.22
	(-)20	8.07	8.50
36	0	7.83	8.24
	(+)10	7.88	8.29
	(-)10	7.82	8.22
	(+)20	7.94	8.36
	(-)20	7.82	823
48	0	8.08	8.53
	(+)10	8.06	8.5
	(-)10	8.14	8.59
	(+)20	8.04	8.49
	(-)20	8.23	8.69
61	0	8.23	8.72
	(+)10	8.24	8.74
	(-)10	8.23	8.72
	(+)20	8.27	8.77
	(-)20	8.26	8.78

Table.16 Sensitivity Analyses for change in Hydraulic conductivity values

The input ET values were increased by +10%, -10%,+20%,-20% and +30%. It is observed from the analysis that, the NRMS does not vary from 6 – 8% for increase in ET value of ±10 and ±20 (except SP-1). The same is increased to many folds when the ET values increased to +30%. Hence, from the analyses it is observed that, the model is sensitive to recharge (Table-17).

Stress Period	**Change in K value**	**RMS error (m)**	**Normalised RMS (%)**
12	0	8.19	8.62
	(+)10	8.66	8.48
	(-)10	8.57	9.02
	(+)20	7.94	8.35
	(-)20	9.19	9.67
	(+) 30	13.74	16.03
24	0	7.64	8.26
	(+)10	7.90	8.32
	(-)10	7.93	8.35
	(+)20	7.93	8.35
	(-)20	8.18	8.62
	(+) 30	12.24	14.29
36	0	7.83	8.24
	(+)10	7.98	8.39
	(-)10	7.82	8.22
	(+)20	8.09	8.15
	(-)20	7.66	8.06
	(+) 30	10.53	12.21
48	0	8.08	8.53
	(+)10	8.16	8.62
	(-)10	8.03	8.40
	(+)20	8.17	8.63
	(-)20	8.06	8.51
	(+) 30	11.01	12.79
61	0	8.23	8.72
	(+)10	8.33	8.83
	(-)10	8.07	8.56
	(+)20	8.41	8.91
	(-)20	7.99	8.47
	(+) 30	9.79	11.35

Table.17 Sensitivity Analyses for change in ET

4.3 Inferences from Modeling studies

The present study was carried out to provide better understanding of the aquifer characteristics and ground water condition in Muvattupuzha Basin, Central Kerala, which spread over Ernakulam, Alapuzha , Kottayam and Idukki districts. A multilayer conceptual model has been developed for the study area, which includes the delineation of the nature and number of the aquifer, lateral and vertical extension of the aquifer. This basin is characterised by both hard rock in the major part (69%) and soft rock adjoining coastal side (31%).

In the hard rock area, the top weathered part forms the phreatic aquifer and the bottom one is the fractured aquifer system. In the western part of the basin there is three aquifer system Viz, Alluvium, Warkalai and Vaikom Beds. Quilon beds are considered as Aquitard due to presence of hard limestone. The first top layer (Alluvium) is in phreatic condition and deeper layers are under confined condition where Warkalai and Quilon beds rest on Vaikom Beds. The aquifers have maximum thickness in the west and pinching out towards east. The top unconfined layer is simulated and kept the bottom confined layers as dummy layers due to lack of individual piezometric data.

The study area was discretized to 9816 active cells of 500 m by 500 m dimension having 154 columns and 138 rows. Cells outside the study area were treated as inactive cells. Constant Head boundary condition is applied in the western side of model boundary as it is connected to sea. Other important boundaries in the domain are River, Lake, Recharge, Evapotranspiration and General Head .

The hydrodynamics of the study area has been simulated by Visual Modflow software ,Version-2 (2014-Classic Interface) for a single layer aquifer system. The model simulation period is five years (2014-2019).

Most of the modal parameters were derived from field data and during calibration the best matched data is kept based on trial and error method to suit the near field condition to simulate single layer aquifer system for steady and transient state conditions.

The model was subjected to steady state run for the first stress period of (August-2014). Steady state calibration was carried out using 47 observation wells monitored during August 2014.The scatter plot of steady state indicate RMS value of 9.76 m and normalised RMS of 10.27 %.The scatter plot analysis indicate that the model is slightly over predicting the calculated head. About 80% of wells have overpredicted head distribution compared to observed head. Recharge component has major contribution in Inflow whereas River discharge and Evapotranspiration (ET) indicate substantial role in maintaining the mass balance compared to wells (draft) and river flow in outflow budget.

Total recharge, total river discharge and total evapotranspiration were estimated to be 2782.69 MCM,1599.15 MCM and 1046.45 MCM and respectively. The model domain has been classified into three zones based on geological uniformity and water holding structures. Each zone plays its role in total budget and recharge component is seen as dominant factor in inflow. For outflow component, well draft and river are controlling Zone-1 whereas ET is playing dominant role in Zone-III.

The results of steady state calibration were used for running transient state for 61 stress periods (1856 days) and calibration was carried out by fine tuning the hydraulic properties. The water table contours thus obtained are comparable to the observed water table contours. The normalised RMS ranges from 10.03 % at 1st stress period to 8.25 % at 36th stress period and finally 8.72 % at 61st stress period (1856 days).The hydrographs show that in many observation wells the computed water table elevation match properly with the observed water table elevation.

Zone -3 is playing a dominant role in zone budget calculations. Sensitivity analyses were carried out to determine the influence of hydraulic parameters/boundaries.

5.0 SUMMARY AND CONCLUSIONS

Hydrodynamics of ground water system in Muvattupuzha basin, was simulated by finite difference numerical modeling method (FDM) using Visual Modflow 2014.2 software. A multilayer layer ground water flow model was conceptualised for the study area with a cell dimension of 500*500m. The top weathered part forms the phreatic aquifer and the bottom one is the fractured aquifer system. In the phreatic aquifer presence of sedimentary aquifer system is integrated with weathered residuum of hard rock.

Initially steady state condition was attempted for a period of one month during August 2014 and calibrated . It is then extended to five years ending August 2019 involving 61 stress periods at the rate of 30 days for transient state.

Different hydraulic parameters affect the water table configuration in different stages while calibrating the model. In steady state, the controlling factors are evapotranspiration and river discharge. In transient condition the specific storage and conductivity values are governing factors determine different flowage in the top layer which finally result in variation in head.

The calculated and observed contours are apparently close to each other in majority of the areas and the discrepancy of 0 % which is within the accepted range of 1% and hence strengthens the validity of overall model simulation.

The error statistics indicate gradual reduction of error at various stress periods during entire transient state run and an average Normalised RMS of 8%indicate better fit/accuracy of the model calibrated.

Ground water budget (zone wise) for the aquifer system also has been computed and provided an estimate of groundwater flow conditions and the interplay of different discharge and recharge components. The zone budget analysis for transient condition indicate that with increase of time there would be reduction in the storage in the inflow and outflow components .

Zone -3 is playing a dominant role. In zone -3 recharge component is the major inflow factor whereas, storage, ET and river leakage are influencing the budget in outflow. Ground water is depleting in higher rate along with river discharge and close proximity to sea and higher K value.

Semi-critical block viz.Elamdesam is falling in zone-1 and necessitate the application of modeling as management tool to design/implement various sustainable strategies in converting this block to safe category by evaluating the interplay of inflow - outflow components and its quantification. It is found that in this zone storage plays an important role and excess rainfall would not augment the recharge component reciprocally and flow out of the zone due to minimal weathered thickness coupled with steep gradient. This factor may be kept in mind while designing the artificial recharge structures for the block.

Water level data were used for validating the model by comparing observed and calculated water level and 26 wells shown residuals within 3.37 m.

Sensitivity analysis were carried out and observed that model is sensitive to ET value (+30%).

5.1 Limitations

The individual piezometric head of confined aquifers (Warkalai/Vaikom) are not available and this lead to the simulation of top layer only and kept the bottom layers as dummy layer. Simulation of confined aquifers is very essential to quantify the IN-OUT component of sedimentary aquifers which has greater impact considering the fast paced industrialization and urbanization in the south Kochi which extending to Cherthala.

From exploratory drilling data, it was observed that hydrochemistry of Warkalai and Vaikom aquifers are brackish in many areas and the delineation of fresh water lens in each aquifer is important to quantify the resources for better management strategy. This model has its limitations on recharge /draft rate of confined aquifers and isotope studies and aquifer performance test can be carried out to supplement the data gap in the model domain.

This model has limitations on canal irrigation data which receives water through inter basin transfer via Moolamattam Hydro-electric station. The river boundary data of Muvattupuzha river is prepared based on limited intersections. In this background, this modeling study can be used as a base for further studies involving saline intrusion using additional field data which may be generated through exploratory drilling, water quality analysis and geophysical investigations. This will help to formulate the management plan more effectively.

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ANNEXURE-1A

Zone wise distribution of recharge rates (m/d) for transient state

tart	End	Kothamangalam	Thodupuzha	Idukki	Elamdesam	Muvattupuzha	Uzhavoor	Kaduthuruthy	Koovapadi	Vazhakulam	Vadavukode	Pambakuda	Ettumanoor	Vaikom	Kanjikuzhi	Aryad	Thykattussery	Pattanakkad	Edappally	Palluruthy	Mulanthuruthy
0	31	0.0045	0.0010	0.0042	0.0010	0.00424	0.00515	0.00112	0.00554	0.00590	0.00522	0.00444	0.00288	0.00344	0.00325	0.00306	0.00273	0.00268	0.00255	0.00276	0.00351
31	59	0.0026	0.0030	0.0022	0.0029	0.00160	0.00176	0.00218	0.00214	0.00249	0.00183	0.00215	0.00148	0.00202	0.00183	0.00165	0.00122	0.00117	0.00105	0.00125	0.00198
59	90	0.0049	0.0054	0.0046	0.0053	0.00233	0.00235	0.00279	0.00274	0.00311	0.00243	0.00275	0.00159	0.00214	0.00195	0.00176	0.00131	0.00126	0.00114	0.00134	0.00209
90	120	0.0012	0.0016	0.0008	0.0015	0.00122	0.00124	0.00166	0.00162	0.00197	0.00131	0.00163	0.00064	0.00117	0.00099	0.00080	0.00090	0.00085	0.00073	0.00092	0.00165
120	151	0.0009	0.0013	0.0006	0.0013	0.00115	0.00117	0.00161	0.00156	0.00193	0.00125	0.00157	0.00069	0.00125	0.00106	0.00086	0.00056	0.00051	0.00039	0.00059	0.00134
151	181	0.0008	0.0012	0.0004	0.0011	0.00070	0.00072	0.00116	0.00111	0.00147	0.00080	0.00112	0.00048	0.00104	0.00085	0.00065	0.00050	0.00045	0.00033	0.00053	0.00128
181	212	0.0008	0.0012	0.0005	0.0011	0.00063	0.00065	0.00104	0.00100	0.00133	0.00072	0.00101	0.00051	0.00101	0.00084	0.00066	0.00045	0.00041	0.00029	0.00048	0.00116
212	243	0.0010	0.0015	0.0007	0.0014	0.00092	0.00094	0.00138	0.00133	0.00170	0.00102	0.00134	0.00072	0.00127	0.00108	0.00089	0.00050	0.00045	0.00033	0.00053	0.00128
243	273	0.0020	0.0025	0.0017	0.0024	0.00216	0.00218	0.00260	0.00256	0.00291	0.00225	0.00256	0.00090	0.00143	0.00125	0.00106	0.00093	0.00088	0.00076	0.00095	0.00168
273	304	0.0020	0.0024	0.0016	0.0024	0.00174	0.00176	0.00220	0.00216	0.00252	0.00184	0.00217	0.00114	0.00170	0.00150	0.00131	0.00088	0.00083	0.00071	0.00091	0.00166
304	334	0.0046	0.0010	0.0043	0.0010	0.00234	0.00295	0.00067	0.00332	0.00368	0.00302	0.00267	0.00236	0.00290	0.00271	0.00253	0.00276	0.00271	0.00259	0.00278	0.00351
334	365	0.0023	0.0006	0.0020	0.0005	0.00181	0.00229	0.00054	0.00268	0.00304	0.00236	0.00215	0.00185	0.00240	0.00221	0.00202	0.00166	0.00162	0.00149	0.00169	0.00245
365	396	0.0014	0.0004	0.0010	0.0004	0.00124	0.00157	0.00040	0.00196	0.00232	0.00165	0.00158	0.00112	0.00167	0.00148	0.00129	0.00094	0.00089	0.00076	0.00096	0.00172
396	424	0.0011	0.0015	0.0007	0.0015	0.00257	0.00259	0.00301	0.00297	0.00332	0.00267	0.00298	0.00165	0.00219	0.00200	0.00182	0.00144	0.00139	0.00127	0.00146	0.00219
424	455	0.0014	0.0019	0.0011	0.0018	0.00270	0.00272	0.00316	0.00311	0.00348	0.00280	0.00312	0.00169	0.00225	0.00206	0.00186	0.00154	0.00149	0.00136	0.00156	0.00232
455	485	0.0013	0.0017	0.0009	0.0016	0.00185	0.00187	0.00229	0.00225	0.00260	0.00195	0.00226	0.00098	0.00152	0.00133	0.00114	0.00176	0.00171	0.00159	0.00179	0.00252
485	516	0.0010	0.0014	0.0006	0.0013	0.00171	0.00173	0.00217	0.00213	0.00249	0.00181	0.00213	0.00079	0.00134	0.00115	0.00096	0.00067	0.00062	0.00050	0.00070	0.00145
516	546	0.0010	0.0014	0.0006	0.0014	0.00070	0.00072	0.00116	0.00111	0.00147	0.00080	0.00112	0.00057	0.00113	0.00094	0.00074	0.00054	0.00049	0.00037	0.00057	0.00132
546	577	0.0008	0.0012	0.0004	0.0011	0.00087	0.00089	0.00129	0.00124	0.00157	0.00096	0.00125	0.00072	0.00122	0.00105	0.00088	0.00051	0.00047	0.00035	0.00054	0.00122
577	608	0.0010	0.0015	0.0007	0.0014	0.00074	0.00076	0.00119	0.00115	0.00151	0.00083	0.00116	0.00050	0.00106	0.00086	0.00067	0.00065	0.00060	0.00048	0.00068	0.00143
608	638	0.0009	0.0014	0.0006	0.0013	0.00072	0.00074	0.00116	0.00111	0.00147	0.00081	0.00112	0.00053	0.00107	0.00088	0.00069	0.00054	0.00049	0.00037	0.00056	0.00129
638	669	0.0016	0.0020	0.0012	0.0019	0.00241	0.00243	0.00286	0.00282	0.00318	0.00250	0.00283	0.00147	0.00203	0.00184	0.00164	0.00167	0.00162	0.00150	0.00170	0.00245
669	699	0.0033	0.0008	0.0030	0.0007	0.00339	0.00426	0.00094	0.00464	0.00499	0.00433	0.00372	0.00254	0.00308	0.00289	0.00271	0.00226	0.00221	0.00209	0.00228	0.00301
699	730	0.0018	0.0005	0.0015	0.0004	0.00271	0.00341	0.00077	0.00380	0.00417	0.00349	0.00305	0.00170	0.00225	0.00206	0.00187	0.00194	0.00189	0.00176	0.00196	0.00272
730	761	0.0017	0.0004	0.0013	0.0004	0.00167	0.00210	0.00051	0.00250	0.00286	0.00218	0.00200	0.00104	0.00159	0.00140	0.00121	0.00136	0.00131	0.00118	0.00138	0.00214
761	789	0.0014	0.0018	0.0010	0.0017	0.00124	0.00126	0.00168	0.00163	0.00199	0.00133	0.00164	0.00069	0.00123	0.00104	0.00086	0.00067	0.00062	0.00050	0.00069	0.00142
789	820	0.0011	0.0016	0.0008	0.0015	0.00144	0.00146	0.00190	0.00185	0.00222	0.00154	0.00186	0.00087	0.00143	0.00124	0.00104	0.00101	0.00097	0.00084	0.00104	0.00180

820	850	0.0010	0.0014	0.0006	0.0013	0.00113	0.00115	0.00157	0.00153	0.00188	0.00122	0.00154	0.00090	0.00144	0.00125	0.00107	0.00103	0.00098	0.00086	0.00106	0.00179
850	881	0.0008	0.0012	0.0004	0.0012	0.00076	0.00078	0.00122	0.00117	0.00154	0.00086	0.00118	0.00047	0.00102	0.00083	0.00064	0.00052	0.00047	0.00034	0.00054	0.00130
881	911	0.0008	0.0012	0.0004	0.0012	0.00094	0.00096	0.00139	0.00135	0.00171	0.00103	0.00136	0.00049	0.00104	0.00085	0.00066	0.00057	0.00052	0.00039	0.00060	0.00135
911	942	0.0007	0.0011	0.0004	0.0010	0.00063	0.00065	0.00104	0.00100	0.00133	0.00072	0.00101	0.00042	0.00092	0.00075	0.00058	0.00045	0.00041	0.00029	0.00048	0.00116
942	973	0.0021	0.0025	0.0017	0.0025	0.00119	0.00121	0.00165	0.00161	0.00197	0.00129	0.00161	0.00061	0.00117	0.00098	0.00078	0.00058	0.00053	0.00040	0.00060	0.00136
973	1003	0.0011	0.0015	0.0007	0.0014	0.00070	0.00072	0.00114	0.00110	0.00145	0.00079	0.00111	0.00053	0.00107	0.00089	0.00070	0.00069	0.00065	0.00052	0.00072	0.00145
1003	1034	0.0018	0.0023	0.0015	0.0022	0.00170	0.00172	0.00215	0.00211	0.00247	0.00179	0.00212	0.00134	0.00190	0.00171	0.00151	0.00151	0.00146	0.00134	0.00154	0.00229
1034	1064	0.0029	0.0007	0.0026	0.0007	0.00333	0.00418	0.00092	0.00456	0.00491	0.00426	0.00366	0.00236	0.00290	0.00271	0.00253	0.00243	0.00238	0.00226	0.00245	0.00318
1064	1095	0.0022	0.0005	0.0019	0.0005	0.00178	0.00225	0.00054	0.00264	0.00300	0.00232	0.00212	0.00160	0.00216	0.00197	0.00178	0.00218	0.00213	0.00201	0.00221	0.00296
1095	1126	0.0034	0.0008	0.0030	0.0008	0.00225	0.00283	0.00065	0.00322	0.00359	0.00291	0.00258	0.00129	0.00185	0.00166	0.00147	0.00193	0.00188	0.00176	0.00196	0.00271
1126	1154	0.0031	0.0035	0.0028	0.0035	0.00267	0.00269	0.00311	0.00307	0.00342	0.00277	0.00308	0.00139	0.00192	0.00174	0.00155	0.00203	0.00198	0.00186	0.00205	0.00278
1154	1185	0.0019	0.0024	0.0016	0.0023	0.00166	0.00168	0.00212	0.00207	0.00243	0.00176	0.00208	0.00132	0.00188	0.00169	0.00150	0.00152	0.00147	0.00134	0.00155	0.00230
1185	1215	0.0015	0.0019	0.0011	0.0018	0.00239	0.00241	0.00283	0.00278	0.00314	0.00248	0.00279	0.00096	0.00150	0.00131	0.00113	0.00097	0.00092	0.00080	0.00100	0.00173
1215	1246	0.0012	0.0016	0.0008	0.0015	0.00080	0.00082	0.00126	0.00122	0.00158	0.00090	0.00122	0.00051	0.00107	0.00088	0.00069	0.00058	0.00053	0.00040	0.00060	0.00136
1246	1276	0.0008	0.0012	0.0004	0.0011	0.00070	0.00072	0.00116	0.00111	0.00147	0.00080	0.00112	0.00047	0.00102	0.00083	0.00064	0.00050	0.00045	0.00033	0.00053	0.00128
1276	1307	0.0008	0.0012	0.0005	0.0012	0.00065	0.00067	0.00107	0.00103	0.00135	0.00074	0.00103	0.00042	0.00092	0.00075	0.00058	0.00050	0.00046	0.00034	0.00053	0.00121
1307	1338	0.0009	0.0014	0.0006	0.0013	0.00106	0.00108	0.00152	0.00147	0.00184	0.00116	0.00148	0.00055	0.00111	0.00092	0.00072	0.00050	0.00045	0.00033	0.00053	0.00128
1338	1368	0.0013	0.0017	0.0010	0.0017	0.00158	0.00160	0.00202	0.00198	0.00233	0.00168	0.00199	0.00097	0.00151	0.00133	0.00114	0.00094	0.00089	0.00077	0.00097	0.00170
1368	1399	0.0027	0.0032	0.0024	0.0031	0.00212	0.00214	0.00257	0.00253	0.00289	0.00221	0.00254	0.00166	0.00222	0.00203	0.00184	0.00142	0.00137	0.00124	0.00144	0.00220
1399	1429	0.0031	0.0007	0.0028	0.0007	0.00378	0.00475	0.00103	0.00513	0.00548	0.00482	0.00411	0.00296	0.00349	0.00331	0.00312	0.00288	0.00283	0.00271	0.00291	0.00364
1429	1460	0.0058	0.0012	0.0054	0.0012	0.00483	0.00605	0.00130	0.00644	0.00681	0.00613	0.00516	0.00303	0.00358	0.00339	0.00320	0.00384	0.00380	0.00367	0.00387	0.00462
1460	1491	0.0053	0.0011	0.0049	0.0011	0.00274	0.00344	0.00170	0.00383	0.00420	0.00352	0.00307	0.00213	0.00269	0.00250	0.00230	0.00230	0.00225	0.00212	0.00232	0.00308
1491	1519	0.0014	0.0018	0.0010	0.0017	0.00103	0.00105	0.00147	0.00143	0.00178	0.00112	0.00144	0.00060	0.00113	0.00095	0.00076	0.00061	0.00057	0.00045	0.00064	0.00137
1519	1550	0.0026	0.0031	0.0023	0.0030	0.00266	0.00268	0.00312	0.00307	0.00344	0.00276	0.00308	0.00158	0.00213	0.00194	0.00175	0.00183	0.00178	0.00165	0.00186	0.00261
1550	1580	0.0024	0.0029	0.0021	0.0028	0.00195	0.00197	0.00239	0.00235	0.00270	0.00205	0.00236	0.00112	0.00166	0.00148	0.00129	0.00141	0.00136	0.00124	0.00144	0.00217
1580	1611	0.0008	0.0012	0.0004	0.0012	0.00091	0.00093	0.00136	0.00132	0.00168	0.00100	0.00133	0.00088	0.00143	0.00124	0.00105	0.00083	0.00078	0.00066	0.00086	0.00161
1611	1641	0.0008	0.0012	0.0004	0.0011	0.00070	0.00072	0.00116	0.00111	0.00147	0.00080	0.00112	0.00047	0.00102	0.00083	0.00064	0.00050	0.00045	0.00033	0.00053	0.00128
1641	1672	0.0010	0.0014	0.0007	0.0014	0.00063	0.00065	0.00104	0.00100	0.00133	0.00072	0.00101	0.00042	0.00092	0.00075	0.00058	0.00045	0.00041	0.00029	0.00048	0.00116
1672	1703	0.0008	0.0012	0.0004	0.0012	0.00071	0.00073	0.00117	0.00113	0.00149	0.00081	0.00113	0.00048	0.00104	0.00085	0.00066	0.00060	0.00055	0.00042	0.00062	0.00138
1703	1733	0.0014	0.0018	0.0010	0.0017	0.00122	0.00124	0.00167	0.00162	0.00198	0.00132	0.00163	0.00057	0.00111	0.00092	0.00073	0.00081	0.00076	0.00064	0.00083	0.00156
1733	1764	0.0011	0.0015	0.0007	0.0015	0.00077	0.00079	0.00123	0.00118	0.00155	0.00087	0.00119	0.00057	0.00113	0.00094	0.00074	0.00104	0.00100	0.00087	0.00107	0.00182
1764	1794	0.0020	0.0005	0.0016	0.0005	0.00165	0.00208	0.00050	0.00246	0.00282	0.00216	0.00198	0.00206	0.00260	0.00241	0.00223	0.00183	0.00179	0.00166	0.00186	0.00259
1794	1825	0.0032	0.0007	0.0029	0.0007	0.00209	0.00263	0.00061	0.00302	0.00339	0.00271	0.00243	0.00208	0.00263	0.00244	0.00225	0.00265	0.00260	0.00248	0.00268	0.00343
1825	1856	0.0042	0.0037	0.0039	0.0009	0.00258	0.00325	0.00074	0.00364	0.00401	0.00333	0.00292	0.00372	0.00428	0.00409	0.00390	0.00421	0.00417	0.00404	0.00424	0.00499

ANNEXURE-1B

Ground water pumping schedule (m^3/day) for transient state

tart	End	Kotha ma ngala m	Thodu puzha	Idukki	Elamd esam	Muvatt up uzha	Uzhavoor	Kaduthu ruthy	Koovapa di	Vazhakul am	Vadavu kode	Pamba kuda	Ettuma noor	Vaikom	Kanjikuzh i	Aryad	Thykatt ussery	Pattana kkad	Edappally	Palluruth y	Mulanthu ruthy
0	**31**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.64	-57.15	-192.42	-62.21	-55.33	`	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-42.65	-85.20
31	**59**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.64	-57.15	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
59	**90**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
90	**120**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
120	**151**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
151	**181**	-360.12	-354.76	-431.54	-309.10	-359.88	-452.51	-375.42	-342.68	-1153.21	-373.27	-331.57	-479.20	-257.60	-564.65	-1306.89	-472.88	-636.80	-1512	-755.22	-511.23
181	**212**	-360.12	-354.76	-431.54	-309.10	-359.88	-452.51	-375.42	-342.68	-1153.21	-373.27	-331.57	-479.20	-257.60	-564.65	-1306.89	-472.88	-636.80	-1512	-755.22	-511.23
212	**243**	-319.39	-314.54	-382.24	-274.26	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
243	**273**	-319.39	-314.54	-382.24	-274.26	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
273	**304**	-319.39	-314.54	-382.24	-274.18	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
304	**334**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
334	**365**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
365	**396**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.64	-57.15	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-42.65	-85.20
396	**424**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.64	-57.15	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
424	**455**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
455	**485**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
485	**516**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
516	**546**	-360.12	-354.76	-431.54	-309.10	-359.88	-452.51	-375.42	-342.68	-1153.21	-373.27	-331.57	-479.20	-257.60	-564.65	-1306.89	-472.88	-636.80	-1512	-755.22	-511.23
546	**577**	-360.12	-354.76	-431.54	-309.10	-359.88	-452.51	-375.42	-342.68	-1153.21	-373.27	-331.57	-479.20	-257.60	-564.65	-1306.89	-472.88	-636.80	-1512	-755.22	-511.23
577	**608**	-319.39	-314.54	-382.24	-274.26	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
608	**638**	-319.39	-314.54	-382.24	-274.26	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
638	**669**	-319.39	-314.54	-382.24	-274.18	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
669	**699**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20

699	**730**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
730	**761**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.64	-57.15	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-42.65	-85.20
761	**789**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.64	-57.15	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
789	**820**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
820	**850**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
850	**881**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
881	**911**	-360.12	-354.76	-431.54	-309.10	-359.88	-452.51	-375.42	-342.68	-1153.21	-373.27	-331.57	-479.20	-257.60	-564.65	-1306.89	-472.88	-636.80	-1512	-755.22	-511.23
911	**942**	-360.12	-354.76	-431.54	-309.10	-359.88	-452.51	-375.42	-342.68	-1153.21	-373.27	-331.57	-479.20	-257.60	-564.65	-1306.89	-472.88	-636.80	-1512	-755.22	-511.23
942	**973**	-319.39	-314.54	-382.24	-274.26	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
973	**1003**	-319.39	-314.54	-382.24	-274.26	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
1003	**1034**	-319.39	-314.54	-382.24	-274.18	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
1034	**1064**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
1064	**1095**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
1095	**1126**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.64	-57.15	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-42.65	-85.20
1126	**1154**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.64	-57.15	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
1154	**1185**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
1185	**1215**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
1215	**1246**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
1246	**1276**	-360.12	-354.76	-431.54	-309.10	-359.88	-452.51	-375.42	-342.68	-1153.21	-373.27	-331.57	-479.20	-257.60	-564.65	-1306.89	-472.88	-636.80	-1512	-755.22	-511.23
1276	**1307**	-360.12	-354.76	-431.54	-309.10	-359.88	-452.51	-375.42	-342.68	-1153.21	-373.27	-331.57	-479.20	-257.60	-564.65	-1306.89	-472.88	-636.80	-1512	-755.22	-511.23
1307	**1338**	-319.39	-314.54	-382.24	-274.26	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
1338	**1368**	-319.39	-314.54	-382.24	-274.26	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
1368	**1399**	-319.39	-314.54	-382.24	-274.18	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
1399	**1429**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
1429	**1460**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
1460	**1491**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.64	-57.15	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-42.65	-85.20
1491	**1519**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.64	-57.15	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
1519	**1550**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
1550	**1580**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
1580	**1611**	-160.77	-158.40	-191.99	-138.03	-160.77	-202.20	-167.68	-153.07	-514.99	-166.74	-148.15	-214.10	-115.03	-252.27	-583.72	-211.12	-284.35	-675.2	-337.36	-228.38
1611	**1641**	-360.12	-354.76	-431.54	-309.10	-359.88	-452.51	-375.42	-342.68	-1153.21	-373.27	-331.57	-479.20	-257.60	-564.65	-1306.89	-472.88	-636.80	-1512	-755.22	-511.23

1641	**1672**	-360.12	-354.76	-431.54	-309.10	-359.88	-452.51	-375.42	-342.68	-1153.21	-373.27	-331.57	-479.20	-257.60	-564.65	-1306.89	-472.88	-636.80	-1512	-755.22	-511.23
1672	**1703**	-319.39	-314.54	-382.24	-274.26	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
1703	**1733**	-319.39	-314.54	-382.24	-274.26	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
1733	**1764**	-319.39	-314.54	-382.24	-274.18	-319.15	-401.40	-333.02	-303.91	-1022.63	-330.95	-294.09	-424.83	-228.35	-500.67	-1158.62	-419.30	-564.72	-1341	-668.96	-453.25
1764	**1794**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
1794	**1825**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-55.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20
1825	**1856**	-60.14	-59.09	-71.78	-51.48	-59.90	-75.54	-62.43	-16.76	-192.42	-62.21	-53.33	-79.87	-43.02	-94.15	-217.73	-78.90	-106.13	-251.9	-125.55	-85.20

ANNEXURE 1C

River stage data for Transient State

Malankara top							KaliyarLower-1						
Start	End	River stage	River Bottom	Riverbed thickness	Riverbed K	River width	Start	End	River stage	River Bottom	Riverbed thickness	Riverbed K	River width
0	31	140	105	2	28	40	0	31	100	70	2	25	30
31	59	140	105	2	28	40	31	59	120	70	2	25	30
59	90	140	105	2	28	40	59	90	120	70	2	25	30
90	120	135	105	2	28	40	90	120	110	70	2	25	30
120	151	130	105	2	28	40	120	151	110	70	2	25	30
151	181	125	105	2	28	40	151	181	100	70	2	25	30
181	212	120	105	2	28	40	181	212	100	70	2	25	30
212	243	110	105	2	28	40	212	243	90	70	2	25	30
243	273	110	105	2	28	40	243	273	90	70	2	25	30
273	304	115	105	2	28	40	273	304	80	70	2	25	30
304	334	120	105	2	28	40	304	334	90	70	2	25	30
334	365	120	105	2	28	40	334	365	100	70	2	25	30
365	396	140	105	2	28	40	365	396	120	70	2	25	30
396	424	140	105	2	28	40	396	424	120	70	2	25	30
424	455	140	105	2	28	40	424	455	120	70	2	25	30
455	485	135	105	2	28	40	455	485	110	70	2	25	30
485	516	130	105	2	28	40	485	516	110	70	2	25	30
516	546	125	105	2	28	40	516	546	100	70	2	25	30
546	577	120	105	2	28	40	546	577	100	70	2	25	30
577	608	110	105	2	28	40	577	608	90	70	2	25	30
608	638	110	105	2	28	40	608	638	90	70	2	25	30
638	669	115	105	2	28	40	638	669	80	70	2	25	30
669	699	120	105	2	28	40	669	699	90	70	2	25	30

699	730	120	105	2	28	40	699	730	100	70	2	25	30
730	761	140	105	2	28	40	730	761	120	70	2	25	30
761	789	140	105	2	28	40	761	789	120	70	2	25	30
789	820	140	105	2	28	40	789	820	120	70	2	25	30
820	850	135	105	2	28	40	820	850	110	70	2	25	30
850	881	130	105	2	28	40	850	881	110	70	2	25	30
881	911	125	105	2	28	40	881	911	100	70	2	25	30
911	942	120	105	2	28	40	911	942	100	70	2	25	30
942	973	110	105	2	28	40	942	973	90	70	2	25	30
973	1003	110	105	2	28	40	973	1003	90	70	2	25	30
1003	1034	115	105	2	28	40	1003	1034	80	70	2	25	30
1034	1064	120	105	2	28	40	1034	1064	90	70	2	25	30
1064	1095	120	105	2	28	40	1064	1095	100	70	2	25	30
1095	1126	140	105	2	28	40	1095	1126	120	70	2	25	30
1126	1154	140	105	2	28	40	1126	1154	120	70	2	25	30
1154	1185	140	105	2	28	40	1154	1185	120	70	2	25	30
1185	1215	135	105	2	28	40	1185	1215	110	70	2	25	30
1215	1246	130	105	2	28	40	1215	1246	110	70	2	25	30
1246	1276	125	105	2	28	40	1246	1276	100	70	2	25	30
1276	1307	120	105	2	28	40	1276	1307	100	70	2	25	30
1307	1338	110	105	2	28	40	1307	1338	90	70	2	25	30
1338	1368	110	105	2	28	40	1338	1368	90	70	2	25	30
1368	1399	115	105	2	28	40	1368	1399	80	70	2	25	30
1399	1429	120	105	2	28	40	1399	1429	90	70	2	25	30
1429	1460	120	105	2	28	40	1429	1460	100	70	2	25	30
1460	1491	140	105	2	28	40	1460	1491	120	70	2	25	30
1491	1519	140	105	2	28	40	1491	1519	120	70	2	25	30
1519	1550	140	105	2	28	40	1519	1550	120	70	2	25	30
1550	1580	135	105	2	28	40	1550	1580	110	70	2	25	30
1580	1611	130	105	2	28	40	1580	1611	110	70	2	25	30
1611	1641	125	105	2	28	40	1611	1641	100	70	2	25	30

1641	1672	120	105	2	28	40	1641	1672	100	70	2	25	30
1672	1703	110	105	2	28	40	1672	1703	90	70	2	25	30
1703	1733	110	105	2	28	40	1703	1733	90	70	2	25	30
1733	1764	115	105	2	28	40	1733	1764	80	70	2	25	30
1764	1794	120	105	2	28	40	1764	1794	90	70	2	25	30
1794	1825	120	105	2	28	40	1794	1825	100	70	2	25	30
1825	1856	140	105	4	28	40	1825	1856	120	70	4	25	30

Kaliyar Lower-2							Kaliyar Lower-3					Kaliyar Lower-4				
Start	End	River stage	River Bottom	Riverbed thickness	River bed K	River width	River stage	River Bottom	River bed thickness	River bed K	River width	River stage	River Bottom	Riverbed thickness	River bed K	River width
0	31	100	70	2	25	30	90	65	2	25	30	44	23	2	25	30
31	59	99	70	2	25	30	88	65	2	25	30	42	23	2	25	30
59	90	98	70	2	25	30	88	65	2	25	30	42	23	2	25	30
90	120	98	70	2	25	30	90	65	2	25	30	42	23	2	25	30
120	151	94	70	2	25	30	85	65	2	25	30	40	23	2	25	30
151	181	90	70	2	25	30	85	65	2	25	30	35	23	2	25	30
181	212	90	70	2	25	30	80	65	2	25	30	35	23	2	25	30
212	243	85	70	2	25	30	75	65	2	25	30	30	23	2	25	30
243	273	80	70	2	25	30	70	65	2	25	30	30	23	2	25	30
273	304	75	70	2	25	30	70	65	2	25	30	25	23	2	25	30
304	334	80	70	2	25	30	75	65	2	25	30	30	23	2	25	30
334	365	90	70	2	25	30	80	65	2	25	30	40	23	2	25	30
365	396	100	70	2	25	30	90	65	2	25	30	44	23	2	25	30
396	424	99	70	2	25	30	88	65	2	25	30	42	23	2	25	30
424	455	98	70	2	25	30	88	65	2	25	30	42	23	2	25	30
455	485	98	70	2	25	30	90	65	2	25	30	42	23	2	25	30
485	516	94	70	2	25	30	85	65	2	25	30	40	23	2	25	30
516	546	90	70	2	25	30	85	65	2	25	30	35	23	2	25	30

546	577	90	70	2	25	30	80	65	2	25	30	35	23	2	25	30
577	608	85	70	2	25	30	75	65	2	25	30	30	23	2	25	30
608	638	80	70	2	25	30	70	65	2	25	30	30	23	2	25	30
638	669	75	70	2	25	30	70	65	2	25	30	25	23	2	25	30
669	699	80	70	2	25	30	75	65	2	25	30	30	23	2	25	30
699	730	90	70	2	25	30	80	65	2	25	30	40	23	2	25	30
730	761	100	70	2	25	30	90	65	2	25	30	44	23	2	25	30
761	789	99	70	2	25	30	88	65	2	25	30	42	23	2	25	30
789	820	98	70	2	25	30	88	65	2	25	30	42	23	2	25	30
820	850	98	70	2	25	30	90	65	2	25	30	42	23	2	25	30
850	881	94	70	2	25	30	85	65	2	25	30	40	23	2	25	30
881	911	90	70	2	25	30	85	65	2	25	30	35	23	2	25	30
911	942	90	70	2	25	30	80	65	2	25	30	35	23	2	25	30
942	973	85	70	2	25	30	75	65	2	25	30	30	23	2	25	30
973	1003	80	70	2	25	30	70	65	2	25	30	30	23	2	25	30
1003	1034	75	70	2	25	30	70	65	2	25	30	25	23	2	25	30
1034	1064	80	70	2	25	30	75	65	2	25	30	30	23	2	25	30
1064	1095	90	70	2	25	30	80	65	2	25	30	40	23	2	25	30
1095	1126	100	70	2	25	30	90	65	2	25	30	44	23	2	25	30
1126	1154	99	70	2	25	30	88	65	2	25	30	42	23	2	25	30
1154	1185	98	70	2	25	30	88	65	2	25	30	42	23	2	25	30
1185	1215	98	70	2	25	30	90	65	2	25	30	42	23	2	25	30
1215	1246	94	70	2	25	30	85	65	2	25	30	40	23	2	25	30
1246	1276	90	70	2	25	30	85	65	2	25	30	35	23	2	25	30
1276	1307	90	70	2	25	30	80	65	2	25	30	35	23	2	25	30
1307	1338	85	70	2	25	30	75	65	2	25	30	30	23	2	25	30
1338	1368	80	70	2	25	30	70	65	2	25	30	30	23	2	25	30
1368	1399	75	70	2	25	30	70	65	2	25	30	25	23	2	25	30
1399	1429	80	70	2	25	30	75	65	2	25	30	30	23	2	25	30
1429	1460	90	70	2	25	30	80	65	2	25	30	40	23	2	25	30
1460	1491	100	70	2	25	30	90	65	2	25	30	44	23	2	25	30
1491	1519	99	70	2	25	30	88	65	2	25	30	42	23	2	25	30
1519	1550	98	70	2	25	30	88	65	2	25	30	42	23	2	25	30

1550	1580	98	70	2	25	30	90	65	2	25	30	42	23	2	25	30
1580	1611	94	70	2	25	30	85	65	2	25	30	40	23	2	25	30
1611	1641	90	70	2	25	30	85	65	2	25	30	35	23	2	25	30
1641	1672	90	70	2	25	30	80	65	2	25	30	35	23	2	25	30
1672	1703	85	70	2	25	30	75	65	2	25	30	30	23	2	25	30
1703	1733	80	70	2	25	30	70	65	2	25	30	30	23	2	25	30
1733	1764	75	70	2	25	30	70	65	2	25	30	25	23	2	25	30
1764	1794	80	70	2	25	30	75	65	2	25	30	30	23	2	25	30
1794	1825	90	70	2	25	30	80	65	2	25	30	40	23	2	25	30
1825	1856	100	70	2	25	30	90	65	4	25	30	44	23	2	25	30

		Kaliyar Lower-5					Kaliyar Lower-6				
Start	End	River stage	River Bottom	Riverbed thickness	Riverbed Kz	River width	River stage	River Bottom	Riverbed thickness	Riverbed Kz	River width
0	31	44	20	3	28	50	28	15	3	28	50
31	59	42	20	3	28	50	26	15	3	28	50
59	90	42	20	3	28	50	26	15	3	28	50
90	120	42	20	3	28	50	28	15	3	28	50
120	151	40	20	3	28	50	26	15	3	28	50
151	181	35	20	3	28	50	26	15	3	28	50
181	212	35	20	3	28	50	25	15	3	28	50
212	243	30	20	3	28	50	23	15	3	28	50
243	273	30	20	3	28	50	20	15	3	28	50
273	304	25	20	3	28	50	20	15	3	28	50
304	334	30	20	3	28	50	24	15	3	28	50
334	365	40	20	3	28	50	26	15	3	28	50
365	396	44	20	3	28	50	28	15	3	28	50
396	424	42	20	3	28	50	26	15	3	28	50
424	455	42	20	3	28	50	26	15	3	28	50
455	485	42	20	3	28	50	28	15	3	28	50
485	516	40	20	3	28	50	26	15	3	28	50
516	546	35	20	3	28	50	26	15	3	28	50
546	577	35	20	3	28	50	25	15	3	28	50
577	608	30	20	3	28	50	23	15	3	28	50
608	638	30	20	3	28	50	20	15	3	28	50
638	669	25	20	3	28	50	20	15	3	28	50
669	699	30	20	3	28	50	24	15	3	28	50
699	730	40	20	3	28	50	26	15	3	28	50
730	761	44	20	3	28	50	28	15	3	28	50
761	789	42	20	3	28	50	26	15	3	28	50
789	820	42	20	3	28	50	26	15	3	28	50

820	850	42	20	3	28	50	28	15	3	28	50
850	881	40	20	3	28	50	26	15	3	28	50
881	911	35	20	3	28	50	26	15	3	28	50
911	942	35	20	3	28	50	25	15	3	28	50
942	973	30	20	3	28	50	23	15	3	28	50
973	1003	30	20	3	28	50	20	15	3	28	50
1003	1034	25	20	3	28	50	20	15	3	28	50
1034	1064	30	20	3	28	50	24	15	3	28	50
1064	1095	40	20	3	28	50	26	15	3	28	50
1095	1126	44	20	3	28	50	28	15	3	28	50
1126	1154	42	20	3	28	50	26	15	3	28	50
1154	1185	42	20	3	28	50	26	15	3	28	50
1185	1215	42	20	3	28	50	28	15	3	28	50
1215	1246	40	20	3	28	50	26	15	3	28	50
1246	1276	35	20	3	28	50	26	15	3	28	50
1276	1307	35	20	3	28	50	25	15	3	28	50
1307	1338	30	20	3	28	50	23	15	3	28	50
1338	1368	30	20	3	28	50	20	15	3	28	50
1368	1399	25	20	3	28	50	20	15	3	28	50
1399	1429	30	20	3	28	50	24	15	3	28	50
1429	1460	40	20	3	28	50	26	15	3	28	50
1460	1491	44	20	3	28	50	28	15	3	28	50
1491	1519	42	20	3	28	50	26	15	3	28	50
1519	1550	42	20	3	28	50	26	15	3	28	50
1550	1580	42	20	3	28	50	28	15	3	28	50
1580	1611	40	20	3	28	50	26	15	3	28	50
1611	1641	35	20	3	28	50	26	15	3	28	50
1641	1672	35	20	3	28	50	25	15	3	28	50
1672	1703	30	20	3	28	50	23	15	3	28	50
1703	1733	30	20	3	28	50	20	15	3	28	50

1733	1764	25	20	3	28	50	20	15	3	28	50
1764	1794	30	20	3	28	50	24	15	3	28	50
1794	1825	40	20	3	28	50	26	15	3	28	50
1825	1856	44	20	3	28	50	28	15	3	28	50

Kaliyar Lower-7							Kaliyar Upper 1					Kaliyar Upper-2				
Start	End	River stage	River Bottom	Riverbed thickness	River bed Kz	River width	River stage	River Bottom	Riverbed thickness	River bed Kz	River width	River stage	River Bottom	Riverbed thickness	River bed Kz	River width
0	31	25	8	4	28	65	40	15	2	25	30	25	10	3	20	40
31	59	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
59	90	23	8	4	28	65	38	15	2	25	40	23	10	3	20	40
90	120	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
120	151	24	8	4	28	65	37	15	2	25	40	24	10	3	20	40
151	181	23	8	4	28	65	35	15	2	25	40	23	10	3	20	40
181	212	21	8	4	28	65	33	15	2	25	40	21	10	3	20	40
212	243	20	8	4	28	65	30	15	2	25	40	20	10	3	20	40
243	273	19	8	4	28	65	28	15	2	25	40	19	10	3	20	40
273	304	18	8	4	28	65	25	15	2	25	40	18	10	3	20	40
304	334	21	8	4	28	65	30	15	2	25	40	21	10	3	20	40
334	365	23	8	4	28	65	35	15	2	25	40	23	10	3	20	40
365	396	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
396	424	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
424	455	23	8	4	28	65	38	15	2	25	40	23	10	3	20	40
455	485	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
485	516	24	8	4	28	65	37	15	2	25	40	24	10	3	20	40
516	546	23	8	4	28	65	35	15	2	25	40	23	10	3	20	40
546	577	21	8	4	28	65	33	15	2	25	40	21	10	3	20	40

577	608	20	8	4	28	65	30	15	2	25	40	20	10	3	20	40
608	638	19	8	4	28	65	28	15	2	25	40	19	10	3	20	40
638	669	18	8	4	28	65	25	15	2	25	40	18	10	3	20	40
669	699	21	8	4	28	65	30	15	2	25	40	21	10	3	20	40
699	730	23	8	4	28	65	35	15	2	25	40	23	10	3	20	40
730	761	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
761	789	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
789	820	23	8	4	28	65	38	15	2	25	40	23	10	3	20	40
820	850	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
850	881	24	8	4	28	65	37	15	2	25	40	24	10	3	20	40
881	911	23	8	4	28	65	35	15	2	25	40	23	10	3	20	40
911	942	21	8	4	28	65	33	15	2	25	40	21	10	3	20	40
942	973	20	8	4	28	65	30	15	2	25	40	20	10	3	20	40
973	1003	19	8	4	28	65	28	15	2	25	40	19	10	3	20	40
1003	1034	18	8	4	28	65	25	15	2	25	40	18	10	3	20	40
1034	1064	21	8	4	28	65	30	15	2	25	40	21	10	3	20	40
1064	1095	23	8	4	28	65	35	15	2	25	40	23	10	3	20	40
1095	1126	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
1126	1154	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
1154	1185	23	8	4	28	65	38	15	2	25	40	23	10	3	20	40
1185	1215	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
1215	1246	24	8	4	28	65	37	15	2	25	40	24	10	3	20	40
1246	1276	23	8	4	28	65	35	15	2	25	40	23	10	3	20	40
1276	1307	21	8	4	28	65	33	15	2	25	40	21	10	3	20	40
1307	1338	20	8	4	28	65	30	15	2	25	40	20	10	3	20	40
1338	1368	19	8	4	28	65	28	15	2	25	40	19	10	3	20	40
1368	1399	18	8	4	28	65	25	15	2	25	40	18	10	3	20	40
1399	1429	21	8	4	28	65	30	15	2	25	40	21	10	3	20	40
1429	1460	23	8	4	28	65	35	15	2	25	40	23	10	3	20	40
1460	1491	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40

1491	1519	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
1519	1550	23	8	4	28	65	38	15	2	25	40	23	10	3	20	40
1550	1580	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40
1580	1611	24	8	4	28	65	37	15	2	25	40	24	10	3	20	40
1611	1641	23	8	4	28	65	35	15	2	25	40	23	10	3	20	40
1641	1672	21	8	4	28	65	33	15	2	25	40	21	10	3	20	40
1672	1703	20	8	4	28	65	30	15	2	25	40	20	10	3	20	40
1703	1733	19	8	4	28	65	28	15	2	25	40	19	10	3	20	40
1733	1764	18	8	4	28	65	25	15	2	25	40	18	10	3	20	40
1764	1794	21	8	4	28	65	30	15	2	25	40	21	10	3	20	40
1794	1825	23	8	4	28	65	35	15	2	25	40	23	10	3	20	40
1825	1856	25	8	4	28	65	40	15	2	25	40	25	10	3	20	40

Thodupuzha-1							Thodupuzha-2						
Start	End	River stage	River Bottom	Riverbed thickness	Riverbed Kz	River width	Start	End	River stage	River Bottom	Riverbed thickness	Riverbed Kz	River width
0	31	100	65	2	28	40	0	31	60	20	2	28	40
31	59	100	65	2	28	40	31	59	60	20	2	28	40
59	90	100	65	2	28	40	59	90	60	20	2	28	40
90	120	95	65	2	28	40	90	120	60	20	2	28	40
120	151	90	65	2	28	40	120	151	55	20	2	28	40
151	181	90	65	2	28	40	151	181	50	20	2	28	40
181	212	85	65	2	28	40	181	212	45	20	2	28	40
212	243	80	65	2	28	40	212	243	40	20	2	28	40
243	273	75	65	2	28	40	243	273	40	20	2	28	40
273	304	70	65	2	28	40	273	304	35	20	2	28	40
304	334	80	65	2	28	40	304	334	40	20	2	28	40
334	365	85	65	2	28	40	334	365	50	20	2	28	40
365	396	100	65	2	28	40	365	396	60	20	2	28	40
396	424	100	65	2	28	40	396	424	60	20	2	28	40
424	455	100	65	2	28	40	424	455	60	20	2	28	40
455	485	95	65	2	28	40	455	485	60	20	2	28	40
485	516	90	65	2	28	40	485	516	55	20	2	28	40
516	546	90	65	2	28	40	516	546	50	20	2	28	40
546	577	85	65	2	28	40	546	577	45	20	2	28	40
577	608	80	65	2	28	40	577	608	40	20	2	28	40
608	638	75	65	2	28	40	608	638	40	20	2	28	40
638	669	70	65	2	28	40	638	669	35	20	2	28	40
669	699	80	65	2	28	40	669	699	40	20	2	28	40
699	730	85	65	2	28	40	699	730	50	20	2	28	40
730	761	100	65	2	28	40	730	761	60	20	2	28	40

761	789	100	65	2	28	40	761	789	60	20	2	28	40
789	820	100	65	2	28	40	789	820	60	20	2	28	40
820	850	95	65	2	28	40	820	850	60	20	2	28	40
850	881	90	65	2	28	40	850	881	55	20	2	28	40
881	911	90	65	2	28	40	881	911	50	20	2	28	40
911	942	85	65	2	28	40	911	942	45	20	2	28	40
942	973	80	65	2	28	40	942	973	40	20	2	28	40
973	1003	75	65	2	28	40	973	1003	40	20	2	28	40
1003	1034	70	65	2	28	40	1003	1034	35	20	2	28	40
1034	1064	80	65	2	28	40	1034	1064	40	20	2	28	40
1064	1095	85	65	2	28	40	1064	1095	50	20	2	28	40
1095	1126	100	65	2	28	40	1095	1126	60	20	2	28	40
1126	1154	100	65	2	28	40	1126	1154	60	20	2	28	40
1154	1185	100	65	2	28	40	1154	1185	60	20	2	28	40
1185	1215	95	65	2	28	40	1185	1215	60	20	2	28	40
1215	1246	90	65	2	28	40	1215	1246	55	20	2	28	40
1246	1276	90	65	2	28	40	1246	1276	50	20	2	28	40
1276	1307	85	65	2	28	40	1276	1307	45	20	2	28	40
1307	1338	80	65	2	28	40	1307	1338	40	20	2	28	40
1338	1368	75	65	2	28	40	1338	1368	40	20	2	28	40
1368	1399	70	65	2	28	40	1368	1399	35	20	2	28	40
1399	1429	80	65	2	28	40	1399	1429	40	20	2	28	40
1429	1460	85	65	2	28	40	1429	1460	50	20	2	28	40
1460	1491	100	65	2	28	40	1460	1491	60	20	2	28	40
1491	1519	100	65	2	28	40	1491	1519	60	20	2	28	40
1519	1550	100	65	2	28	40	1519	1550	60	20	2	28	40
1550	1580	95	65	2	28	40	1550	1580	60	20	2	28	40
1580	1611	90	65	2	28	40	1580	1611	55	20	2	28	40
1611	1641	90	65	2	28	40	1611	1641	50	20	2	28	40
1641	1672	85	65	2	28	40	1641	1672	45	20	2	28	40

1672	1703	80	65	2	28	40	1672	1703	40	20	2	28	40
1703	1733	75	65	2	28	40	1703	1733	40	20	2	28	40
1733	1764	70	65	2	28	40	1733	1764	35	20	2	28	40
1764	1794	80	65	2	28	40	1764	1794	40	20	2	28	40
1794	1825	85	65	2	28	40	1794	1825	50	20	2	28	40
1825	1856	100	65	4	28	40	1825	1856	60	20	4	28	40

Thodupuzha -3							Thodupuzha -4						
Start	End	River stage	River Bottom	Riverbed thickness	Riverbed Kz	River width	Start	End	River stage	River Bottom	Riverbed thickness	Riverbed Kz	River width
0	31	63	5	2	30	50	0	31	38	4	2	30	50
31	59	60	5	2	30	50	31	59	35	4	2	30	50
59	90	58	5	2	30	50	59	90	33	4	2	30	50
90	120	58	5	2	30	50	90	120	33	4	2	30	50
120	151	60	5	2	30	50	120	151	35	4	2	30	50
151	181	60	5	2	30	50	151	181	35	4	2	30	50
181	212	60	5	2	30	50	181	212	35	4	2	30	50
212	243	63	5	2	30	50	212	243	37	4	2	30	50
243	273	63	5	2	30	50	243	273	37	4	2	30	50
273	304	63	5	2	30	50	273	304	38	4	2	30	50
304	334	60	5	2	30	50	304	334	35	4	2	30	50
334	365	60	5	2	30	50	334	365	35	4	2	30	50
365	396	63	5	2	30	50	365	396	38	4	2	30	50
396	424	60	5	2	30	50	396	424	35	4	2	30	50
424	455	58	5	2	30	50	424	455	33	4	2	30	50
455	485	58	5	2	30	50	455	485	33	4	2	30	50
485	516	60	5	2	30	50	485	516	35	4	2	30	50

516	546	60	5	2	30	50	516	546	35	4	2	30	50
546	577	60	5	2	30	50	546	577	35	4	2	30	50
577	608	63	5	2	30	50	577	608	37	4	2	30	50
608	638	63	5	2	30	50	608	638	37	4	2	30	50
638	669	63	5	2	30	50	638	669	38	4	2	30	50
669	699	60	5	2	30	50	669	699	35	4	2	30	50
699	730	60	5	2	30	50	699	730	35	4	2	30	50
730	761	63	5	2	30	50	730	761	38	4	2	30	50
761	789	60	5	2	30	50	761	789	35	4	2	30	50
789	820	58	5	2	30	50	789	820	33	4	2	30	50
820	850	58	5	2	30	50	820	850	33	4	2	30	50
850	881	60	5	2	30	50	850	881	35	4	2	30	50
881	911	60	5	2	30	50	881	911	35	4	2	30	50
911	942	60	5	2	30	50	911	942	35	4	2	30	50
942	973	63	5	2	30	50	942	973	37	4	2	30	50
973	1003	63	5	2	30	50	973	1003	37	4	2	30	50
1003	1034	63	5	2	30	50	1003	1034	38	4	2	30	50
1034	1064	60	5	2	30	50	1034	1064	35	4	2	30	50
1064	1095	60	5	2	30	50	1064	1095	35	4	2	30	50
1095	1126	63	5	2	30	50	1095	1126	38	4	2	30	50
1126	1154	60	5	2	30	50	1126	1154	35	4	2	30	50
1154	1185	58	5	2	30	50	1154	1185	33	4	2	30	50
1185	1215	58	5	2	30	50	1185	1215	33	4	2	30	50
1215	1246	60	5	2	30	50	1215	1246	35	4	2	30	50
1246	1276	60	5	2	30	50	1246	1276	35	4	2	30	50
1276	1307	60	5	2	30	50	1276	1307	35	4	2	30	50
1307	1338	63	5	2	30	50	1307	1338	37	4	2	30	50
1338	1368	63	5	2	30	50	1338	1368	37	4	2	30	50
1368	1399	63	5	2	30	50	1368	1399	38	4	2	30	50
1399	1429	60	5	2	30	50	1399	1429	35	4	2	30	50

1429	1460	60	5	2	30	50	1429	1460	35	4	2	30	50
1460	1491	63	5	2	30	50	1460	1491	38	4	2	30	50
1491	1519	60	5	2	30	50	1491	1519	35	4	2	30	50
1519	1550	58	5	2	30	50	1519	1550	33	4	2	30	50
1550	1580	58	5	2	30	50	1550	1580	33	4	2	30	50
1580	1611	60	5	2	30	50	1580	1611	35	4	2	30	50
1611	1641	60	5	2	30	50	1611	1641	35	4	2	30	50
1641	1672	60	5	2	30	50	1641	1672	35	4	2	30	50
1672	1703	63	5	2	30	50	1672	1703	37	4	2	30	50
1703	1733	63	5	2	30	50	1703	1733	37	4	2	30	50
1733	1764	63	5	2	30	50	1733	1764	38	4	2	30	50
1764	1794	60	5	2	30	50	1764	1794	35	4	2	30	50
1794	1825	60	5	2	30	50	1794	1825	35	4	2	30	50
1825	1856	63	5	3	30	50	1825	1856	38	4	4	30	50

		Muvattupuzha -1					Muvattupuzha-2					Muvattupuzha-3				
Start	End	River stage	River Bottom	River bed thickness	River bed Kz	River width	River stage	River Bottom	Riverbed thickness	River bed Kz	River width	River stage	River Bottom	River bed thickness	River bed Kz	River width
0	31	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
31	59	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
59	90	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
90	120	17	2	4	20	125	10	2	4	20	125	8	1	4	10	125
120	151	16	2	4	20	125	8	2	4	20	125	7	1	4	10	125
151	181	16	2	4	20	125	6	2	4	20	125	6.5	1	4	10	125
181	212	15	2	4	20	125	6	2	4	20	125	6.5	1	4	10	125
212	243	15	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
243	273	14	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
273	304	14	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
304	334	16	2	4	20	125	7	2	4	20	125	7.2	1	4	10	125
334	365	16	2	4	20	125	7	2	4	20	125	7.6	1	4	10	125
365	396	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
396	424	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
424	455	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
455	485	17	2	4	20	125	10	2	4	20	125	8	1	4	10	125
485	516	16	2	4	20	125	8	2	4	20	125	7	1	4	10	125
516	546	16	2	4	20	125	6	2	4	20	125	6.5	1	4	10	125
546	577	15	2	4	20	125	6	2	4	20	125	6.5	1	4	10	125
577	608	15	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
608	638	14	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
638	669	14	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
669	699	16	2	4	20	125	7	2	4	20	125	7.2	1	4	10	125

699	730	16	2	4	20	125	7	2	4	20	125	7.6	1	4	10	125
730	761	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
761	789	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
789	820	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
820	850	17	2	4	20	125	10	2	4	20	125	8	1	4	10	125
850	881	16	2	4	20	125	8	2	4	20	125	7	1	4	10	125
881	911	16	2	4	20	125	6	2	4	20	125	6.5	1	4	10	125
911	942	15	2	4	20	125	6	2	4	20	125	6.5	1	4	10	125
942	973	15	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
973	1003	14	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
1003	1034	14	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
1034	1064	16	2	4	20	125	7	2	4	20	125	7.2	1	4	10	125
1064	1095	16	2	4	20	125	7	2	4	20	125	7.6	1	4	10	125
1095	1126	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
1126	1154	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
1154	1185	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
1185	1215	17	2	4	20	125	10	2	4	20	125	8	1	4	10	125
1215	1246	16	2	4	20	125	8	2	4	20	125	7	1	4	10	125
1246	1276	16	2	4	20	125	6	2	4	20	125	6.5	1	4	10	125
1276	1307	15	2	4	20	125	6	2	4	20	125	6.5	1	4	10	125
1307	1338	15	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
1338	1368	14	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
1368	1399	14	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
1399	1429	16	2	4	20	125	7	2	4	20	125	7.2	1	4	10	125
1429	1460	16	2	4	20	125	7	2	4	20	125	7.6	1	4	10	125
1460	1491	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
1491	1519	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
1519	1550	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125
1550	1580	17	2	4	20	125	10	2	4	20	125	8	1	4	10	125
1580	1611	16	2	4	20	125	8	2	4	20	125	7	1	4	10	125
1611	1641	16	2	4	20	125	6	2	4	20	125	6.5	1	4	10	125

1641	1672	15	2	4	20	125	6	2	4	20	125	6.5	1	4	10	125
1672	1703	15	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
1703	1733	14	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
1733	1764	14	2	4	20	125	6	2	4	20	125	6.2	1	4	10	125
1764	1794	16	2	4	20	125	7	2	4	20	125	7.2	1	4	10	125
1794	1825	16	2	4	20	125	7	2	4	20	125	7.6	1	4	10	125
1825	1856	18	2	4	20	125	10	2	4	20	125	8	1	4	10	125

ANNEXURE-1D

Evapotranspiration (ET) rate for transient state

Zone-1				Zone-2		Zone-3	
Start time	Stop time	ET (m/d)	Extinction Depth (m)	ET (m/d)	Extinction Depth (m)	ET (m/d)	Extinction Depth (m)
0	31	0.00207	1	0.00243	1.8	0.00233	2.5
31	59	0.00175	1	0.00234	1.8	0.00283	2.5
59	90	0.00234	1	0.00282	1.8	0.00277	2.5
90	120	0.00210	1	0.00227	1.8	0.00188	2.5
120	151	0.00187	1	0.00231	1.8	0.00194	2.5
151	181	0.00166	1	0.00270	1.8	0.00286	2.5
181	212	0.00154	1	0.00289	1.8	0.00389	2.5
212	243	0.00125	1	0.00119	1.8	0.00351	2.5
243	273	0.00158	1	0.00190	1.8	0.00209	2.5
273	304	0.00192	1	0.00263	1.8	0.00240	2.5
304	334	0.00264	1	0.00328	1.8	0.00277	2.5
334	365	0.00243	1	0.00294	1.8	0.00286	2.5
365	396	0.00207	1	0.00243	1.8	0.00233	2.5
396	424	0.00175	1	0.00234	1.8	0.00283	2.5
424	455	0.00234	1	0.00282	1.8	0.00277	2.5
455	485	0.00210	1	0.00227	1.8	0.00188	2.5
485	516	0.00187	1	0.00231	1.8	0.00194	2.5
516	546	0.00166	1	0.00270	1.8	0.00286	2.5
546	577	0.00154	1	0.00289	1.8	0.00389	2.5
577	608	0.00125	1	0.00119	1.8	0.00351	2.5
608	638	0.00158	1	0.00190	1.8	0.00209	2.5
638	669	0.00192	1	0.00263	1.8	0.00240	2.5

669	699	0.00264	1	0.00328	1.8	0.00277	2.5
699	730	0.00243	1	0.00294	1.8	0.00286	2.5
730	761	0.00207	1	0.00243	1.8	0.00233	2.5
761	789	0.00175	1	0.00234	1.8	0.00283	2.5
789	820	0.00234	1	0.00282	1.8	0.00277	2.5
820	850	0.00210	1	0.00227	1.8	0.00188	2.5
850	881	0.00187	1	0.00231	1.8	0.00194	2.5
881	911	0.00166	1	0.00270	1.8	0.00286	2.5
911	942	0.00154	1	0.00289	1.8	0.00389	2.5
942	973	0.00125	1	0.00119	1.8	0.00351	2.5
973	1003	0.00158	1	0.00190	1.8	0.00209	2.5
1003	1034	0.00192	1	0.00263	1.8	0.00240	2.5
1034	1064	0.00264	1	0.00328	1.8	0.00277	2.5
1064	1095	0.00243	1	0.00294	1.8	0.00286	2.5
1095	1126	0.00207	1	0.00243	1.8	0.00233	2.5
1126	1154	0.00175	1	0.00234	1.8	0.00283	2.5
1154	1185	0.00234	1	0.00282	1.8	0.00277	2.5
1185	1215	0.00210	1	0.00227	1.8	0.00188	2.5
1215	1246	0.00187	1	0.00231	1.8	0.00194	2.5
1246	1276	0.00166	1	0.00270	1.8	0.00286	2.5
1276	1307	0.00154	1	0.00289	1.8	0.00389	2.5
1307	1338	0.00125	1	0.00119	1.8	0.00351	2.5
1338	1368	0.00158	1	0.00190	1.8	0.00209	2.5
1368	1399	0.00192	1	0.00263	1.8	0.00240	2.5
1399	1429	0.00264	1	0.00328	1.8	0.00277	2.5
1429	1460	0.00243	1	0.00294	1.8	0.00286	2.5
1460	1491	0.00207	1	0.00243	1.8	0.00233	2.5
1491	1519	0.00175	1	0.00234	1.8	0.00283	2.5
1519	1550	0.00234	1	0.00282	1.8	0.00277	2.5
1550	1580	0.00210	1	0.00227	1.8	0.00188	2.5

1580	1611	0.00187	1	0.00231	1.8	0.00194	2.5
1611	1641	0.00166	1	0.00270	1.8	0.00286	2.5
1641	1672	0.00154	1	0.00289	1.8	0.00389	2.5
1672	1703	0.00125	1	0.00119	1.8	0.00351	2.5
1703	1733	0.00158	1	0.00190	1.8	0.00209	2.5
1733	1764	0.00192	1	0.00263	1.8	0.00240	2.5
1764	1794	0.00264	1	0.00328	1.8	0.00277	2.5
1794	1825	0.00243	1	0.00294	1.8	0.00286	2.5
1825	1856	0.00214	1	0.00237	1.8	0.00234	2.5

ANNEXURE-1E

Constant Head Variations for Transient State

Relative time	Start time head	Stop time head
31	0	0.1
59	0	0.1
90	0	0.1
120	0	0.1
151	0	0.1
181	0	0.1
212	0	0.1
243	0	0.1
273	0	0.1
304	0	0.1
334	0	0.1
365	0	0.1
396	0	0.1
424	0	0.1
455	0	0.1
485	0	0.1
516	0	0.1
546	0	0.1
577	0	0.1
608	0	0.1
638	0	0.1
669	0	0.1
699	0	0.1
730	0	0.1
761	0	0.1
789	0	0.1
820	0	0.1
850	0	0.1
881	0	0.1
911	0	0.1
942	0	0.1
973	0	0.1
1003	0	0.1
1034	0	0.1
1064	0	0.1
1095	0	0.1
1126	0	0.1

1154	0	0.1
1185	0	0.1
1215	0	0.1
1246	0	0.1
1276	0	0.1
1307	0	0.1
1338	0	0.1
1368	0	0.1
1399	0	0.1
1429	0	0.1
1460	0	0.1
1491	0	0.1
1519	0	0.1
1550	0	0.1
1580	0	0.1
1611	0	0.1
1641	0	0.1
1672	0	0.1
1703	0	0.1
1733	0	0.1
1764	0	0.1
1794	0	0.1
1825	0	0.1
1856	0	0.1

ANNEXURE-1F

General Head Boundary (GHB) Variations for Transient State

South side-1					South side-2				
End time	Boundary head	Boundary distance	Avg K	Face	End time	Boundary head	Boundary distance	Avg K	Face
31	3	2500	20	East/West	31	3	3000	20	East/West
59	3	2500	20	East/West	59	3	3000	20	East/West
90	3	2500	20	East/West	90	3	3000	20	East/West
120	3	2500	20	East/West	120	3	3000	20	East/West
151	2.8	2500	20	East/West	151	2.8	3000	20	East/West
181	2.7	2500	20	East/West	181	2.7	3000	20	East/West
212	2.6	2500	20	East/West	212	2.6	3000	20	East/West
243	2.5	2500	20	East/West	243	2.5	3000	20	East/West
273	2.4	2500	20	East/West	273	2.4	3000	20	East/West
304	2.3	2500	20	East/West	304	2.3	3000	20	East/West
334	2.2	2500	20	East/West	334	2.2	3000	20	East/West
365	2.1	2500	20	East/West	365	2.1	3000	20	East/West
396	3	2500	20	East/West	396	3	3000	20	East/West
424	3	2500	20	East/West	424	3	3000	20	East/West
455	3	2500	20	East/West	455	3	3000	20	East/West
485	3	2500	20	East/West	485	3	3000	20	East/West
516	2.8	2500	20	East/West	516	2.8	3000	20	East/West
546	2.7	2500	20	East/West	546	2.7	3000	20	East/West
577	2.6	2500	20	East/West	577	2.6	3000	20	East/West
608	2.5	2500	20	East/West	608	2.5	3000	20	East/West
638	2.4	2500	20	East/West	638	2.4	3000	20	East/West
669	2.3	2500	20	East/West	669	2.3	3000	20	East/West
699	2.2	2500	20	East/West	699	2.2	3000	20	East/West
730	2.1	2500	20	East/West	730	2.1	3000	20	East/West
761	3	2500	20	East/West	761	3	3000	20	East/West
789	3	2500	20	East/West	789	3	3000	20	East/West
820	3	2500	20	East/West	820	3	3000	20	East/West
850	3	2500	20	East/West	850	3	3000	20	East/West
881	2.8	2500	20	East/West	881	2.8	3000	20	East/West
911	2.7	2500	20	East/West	911	2.7	3000	20	East/West
942	2.6	2500	20	East/West	942	2.6	3000	20	East/West
973	2.5	2500	20	East/West	973	2.5	3000	20	East/West
1003	2.4	2500	20	East/West	1003	2.4	3000	20	East/West

1034	2.3	2500	20	East/West	1034	2.3	3000	20	East/West
1064	2.2	2500	20	East/West	1064	2.2	3000	20	East/West
1095	2.1	2500	20	East/West	1095	2.1	3000	20	East/West
1126	3	2500	20	East/West	1126	3	3000	20	East/West
1154	3	2500	20	East/West	1154	3	3000	20	East/West
1185	3	2500	20	East/West	1185	3	3000	20	East/West
1215	3	2500	20	East/West	1215	3	3000	20	East/West
1246	2.8	2500	20	East/West	1246	2.8	3000	20	East/West
1276	2.7	2500	20	East/West	1276	2.7	3000	20	East/West
1307	2.6	2500	20	East/West	1307	2.6	3000	20	East/West
1338	2.5	2500	20	East/West	1338	2.5	3000	20	East/West
1368	2.4	2500	20	East/West	1368	2.4	3000	20	East/West
1399	2.3	2500	20	East/West	1399	2.3	3000	20	East/West
1429	2.2	2500	20	East/West	1429	2.2	3000	20	East/West
1460	2.1	2500	20	East/West	1460	2.1	3000	20	East/West
1491	3	2500	20	East/West	1491	3	3000	20	East/West
1519	3	2500	20	East/West	1519	3	3000	20	East/West
1550	3	2500	20	East/West	1550	3	3000	20	East/West
1580	3	2500	20	East/West	1580	3	3000	20	East/West
1611	2.8	2500	20	East/West	1611	2.8	3000	20	East/West
1641	2.7	2500	20	East/West	1641	2.7	3000	20	East/West
1672	2.6	2500	20	East/West	1672	2.6	3000	20	East/West
1703	2.5	2500	20	East/West	1703	2.5	3000	20	East/West
1733	2.4	2500	20	East/West	1733	2.4	3000	20	East/West
1764	2.3	2500	20	East/West	1764	2.3	3000	20	East/West
1794	2.2	2500	20	East/West	1794	2.2	3000	20	East/West
1825	2.1	2500	20	East/West	1825	2.1	3000	20	East/West
1856	3	2500	20	East/West	1856	3	3000	20	East/West