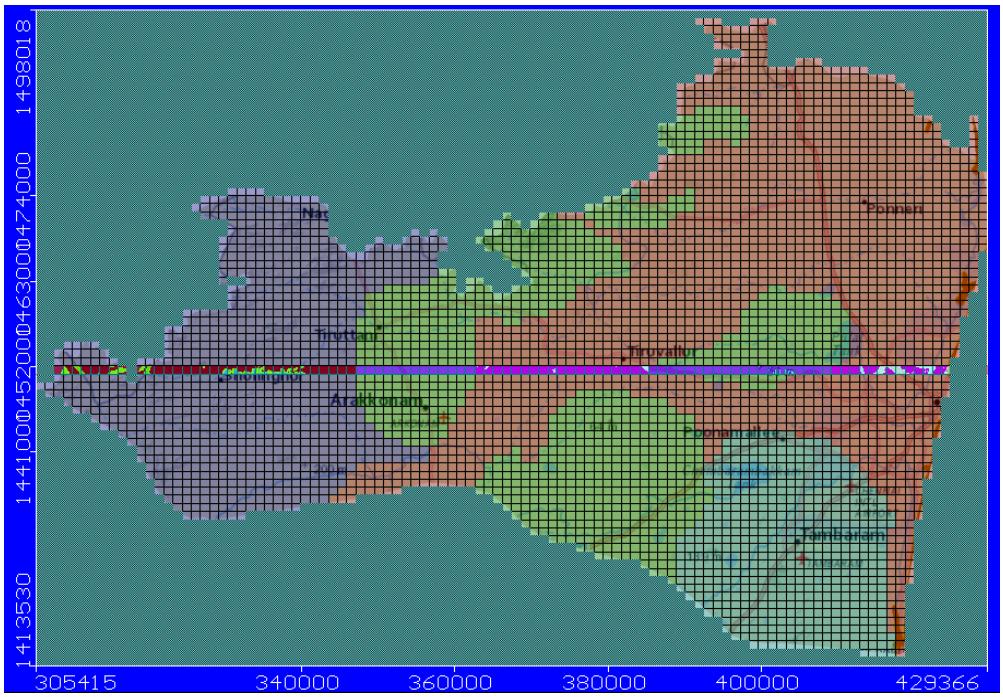
Groundwater Flow Simulation and Aquifer Management Plan for Chennai Aquifer System, Tamil Nadu, India



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1.0 INTRODUCTION

Ground water is being increasingly recognized as a dependable source of supply to meet the demands of domestic, irrigation and industrial sectors of the country. The development activities over the years have adversely affected the ground water regime in many parts of the country. Hence, there is a need for scientific planning in development of groundwater under different hydrogeological situations and to evolve effective management practices with involvement of community for better groundwater governance.

Aquifer Mapping has been taken up in Chennai Aquifer system basin in a view to formulate strategies for sustainable management plan for the aquifer system in accordance with the nature of the aquifer, the stress on the groundwater resource and prevailing groundwater quality which will help in achieving water security related to drinking water and improved irrigation facility. It will also result in better management of vulnerable areas.

A better understanding of the hydrogeologic process that control the distribution and availability of groundwater in the Chennai aquifer is imperative for optimal resource management. The optimization concept of managing the Chennai aquifer involves a procedure for aquifer use that enables the greatest number of the desired benefits to be accomplished. For water resources managers and planners to develop and implement effective long term and short term aquifer management strategies, a host of scientific questions must be answered. These questions can be best answered through a comprehensive process that integrates the best scientific data available.

To understand and to evaluate the response of the Chennai aquifer to various hydrologic stress, Central Ground Water Board desired for numerical groundwater flow model so as to evolve better aquifer management plan.

2.0 PURPOSE AND OBJECTIVE

The purpose of this report is to document the numerical groundwater flow model of Chennai groundwater basin. This report describes a) the hydrogeology of the Chennai aquifer and the conceptual model upon which the Chennai aquifer model is based. b) the construction and calibration of the Chennai aquifer model. c) the results of the Chennai aquifer model simulation d) the results of the steady-state and transient simulations. The simulation incorporates the recently revised hydrogeologic framework carried out by CGWB (2017).

The primary purpose of the model is to assist in evaluation of the responses of the unconfined aquifers to groundwater withdrawals. Development of the aquifer model included the identification of pertinent aquifer properties (physical properties) and processes to be simulated, design of the numerical discretization, specification of boundary and initial conditions and calibration of simulated to observed groundwater heads. For groundwater management strategy, the water managers who wish to assess the possible future regional groundwater drawdown resulting from proposed groundwater withdrawals may modify appropriate model-input files to run predictive simulations.

The 07 year transient model described in this report addresses the scientific issues pertaining to the study area

- **Primarily agricultural region** that depends on groundwater.
- Declining groundwater levels and low sustainability.
- Threat of **Sea water Intrusion** as the study area **bordered by the Bay of Bengal** in East
- Groundwater Mining for Chennai city water demands.
- **Chennai City located** within the aquifer system. Urbanization and huge demand for groundwater to cater to the growing Chennai City Population.
- Gondwana sandstone - Low yielding aquifer units.
- **Four Major Reservoirs** viz. Chembarkkam, Pondi & Red Hills exists within the area.
- Major Rivers: *Arani , Koratalaiyar, Coovum and Adyar.*
- Monsoon failure leads to increased stress on groundwater.

3.0 OBJECTIVES OF THE STUDY

Three dimensional groundwater flow model was conceptualized with the following objectives

- To simulate regional groundwater flow – distribution of heads
- Impact assessment on the Chennai aquifer system due to various hydrological & climatic stresses.
- To develop few scenarios based on steady and transient simulations for proper understanding of the aquifer system.
- Fresh Water /Sea Water interface movement through FDM
- Roadmap for efficient and sustainable management of the aquifer system.

4.0 BACKGROUND

National Project on Aquifer Mapping (NAQUIM) initiated by Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India with a vision to identify and map the aquifers with their characteristics, to quantify the available groundwater resources, propose plans appropriate to the scale of demand and institutional arrangements for participatory management in order to formulate a viable strategy for the sustainable development and management of the precious resource which is subjected to depletion and contamination due to indiscriminate development in the recent past.

Prior to this study, the groundwater hydrology has been studied only in separate parts with many areas left untouched. Therefore, there was no hydrogeologic framework to understand the potential regional effects of groundwater development in the Chennai aquifer system.

CGWB, under national aquifer mapping had carried out mapping of aquifers upto 200 m bgl. Aquifer mapping and detailed hydrogeological studies were taken up by CGWB for an area of 6288 sq.km during 2017– 18. The data and the hydrogeological information obtained from the above studies were used in the model study.

5.0 DESCRIPTION OF CHENNAI AQUIFER SYSTEM

The Chennai aquifer system covering an area of 6629 sq.km comprises of 341 sq.km of hilly area and 6288 sq.km of mappable area and is situated between latitudes 12°40'N and 13°40'N

and longitudes 79°10'E and 80°25'E at the north and north east corner of Tamil Nadu **(Figure 1).** Its boundaries shared by Andhra Pradesh state in the North; Palar River aquifer system in the West and South and the Bay of Bengal sea on the East. *Araniyar* (763 km^2), *Kosathalayar* (3.240 km^2), *Cooum* (682 km^2) and *Adyar* (857 km^2) are the four rivers draining through the basin region. The aquifer system occupies partly or fully 26 blocks of Tiruthani, Thiruvallur, Saidapet, Tambaram, Ponneri, Sriperumbudur, Arakonam, and Walajapet taluks of Thiruvallur, Kanjeepuram, Chennai and Vellore districts. There are 109 firkas out of which 38 are over exploited/critical firkas (**Table 1**). The major part of the basin area comes under Thiruvallur and Chennai districts (fully covered) and only a few regions of Vellore and Kanjeepuram districts are covered. Of the four rivers, the Adyar River carries the floodwater and drainage of Chennai city and its environs. It does not have any direct irrigation and carries only the flood discharge during the northeast monsoon period for few days. The Coovum River serves as drainage and sewerage carrier within the Chennai city limits.

The coastal plain climate is hot and humid and winters are moderate. The mean annual temperature is about 27^0C .The mean annual precipitation for the model area is 1290 mm. Periods of excessive rainfall followed by droughts are characteristic of the area and have significant hydrological impacts.

6.0 RAINFALL

The Chennai aquifer system has a monsoon climate as it lies within the tropical monsoon zone. Based on the hydrometeorological feature of the basin, year is divided into 2 periods Monsoon period spanning from June to December and Non-monsoon period spanning from January to May. The monsoon period is further sub-divided into 1) South West monsoon period spanning from June to September (4 months) and 2) Northeast monsoon period spanning from October to December (3 months). Similarly, the non-monsoon period is further sub-divided into (1) Winter period spanning January and February (2 months) and (2) Summer period spanning from March to May (3 months). As the monsoon period brings heavy rainfall it improves the recharging of ground water and storage of surface water. Hence, the monsoon period is hydrologically significant for water resources analysis, whereas the Non-monsoon, it is insignificant. Annual rainfall recorded during monsoon in mm is tabulated in **Annexure-I.**

Table 1: Chennai Aquifer System area details

Sl. No	District	Area Sq.Km.	No. of Firkas	No. of OE and Critical Firkas
1	Chennai	179	20	20
2	Kancheepuram	1914	33	4
3	Tiruvallur	3538	46	12
4	Vellore	998	10	2
Total		6629	109	38

7.0 DATA ADEQUACY

Exploratory well data is available for 274 wells drilled by CGWB (177 nos) and State Departments (97 nos). 32 new wells have been constructed through outsourcing in identified gaps in the hydrogeological data. Water level (211 nos) and Water Quality monitoring data (148 nos) were available for a long period i.e., more than ten years. 124 Vertical electrical sounding data was available. Cropping pattern and Soil data has been collected from Agricultural and Statistics Department. After plotting the available historical data on 1:50,000 scale maps, data gaps have been identified and data generation processes were taken up in those gap areas to complete the Aquifer map on the desired resolution of 1:50,000 toposheets. Top elevation has been prepared using SRTM 30 m resolution data. Groundwater draft has been estimated using the cropping pattern and electricity consumption data.

8.0 HYDROGEOLOGIC FRAMEWORK

Hydrogeologically, the Chennai aquifer system comprises of marine, estuarine and fluvial alluvium underlined by Precambrian gneisses and Charnockites. The charnockites form the major rock types and constitute the residual hills around southern part of the study area. Beds of upper Gondwanas are found in and around central and northern portion. These Upper Gondwana formations with type area Sathyavedu comprises of conglomerates, shale, and sandstone, and are enveloped by a thick cover of laterite. Tertiary sandstone is seen in small patches in the study area ie., in the northwest of Chennai city and upto Satyavedu, and is capped by lateritic soil **(Figure 2).** Geologic succession of the Chennai Aquifer System is presented in **Table 3.**

Precambrian Rocks

The hard rocks include granite, gneissic complex, schists and charnockites associated with basic and ultra-basic intrusives. The charnockites form the major rock types and constitute the residual hills around Pallavaram, Tambaram and Vandalur. Beds of upper Gondwanas are found in and around Anna Nagar, Mogapair, Valasarawakkam, Mambalam, and upto Sriperumbudur. West of the Chennai Aquifer system **(Figure 2)** gneissic rocks are present and they cover an area of 1355 sq.km and Charnockite formation is found in the eastern part of the study area covering about 537 sq.km.

Gondwanas

The Gondwana series is named after the ancient kingdom of Gonds of Madhya Pradesh. Theses series comprises of massive pile of lacustrine and fluvial deposits. These semi-consolidated formations occurring in the area represent the Upper Gondwanas of Jurassic to Lower Cretaceous rocks and the marine beds of the Cretaceous age. The Upper Gondwana Sediments consist of two stages viz. the lower Sriperumpudur stage consisting of fluvial clays, shales and feldspathic sandstones and the Satyavedu stage representing the marine sediments of ferruginous sandstones, conglomerates and boulders. The Sriperumpudur beds occur as patches, with easterly dips at low angles. The age of the Sriperumpudur formation is not certain; but the impressions of the foraminifera and ammonites are suggestive of an age varying from Upper Jurassic to Lower Cretaceous. They cover about 1297 sq.km area in the Chennai aquifer system.

The Satyavedu stage comprises beds of conglomerate mixed with a few beds of coarse mottled sandstone, beds of clayey sandstones and sandy shales. The conglomerates with a sandy clayey matrix is hard and compact and exposures of it are invariably strewn with shingle, pebbles and boulders. The strata show, in general, a decreasing lateral gradation in the coarseness of component deposits. The conglomerates and boulder beds occur nearer to the crystalline rocks. The total thickness of the formation exceeds 30 m.

Tertiary

The Tertiary beds comprise friable, white, speckled and reddish-brown mottled quartz grit, friable quartzose grits, which are white and brownish in colour becoming whiter at lower depths. Coarse laterite capping changes with depths into reticular cellular, sandy clay grits. The latter again appear to grade into coarse, friable, mottled grits which become pure white with depth. Similar formations are traced north of the Araniyar river and along the southern bank of the Korattalaiyar river in a line running from the Red Hill lake to the north-northwest. The rocks belonging to this period have been assigned the Miocene-Pliocene (Cuddalore) series but no fossil evidence for age has been found. It is only on stratigraphical and lithological evidence, that they are separated from the upper Gondwanas.

Quaternary

Boulder Bed: Gondwana series is overlain by the deposits known as Boulder bed in the eastern part of the study area. This bed consists of a mixture of rounded to sub-rounded boulders, cobbles, pebbles and gravel in a clayey sandy matrix and partly compacted. These deposits represent marginal facies of fluvial deposits worked out from Gondwana

conglomerates. Further east, this bed abruptly thins out to a few feet in thickness and as it is overlain by alluvium, forms a good marker of transition to Gondwana deposits.

Laterite

The Tertiary friable sandstone and Gondwana series are commonly capped by scoriaceous and pisolitic laterite. It is noticed around Kannigapuram, Red Hills and Palaiya Erumaimattupalaiyam area. The laterite of Red Hills is of a conglomeratic type comprising mainly fragments of sub-rounded quartz bound by cindered ferruginous cement. Its thickness ranges from 1.50 to 6.5 m and it occurs in the central portion of the study area with spatial distribution of around 322 sq.km

Alluvium

The youngest formations in the area are the alluvium, which were deposited on the worn-down and eroded surface of Tertiary and Gondwana rocks by the major rivers covering an area of 2036 sq.km spatially. It is noted that the alluvial plains in the eastern part of the area, entirely spans the lower reaches of Araniyar and Korattalaiyar and branches off into two separate plains farther east. A cross-section along the west-east direction near the Panjetty-Minjur area is represented in **Figure 2**. The alluvium consists of gravel, fine to coarse sand, clay and sandy clay of various shades of grey and brown. Commonly, the different types are intercalated (or) dovetailed in the form of lenses and pockets which point out the erratic geometry of the deposition, caused by the migration and varying flow velocities of old rivers. Exploratory drilling shows that the thickness of these deposits increase progressively in an easterly direction towards the coast line east of Minjur, where it is about 50-60 m thick. The wind deposited sand, in the form of irregular, low flat dunes ranging in width from less than 0.1 km to about a kilometer occur all along the coast, except where they are interrupted by the river outlets. The most striking dunes are near Pulicat, where they have grown by wind action into irregular mounds of 12 to 15 m high.

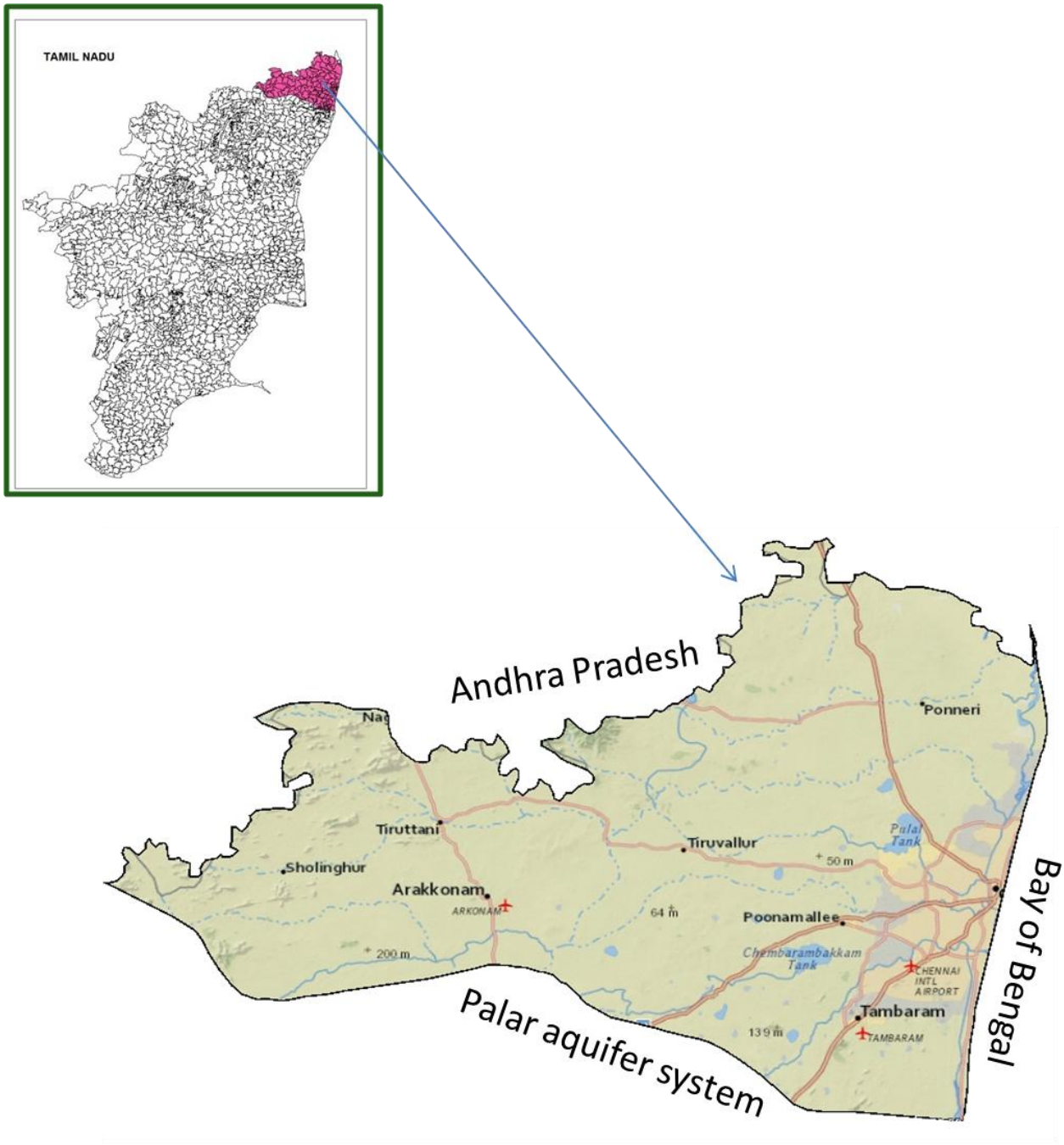

Figure 1: Map showing the location of Chennai *A*quifer *S*ystem, Tamil Nadu

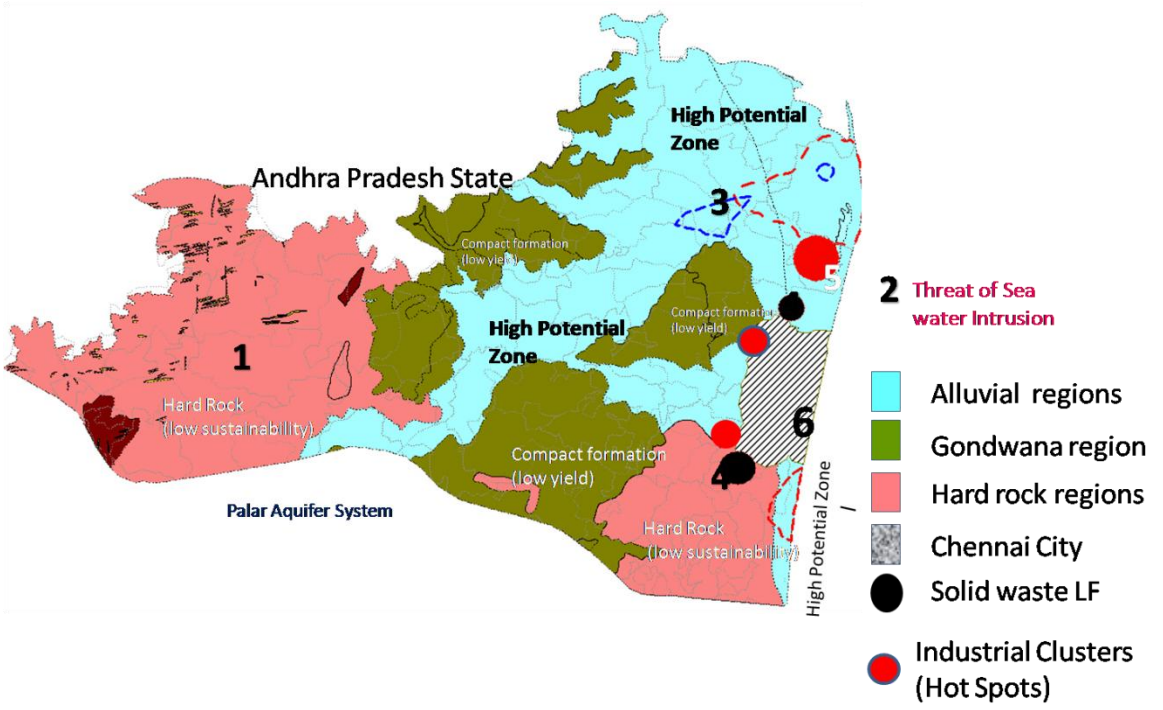

Figure 2: Regional hydrogeology of Chennai *A*quifer *S*ystem.

Figure 3: Study area map.

Table 2. Geological succession of the Chennai Aquifer System

S.No	Group	System	Lithology	Groundwater relevance
1.	Quaternary	Recent – Sub-recent	Soils, coastal /river Alluvium (sand & silt), Black Clay, Laterite	Moderate to very good porous aquifer system
2.	Tertiary	Sandstone (Eocene to Pliocene)	Sandstone & and shale	Moderately porous Aquifer.
3.	Mesozoic	Upper Gondwana (Sathyavedu & Sriperumbudur)	Conglomerates, Sandstone and siltstone; Grey shale; Black shale.	Very low Porous aquifer.
4.	Azoic	Archaean	Charnockites, Granites, Gneisses.	Weathered and Fractured Aquifer units.

9.0 CONCEPTUALIZATION OF THE CHENNAI AQUIFER SYSTEM

The conceptualization of the Chennai coastal aquifer includes description of the geologic and hydrogeologic setting within which the aquifer functions. **(Figure 4)** Paleo-geographic and structural features and major depositional provinces have influenced the distribution of hydrologic characteristics of the recent formation, upper cretaceous and hard rock formation composing the Chennai coastal aquifer. The conceptualization of the NAQUIM report of Chennai aquifer system **(Figure 4)** is the basis of the Chennai aquifer model.

The conceptual model of the system was arrived from the detailed study of geology, borehole lithology, geophysical logs, cross section and water level fluctuations in wells. Groundwater of the study area is found to occur in the quaternary formations (recent alluvium), Gondwana sandstone formations of the Upper Cretaceous period and hard rock formations of Archean. The major water bearing formation of the Chennai aquifer system is the recent alluvium and occur under unconfined conditions.

The conceptual model of the Chennai coastal aquifer includes a) descriptions of the hydrogeologic framework and hydraulic properties of the aquifer b) descriptions of the spatial and temporal characteristics of the model boundaries c) estimates of inflows, outflows across model boundaries d) description of the approaches used to estimate the steady state water budget and an assessment of the uncertainties associated with those estimates e) descriptions of groundwater flow paths f) descriptions of stratigraphic, structural and hydrologic controls on groundwater flow.

The Chennai aquifer system has been conceptualized as a two layered aquifer system with a combination of soft and hard rock aquifers. In the east and central portion, the alluvium forms the Aquifer 1 and is underlined by compact conglomerates of upper Gondwana forming the Aquifer II. In the southern and western portion of the study area the hard rock forms the aquifer system. Aquifer unit 1 comprises of weathered formation and is underlined by

fractured/jointed aquifer forming the aquifer unit II. **Figure 4a & b** clearly shows the disposition of the aquifer units of the Chennai aquifer system.

Data limitations included

a) Uneven spatial distribution of wells and boreholes, laterally and vertically

b) Uncertainties arising from partial well that complicate interpretations of water – level in very few locations and

c) Discontinuous or nonexistent hydrologic records.

10. 0 PRECIPITATION

Rainfall is the main component of groundwater recharge, which is specified as a temporally variable boundary flux in the groundwater model. The normal rainfall experienced by the area is 1100 mm/year. The groundwater recharge to the model was quantified by simple analysis of spatial and temporal variations of precipitation. The rainfall data (1994 – 2018) for the Chennai, Tiruvallur station along with 50 years distribution are given as **Annexure-I.**

11.0 EVAPOTRANSPIRATION

Water evaporates from the water table, the intervening unsaturated zone, and through the plant stomata (transpiration). It is difficult to separate the amounts of transpiration and evaporation over vegetated land areas, and these two processes commonly are combined and represented by an evapotranspiration (ET) term in hydrologic models. In Chennai coastal plain, the ET losses from the saturated groundwater system are probably negligible when the water table is deeper than 3 m below land surface. The evaporation is higher during May to August. Evaporation is 10.8 mm (max)and 2.8 (min) recorded during May 2016.

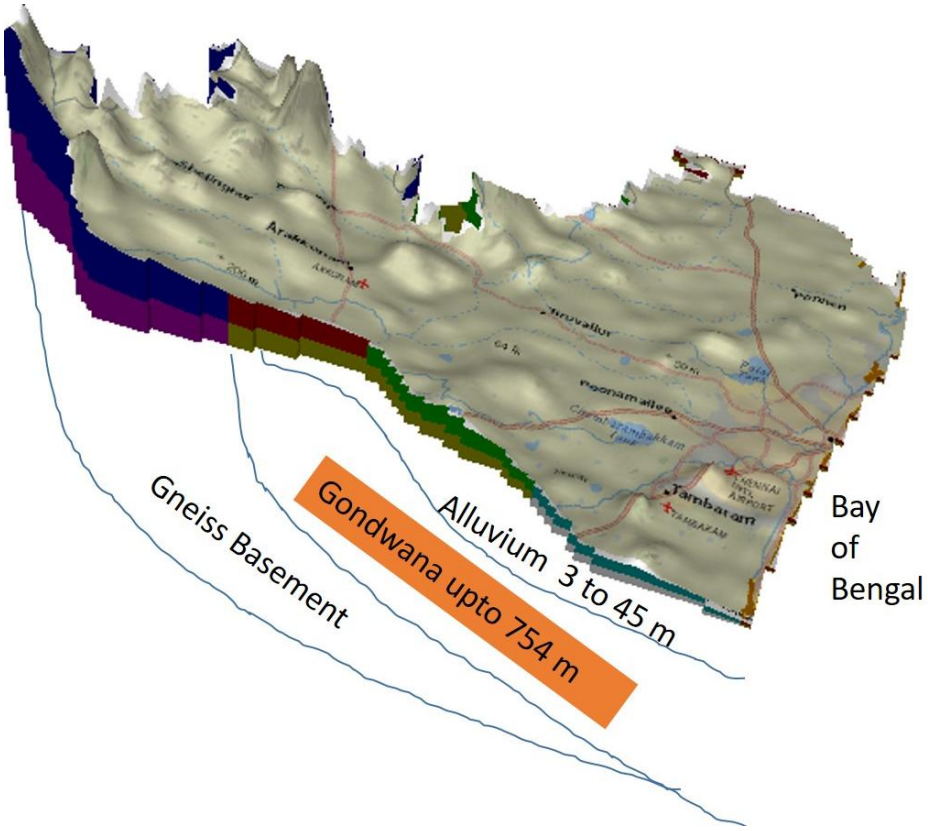

Figure 4 : Conceptual setup of Chennai Aquifer System.

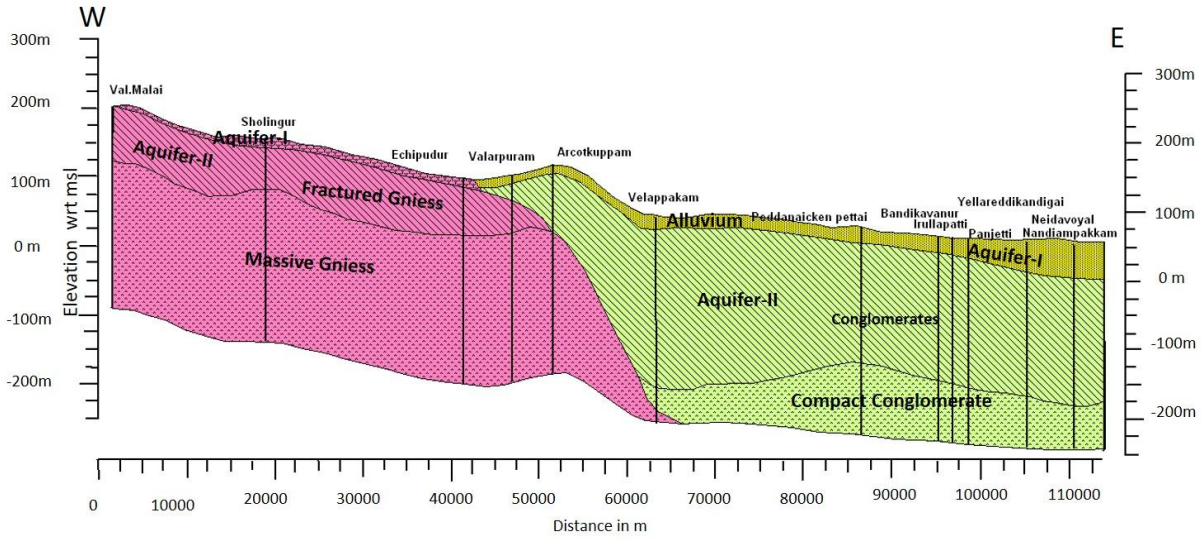

Figure 4a: Cross-section along West-East of Chennai aquifer system.

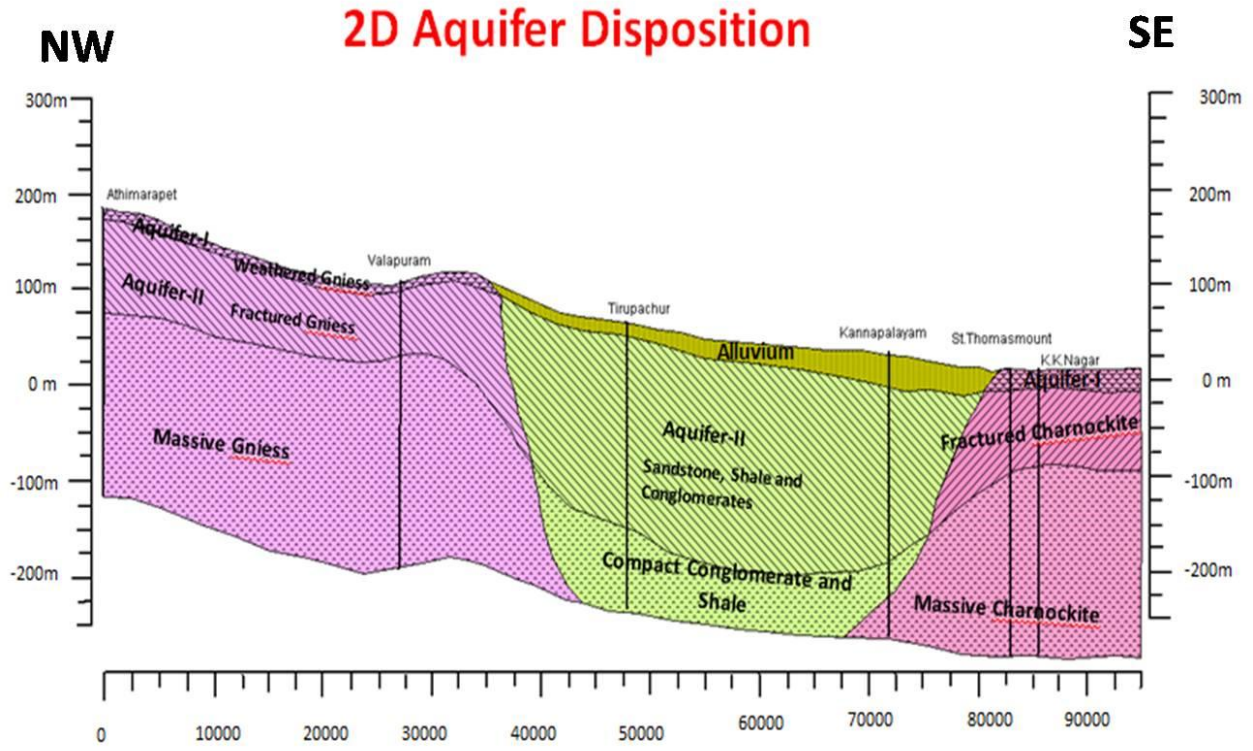

Figure 4b: Cross-section along northwest-southeast of Chennai aquifer system

12.0 BOUNDARY CONDITIONS

The study area the Chennai aquifer system is also a river basin. The boundary conditions modeled are as per the watershed boundary **(Figure 5).** The northern boundary is the state boundary and there is movement of flux in and out of the boundary, hence it was modeled as flux boundary. Southern boundary is bounded by the Palar river basin and forms a river basin boundary and hence it was modeled as no flow boundary. The eastern part of the study area is bounded by Bay of Bengal sea and hence it was modeled as a constant head boundary. Four seasonal rivers namely Arani, Korratalaiyar, Coovum and Adyar flow from the west to the east and was modeled using the river package.

The aquifer top and bottom were derived mainly based on the lithology of boreholes, geophysical logs and by intensive field surveys. The study area has been vertically divided into two layers. First unconfined layer is comprising of the top soil and quaternary alluvium in the eastern and central portion which is underlain by Conglomerates which occurs under confined/unconfined conditions. In the western and southern portion unconfined aquifer is the weathered portion of granitic gneiss and charnockites and this is further underlain by the fractured/jointed aquifer unit occurring under confined conditions. There are four major reservoirs situated in the model area and they are Poondi (Sathyamoorthy Sagar), Red Hills,

Sholavaram and Chembarambakkam. These water bodies were modeled using the general head boundary.

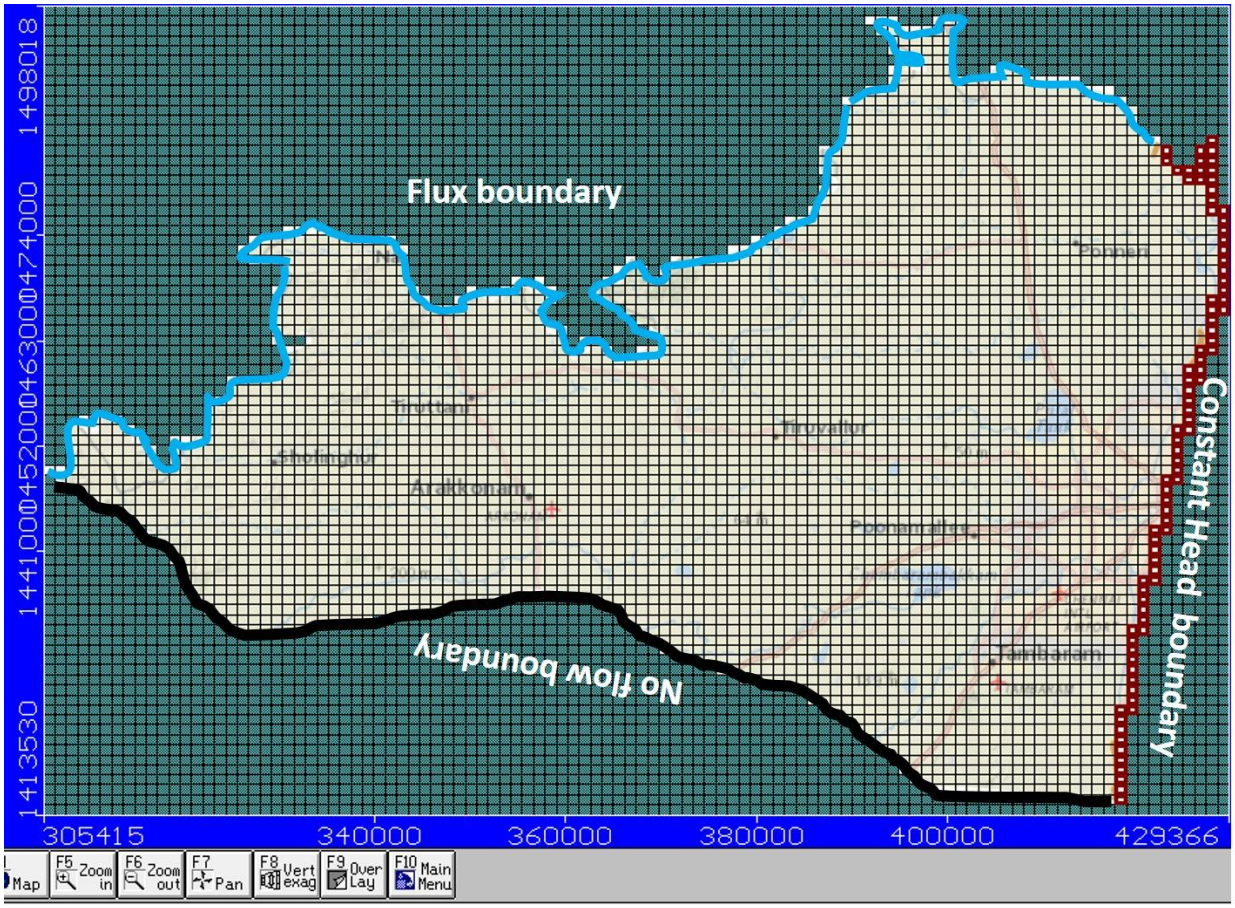

Figure 5 : Boundary conditions modeled for the Chennai aquifer system

13.0 GRID DESIGN

The geographic boundaries of the model grid covering 6288 km^2 of the study area were determined using the map module. The map was projected using the metric coordinates in the map module and then imported into the MODFLOW. The finite-difference grid superimposed on the study area was constructed based on the conceptual model representing the physical properties of the groundwater system. The gird network has a constant spacing 1.0 km by 1.0 km. The model grid are discretized into 120 rows and 80 columns, and vertically by 2 layers **(Figure 6).** The layer disposition along north south and west east is given in Figure 6.

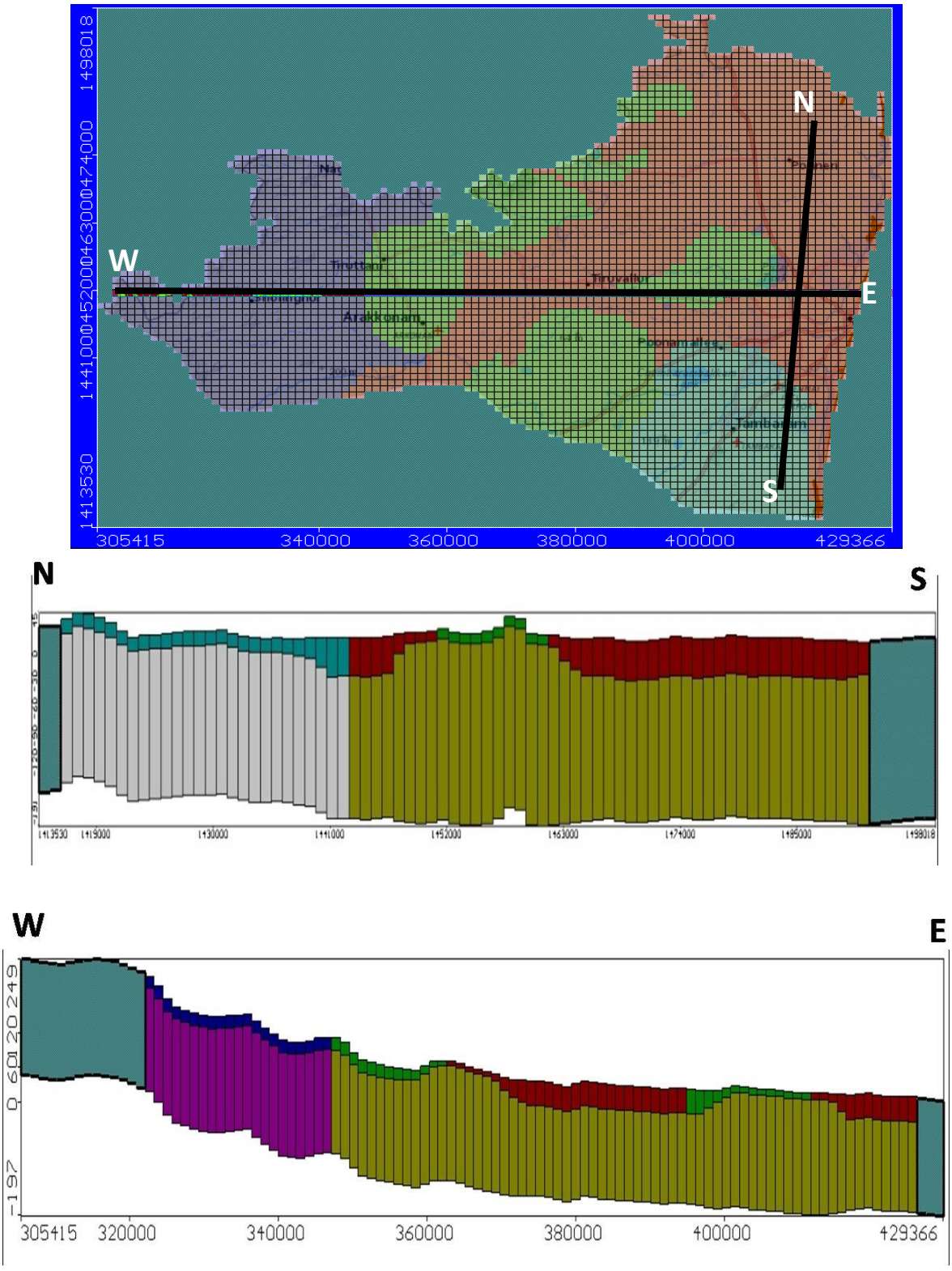

Figure 6: Grid Design of the Chennai aquifer system and vertical layer design along North South & West East direction

14.0 AQUIFER GEOMETRY

The aquifer geometry includes defining the aquifer top, bottom of Ist layer and bottom of IInd layer for all the cells **(Figure 7a, b & c).** They were mainly derived from the subsurface characterization using the lithologs and geological field work. The top elevation was derived from SRTM 30 m resolution data. 50000 points were randomly created within the boundary area and values of reduced level were extracted from the SRTM data. This data was crosschecked and validated from the available RL data of the exploratory wells in the study area. These values were extrapolated for the entire area considering the lithological variations and field study of well sections. The Ist layer is characterized by recent alluvium with a maximum thickness of 50m and is underlined by Gondwana conglomerate beds upto a depth of 300m. The western and southern portion comprise the hard rock aquifers. The thickness of the weathered aquifer units ranged from 8 to 30 m. The second aquifer unit for the hard rock regions ranged 8 to 190 m. Equis porous medium (EPM) approach was adapted for modeling the hard rock regions.

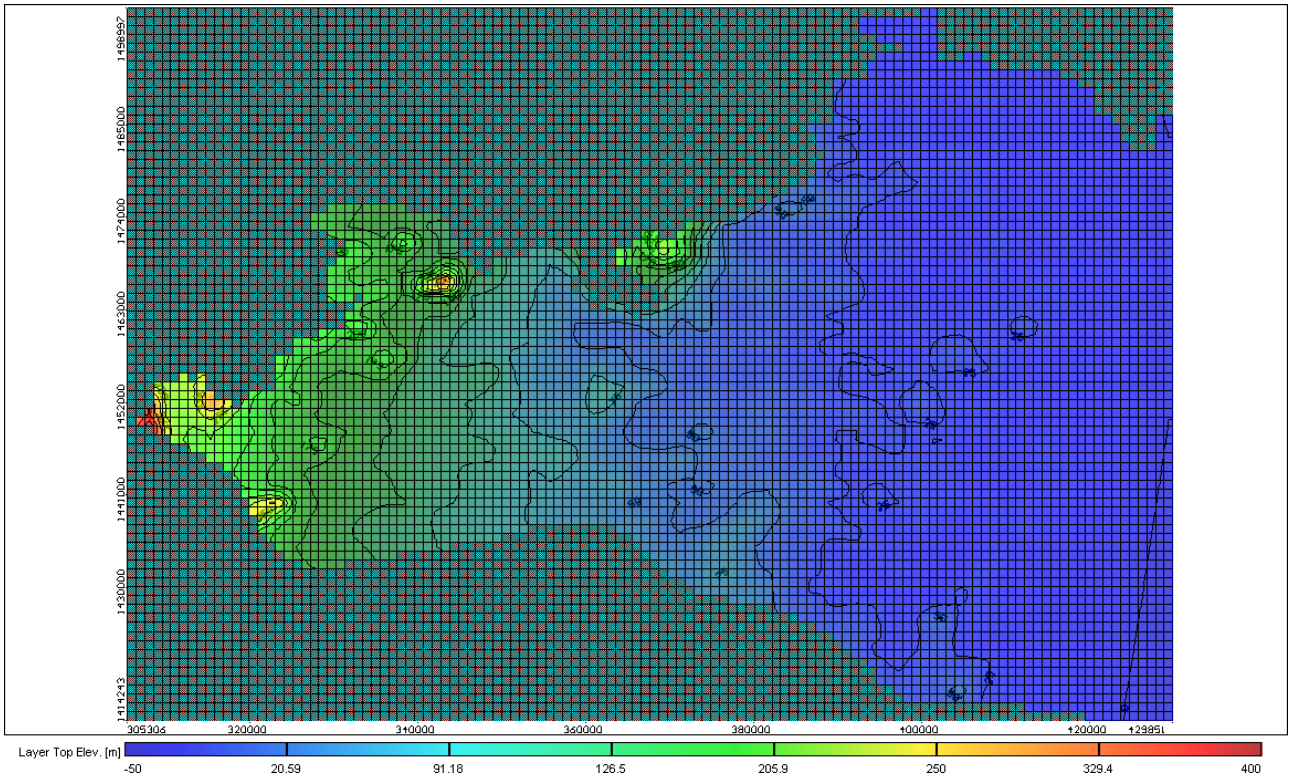

Figure 7a: Top elevation of the study area

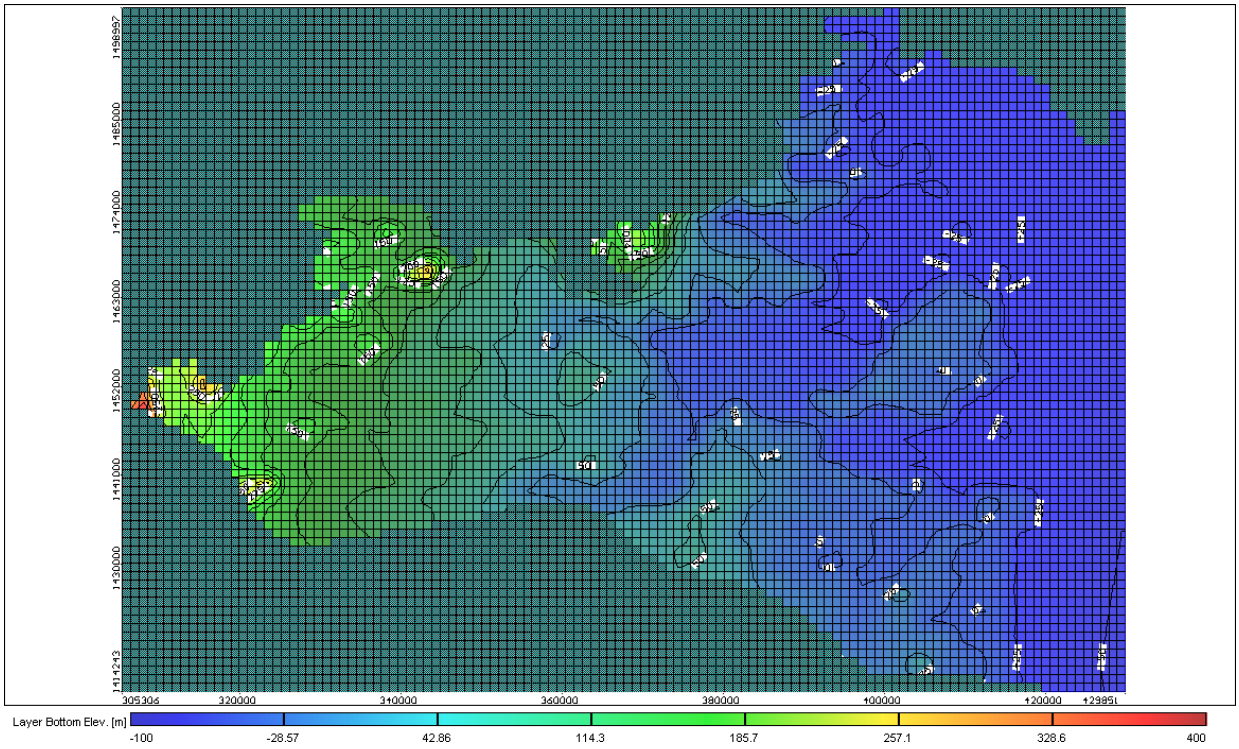

Figure 7b: Bottom elevation of the Ist layer of the study area

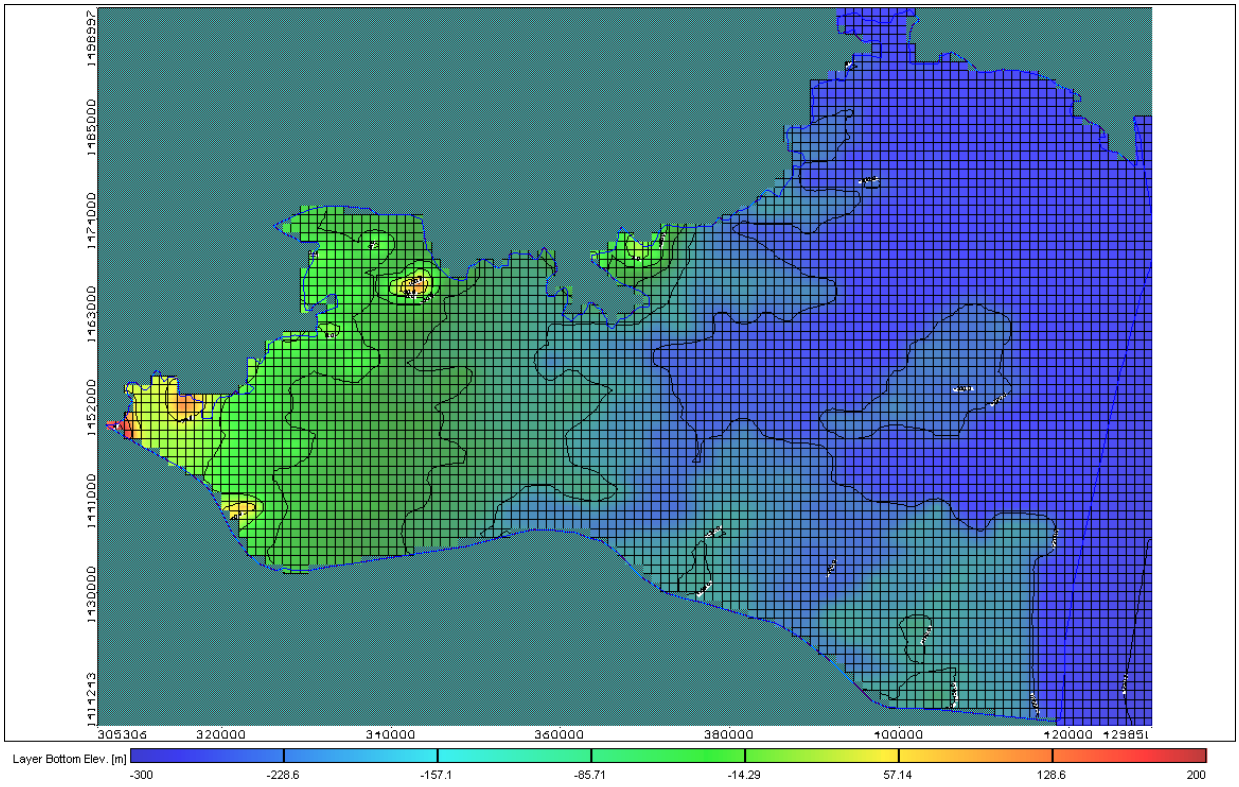

Figure 7c: Bottom elevation of the IInd layer of the study area

15.0 AQUIFER CHARACTERISTICS

The aquifer properties such as horizontal hydraulic conductivity and specific yield and specific storage used in the model were derived from 43 pumping tests results and are given in the **Annexure -II**.

In steady-state groundwater flow, the water – level distribution and groundwater flux is controlled by hydraulic conductivity (K), which depends on the intrinsic permeability of the porous media and the density and viscosity of the fluid. Hydraulic conductivity (Kx, Ky & Kz) used in the model for the layer 1 is represented in **Figure 8a.** The hydraulic conductivity values range for the alluvial areas is 40 m/d while for the conglomerate (Gondwana formation) it was 2 m/d. For weathered granitic gneiss values ranged from 6 to 8 m /d while the values for weathered charnockitic regions ranged from 4 to 6 m/d.

The hydraulic conductivity values used in the model for layer 2 is represented in **Figure 8b**. The hydraulic conductivity value considered for the conglomerate (Gondwana formation) was 1 m/d. For the fractured and jointed granitic gneiss and charnockitic regions it was considered to be 3 m/d.

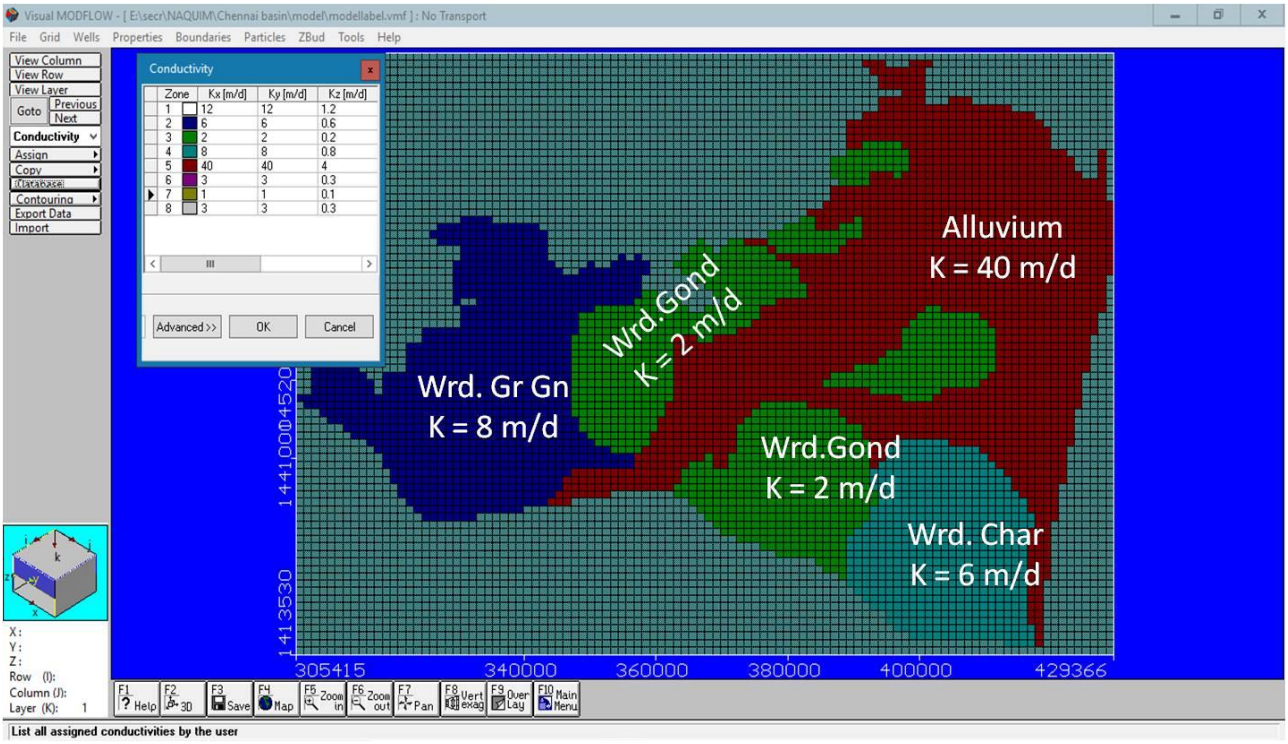

Figure 8a: Hydraulic conductivity values used in the model for layer 1.

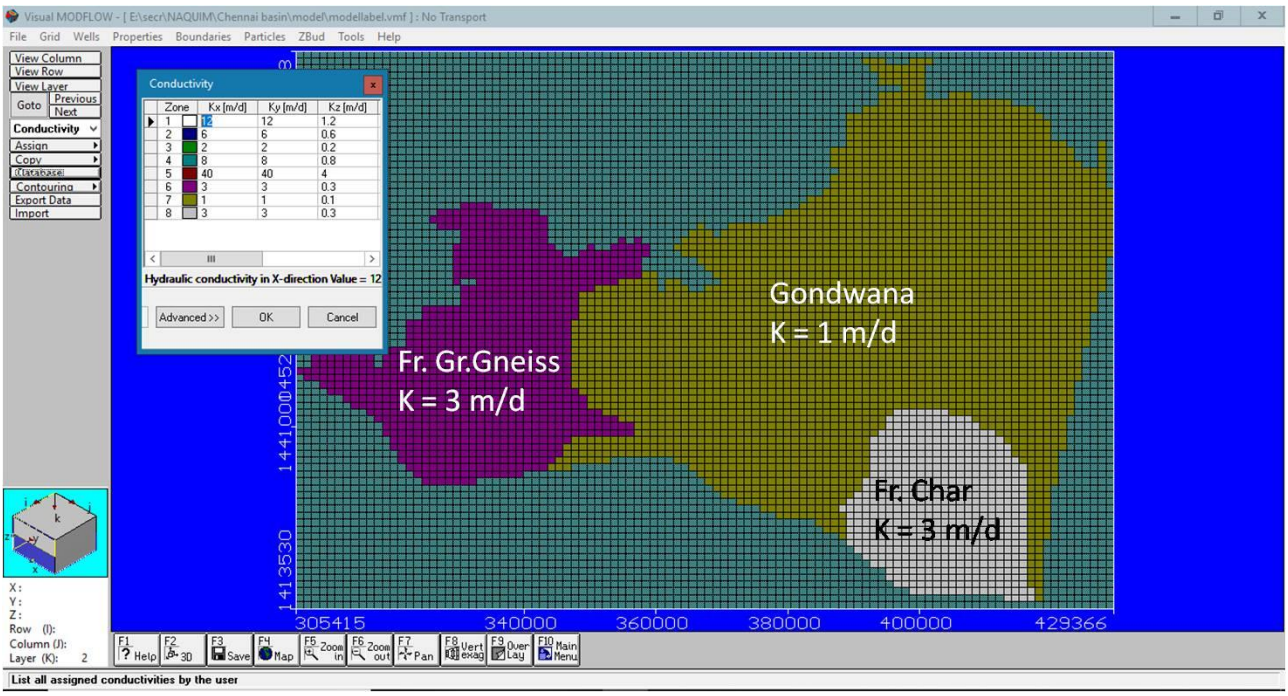

Figure 8b: Hydraulic conductivity values used in the model for layer 2

Specific yield values used in the model for the layer 1 is represented in **Figure 9**. The Specific yield (sy) values ranges from 15 to 20 % for the alluvial areas while for the conglomerate (gondwana formation) it was 1%. A small portion in the central and north-central part had laterite capping on the conglomerate formation. The thickness of these laterite beds ranged from 6 to 8 m. the Specific yield value of 4 % was considered for this formation. For the weathered granitic gneiss the specific yield values of 1.5 % was considered while the weathered charnockitic regions if was 1 %.

For the layer 2 Storativity values of 0.003 for the fractured/jointed granitic gneiss and charnockite was considered. The Gondwana formation comprising of conglomerates the storativity value of 0.002 was considered.

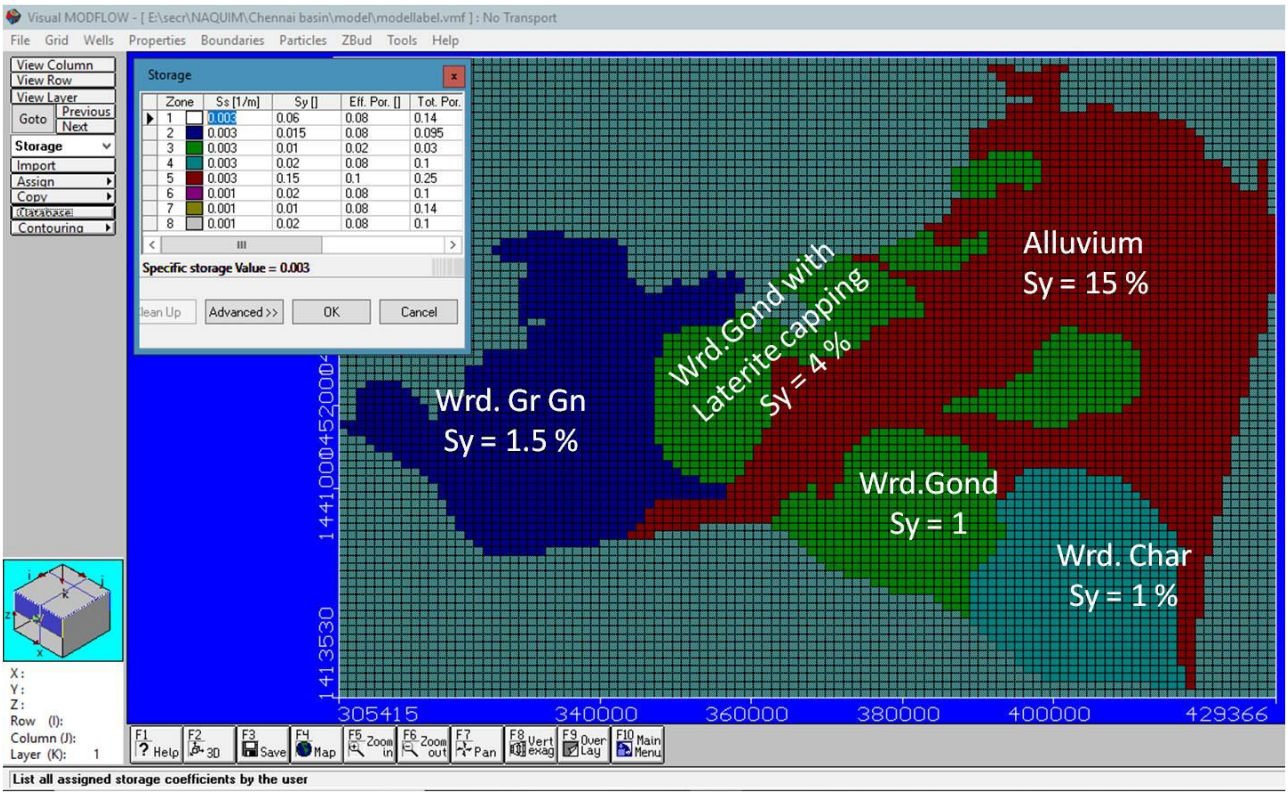

Figure 9: Specific yield values used in the model for layer 1

16.0 INITIAL GROUNDWATER HEAD

The initial groundwater head of the Chennai aquifer system is shown in **Figure 10**. After detailed analysis of the hydrographs, rainfall and water level fluctuation, it was decided that the groundwater head data of Jan 2010 represents the spatial groundwater distribution of the study area. The during this period the rainfall was also normal and the groundwater fluctuation was representative of the normal year.

17.0 GROUNDWATER ABSTRACTION

The discharge from Chennai aquifer occurs as withdrawals by irrigation, industrial and public-supply wells. The public supply wells include drinking and domestic needs of the people of the area as well as supply to Chennai city. Agriculture activity of the study area is mainly dependant on groundwater resource available in the area, there is no canal network in the study area. The landuse pattern, drainage pattern and the period of flow of water in the river shows that groundwater is used only during the summer period (one season) in the study area. The domestic and drinking water requirement of the study area was calculated based on the population. The total annual draft of the Chennai aquifer system is about 899 mcm/yr **(Table 3a**). The major draft of groundwater is from the aquifer unit 1 and is about 754 mcm annually. The second aquifer unit (aquifer II) has a groundwater draft of 154 mcm annually **(Table 3b**). The groundwater draft has been calculated by using landuse data, electricity consumption data and yield of the wells. The groundwater data and calculated sheet for layer 1 is attached as **Annexure IIIa** and for layer II is attached as **Annexure IIIb**. Spatial distribution of the groundwater abstraction structures in the model area is

represented in **Figure11a**. The layer wise distribution of groundwater abstraction structures is represented in **Figure 11b**.

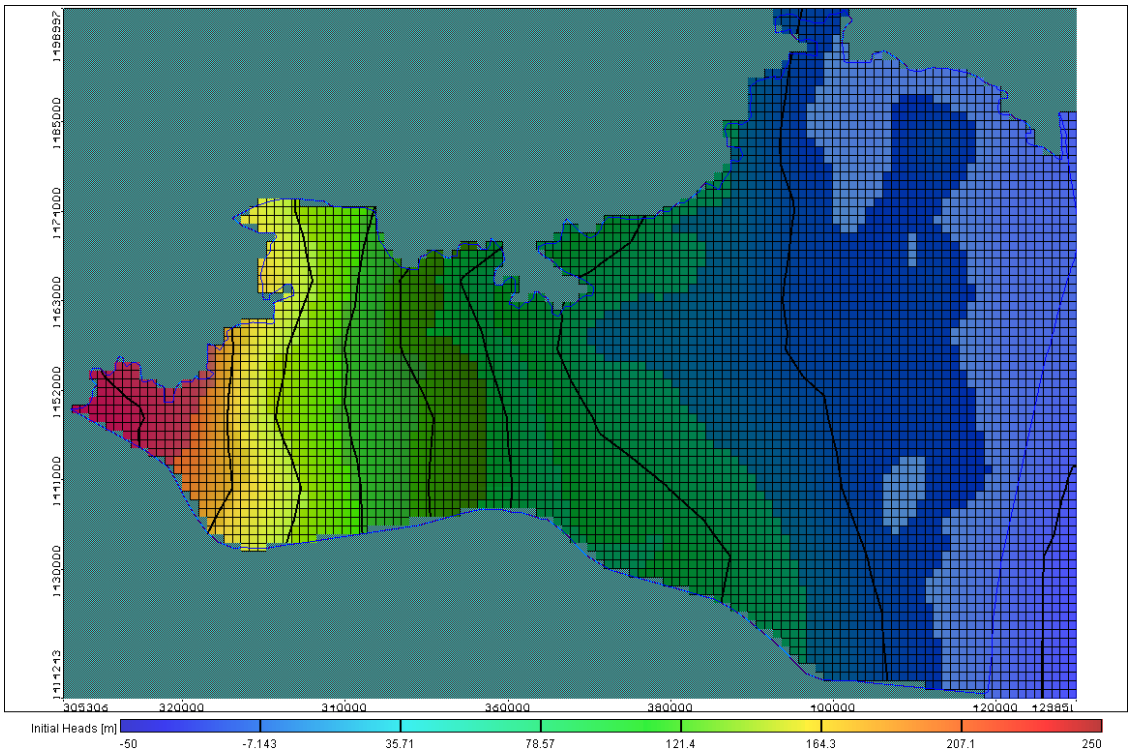

Figure10: Initial groundwater head values used in the model for layer 1

Table 3a: Total annual draft of the Chennai aquifer system

District	BW	DCB	DW	Total all wells	Total Draft (mcm/yr)
Chennai	11672	788	1245	13705	**27.68**
Kancheepuram	31619	6576	37517	75712	108.03
Tiruvallur	78498	1371	13516	93385	491.47
Vellore	6391	3759	24882	35032	171.56
Total	116508	11706	75915	204129	**898.74**

Table 3b: Aquifer wise annual draft of the Chennai aquifer system

Aquifer unit	Total draft (mcm/yr)
Aquifer 1	745
Aquifer II	154
Total draft	899

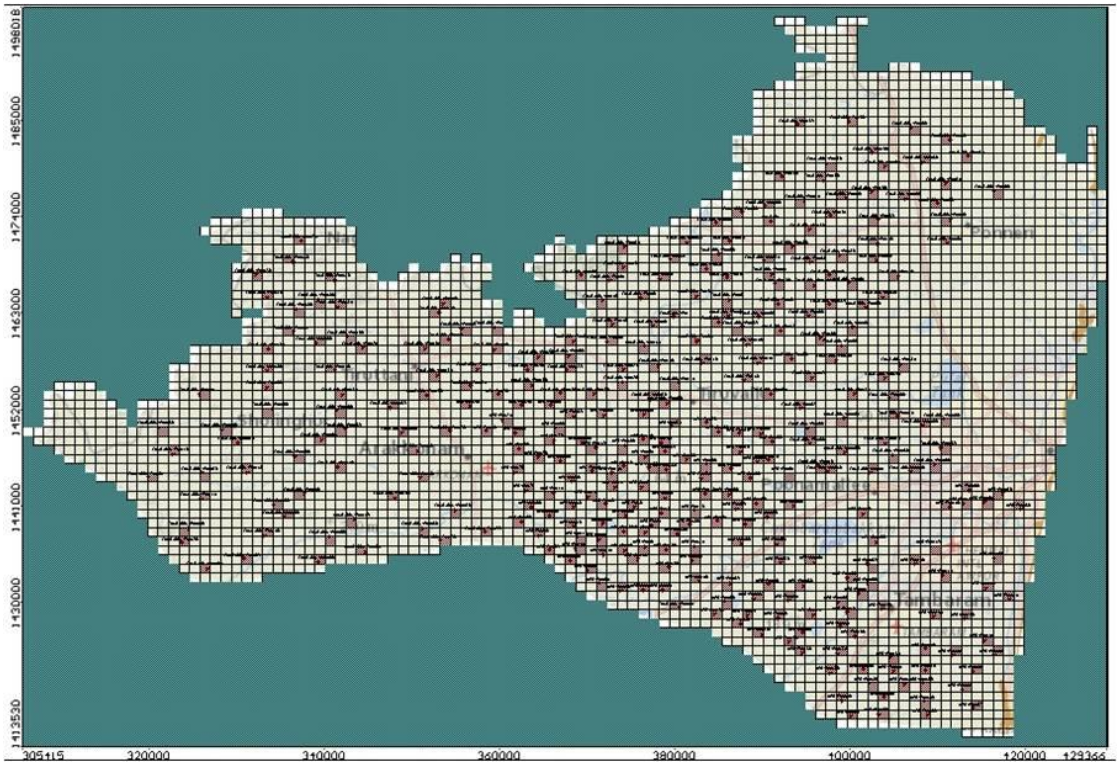

Figure11a: Spatial distribution of groundwater abstraction structures for layer 1

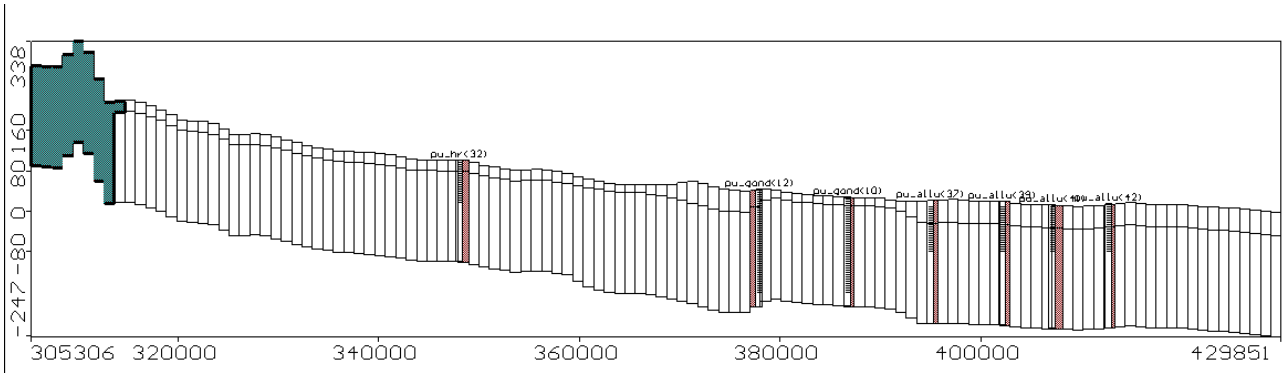

Figure11b: Vertical distribution of groundwater abstraction structures for layer 1

18.0 GROUNDWATER RECHARGE

The recharge of the Chennai aquifer system varies considerably due to differences in land use pattern, soil type, geology, topography and relief. The recharge to the aquifer system is from rainfall, irrigation and inflow from the river and storage tanks. Rainfall is the principal source of groundwater recharge. The rainfall hydrograph were studied to understand the recharge pattern in the study area. The aquifer gets recharged and groundwater level shoots with rainfall above 45 mm. The entire portion of the study area is geologically characterised by alluvial, laterite, conglomerates, weathered granitic gneiss and charnockites. The infiltration capacity of the formations range from 0 – 14% (Groundwater resources estimation committee report, 1997). **Table 4** shows the rainfall infiltration factor used in modeling for groundwater recharge calculation.

Table 4: Rainfall vs infiltration factor used in groundwater recharge calculations.

s.no	Rainfall (mm)	Infiltration factor (%)		
		Alluvium	Laterite	Weathered gr.gniess/ charnockite
1	0 -45	0	0	0
2	45 -100	10	6	4
3	100 -200	12	8	6
4	200 -300	14	10	8
5	300 -400	12	8	6

The rate of leakage between the river and aquifer was estimated using the difference between the river head and groundwater head. The rivers situated in the study area and its contribution to groundwater recharge was calculated based in the difference between the head in the adjoining wells and reservoir head. The river head data was one input parameter into the model. Similarly the recharge from water bodies was also estimated using the difference between the water bodies and groundwater head.

Five recharge zones have been demarcated in the study area and they comprise of zone 1 Alluvial areas, zone 2 Conglomerate zones, zone 3 – laterite capping on conglomerates, zone 4 – granitic gneiss areas and zone 5- charnockitic area shown in **Figure 12**.

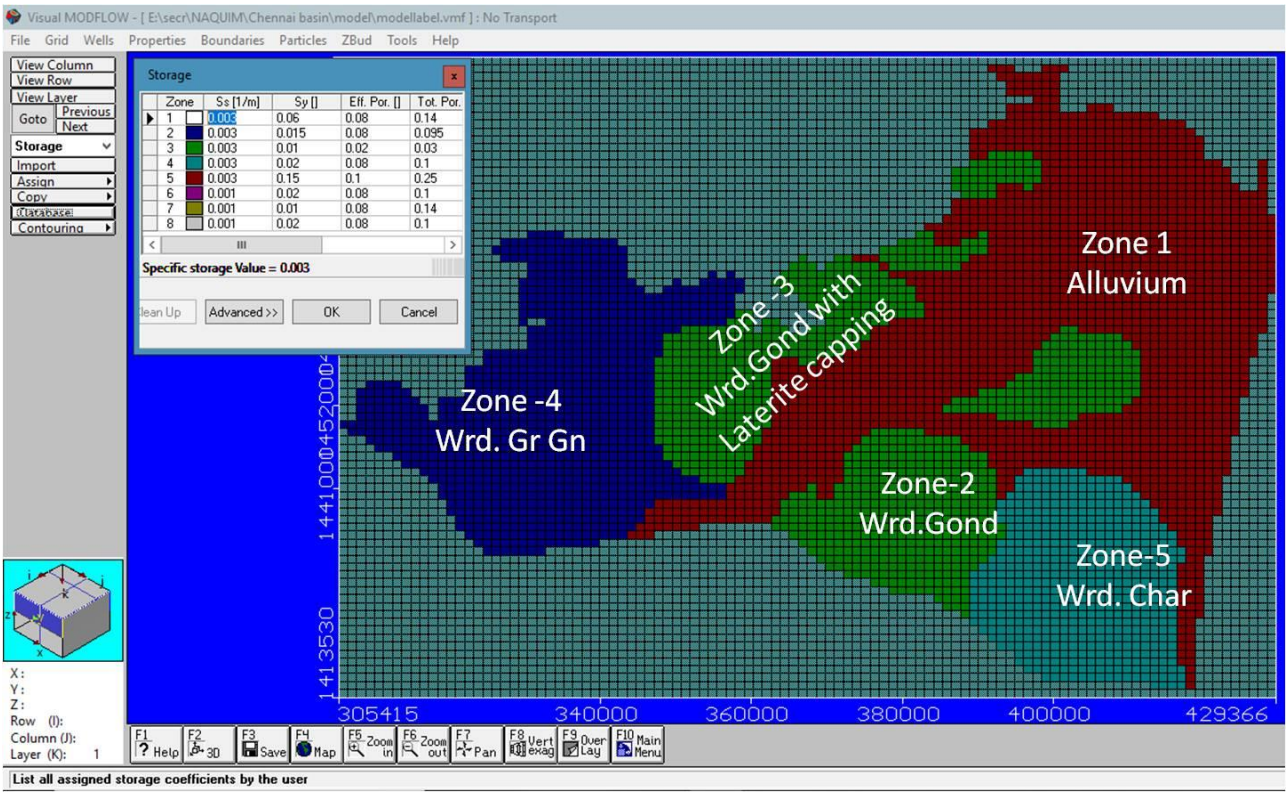

Figure12: Groundwater recharge zones of the model area

19.0 GROUNDWATER FLOW

The hydrostratigraphic framework of the aquifer that supports the groundwater flow system is composed of an unconfined aquifer system (recent alluvium) and underlined by the confined aquifer systems of Gondwana sandstone composition and weathered and fractured hard rock regions in the west and south.

20.0 HYDROGEOLOGICAL MODELLING

Hydrogeological modelling involves representation of the subsurface system in order to simulate groundwater flow and transport of solutes. The general three-dimensional groundwater flow defined by a partial differential equation can be solved mathematically using the two major classes of numerical methods. They are the finite-difference and finite-element methods. In the present study, groundwater flow of the study area was simulated using the finite-difference method of approximation. Finite-difference methods approximate the first derivatives in the partial differential equations as difference (the differences between values of independent variables at adjacent nodes with respect to the distance between the nodes, and at two successive time levels with respect to the duration of the time step increment). These derivatives (or slopes of curves) are approximated by discrete linear changes over discrete intervals of space or time. If the intervals are sufficiently small, then all of the linear increments will represent a good approximation of the true curvilinear surface or hydrograph (Konikow and Reilly 1998).

21.0 GROUNDWATER FLOW EQUATION

Anisotropic and heterogeneous three-dimensional flow of groundwater, assumed to have constant density, and described by the partial-differential equation given by Rushton and Redshaw (1979) was used to model the groundwater flow in this study

$$\frac{\delta}{\delta x} K_{xx} \frac{\delta h}{\delta x} + \frac{\delta}{\delta y} K_{yy} \frac{\delta h}{\delta y} + \frac{\delta}{\delta z} K_{zz} \frac{\delta h}{\delta z} - W = S_s \frac{\delta h}{\delta t}$$

Where,

K_{xx}, K_{yy}, K_{zz}	-	components of the hydraulic conductivity tensor
h	-	Potentiometric head
W	-	Source or sink term,
S_s	-	Specific storage
t	-	time

22.0 MODELLING PROTOCOL

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

- Data collection, acquisition and processing of primary data
- Conceptual model building
- Numerical model building
- Model application
- Result generation

These steps are given in a form of a flowchart **(Figure 13).**

23.0 COMPUTER CODE

The computer software program MODFLOW (McDonald and Harbaugh 1998) developed by the United States Geological Survey (USGS) was used for the present study. The computer program uses the finite-difference technique and block-centered formulation to solve the groundwater flow equation for the three-dimensional steady and transient flow in heterogeneous media. The pre and post processor, Visual Modflow Classic was used to give input data and process the model output. Modelling studies were carried out in the Central Ground Water Board, SECR Chennai office.

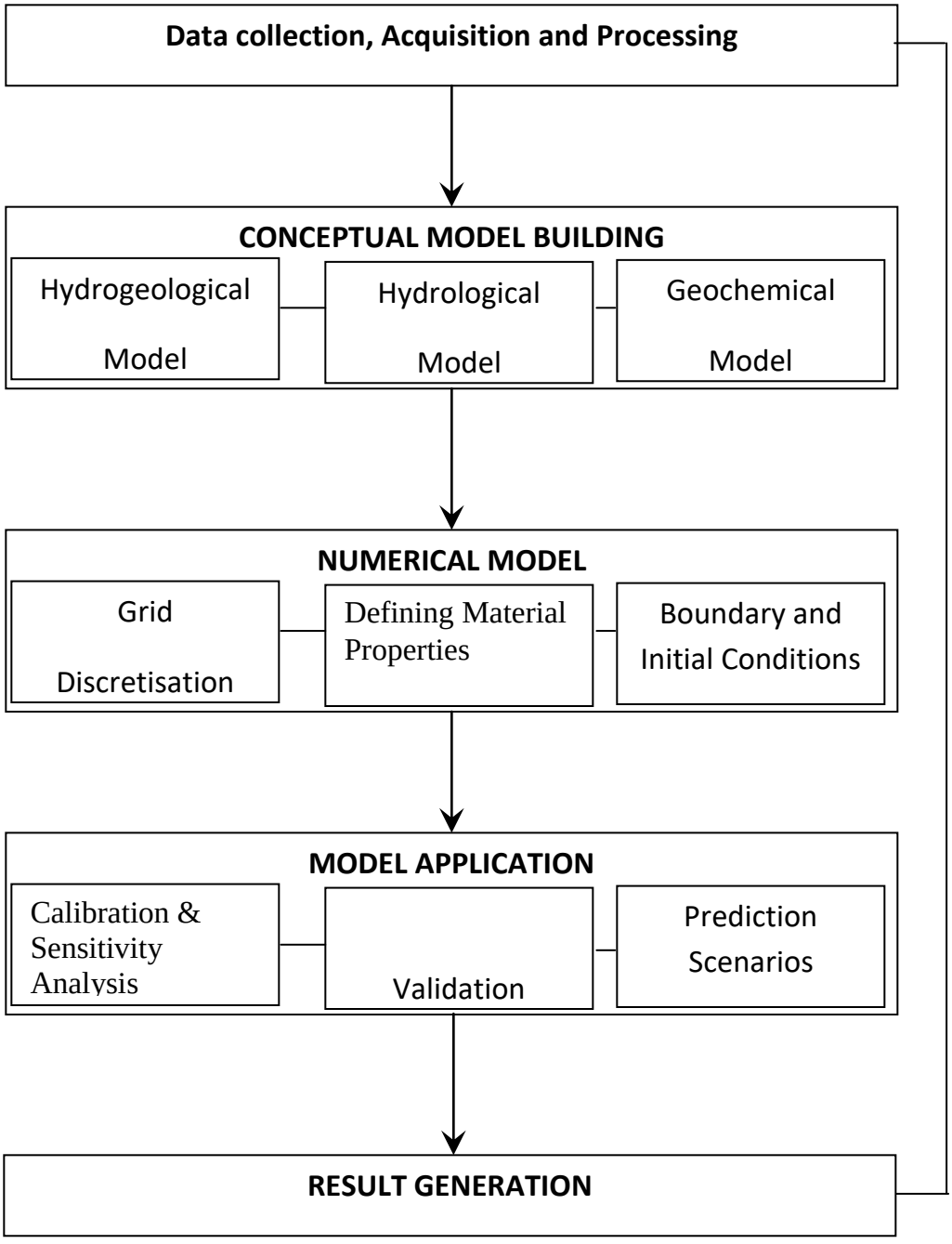

Figure13: Flowchart of the groundwater modeling of Chennai aquifer system

24.0 MODEL CALIBRATION

The calibration strategy was to initially vary the best known parameters as little as possible, and vary the poorly known or unknown values the most to achieve the best overall agreement between simulated and observed. Steady state model calibration was carried out to minimize the difference between the computed and field water level condition. Steady state calibration was carried out with the water level data of Jan 2010 in 28 wells distributed over the study area. Out of all the input parameters, the hydraulic conductivity value is the only poorly known as only 43 pumping tests have been carried out in this area. The lithological variations in the area and borehole lithology of existing large diameter wells were studied. Based on this it was decided to vary hydraulic conductivity values upto 10% of the pumping test results for layer in order to get a good match of the computed and observed heads (**Figure 14a & b**). The figure indicates that there is a very good match between the calculated and observed water heads in most of the wells of the study area. Root mean square error and the mean error were minimized through numerous trial runs.

Transient state simulation was carried out for a period of 9 years from Jan 2010 to Dec 2018 with monthly stress periods and 24 hour time step. The trial and error process by which calibration of transient model was achieved by several trials until a good match between computed and observed heads over space and time. The hydraulic conductivity values incorporated in the transient model were modified slightly from those calibrated by the steady state model. Based on the close agreement between measured and computed heads from Jan 2010 to Dec 2018 at 28 observation wells distributed through out the aquifer (**Figure14b**), the transient models were considered to be calibrated satisfactorily. The sensitivity of the model to input parameters were tested by varying only the parameter of interest over a range of values and monitoring the response of the model by determining the root mean square error of the simulated heads compared to the measured heads.

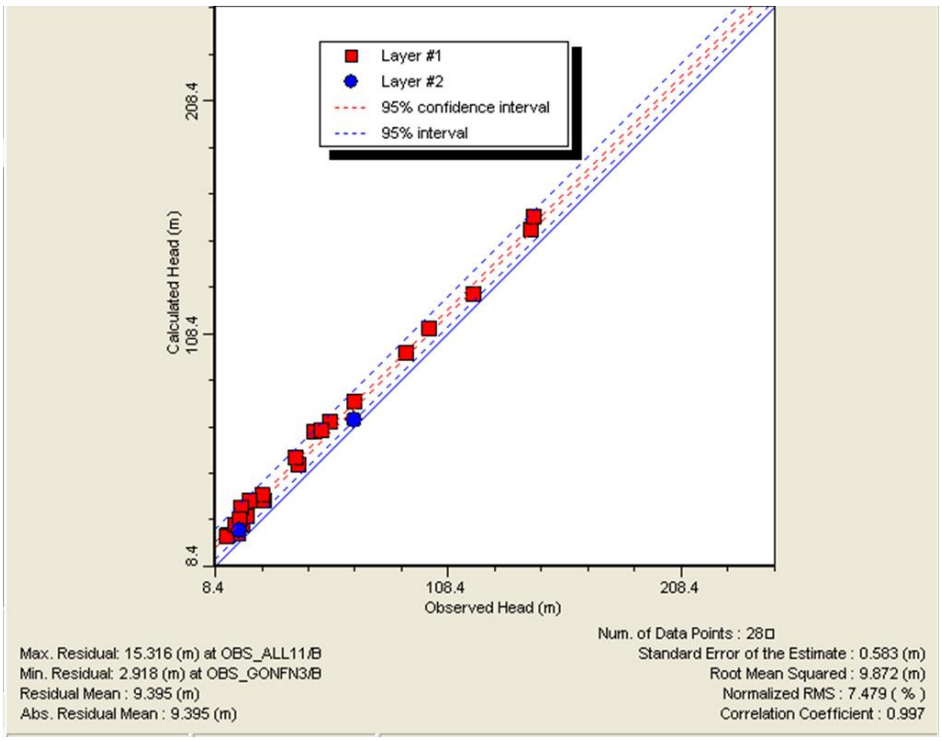

Figure 14a: Comparison of computed & observed GW head under steady state condition.

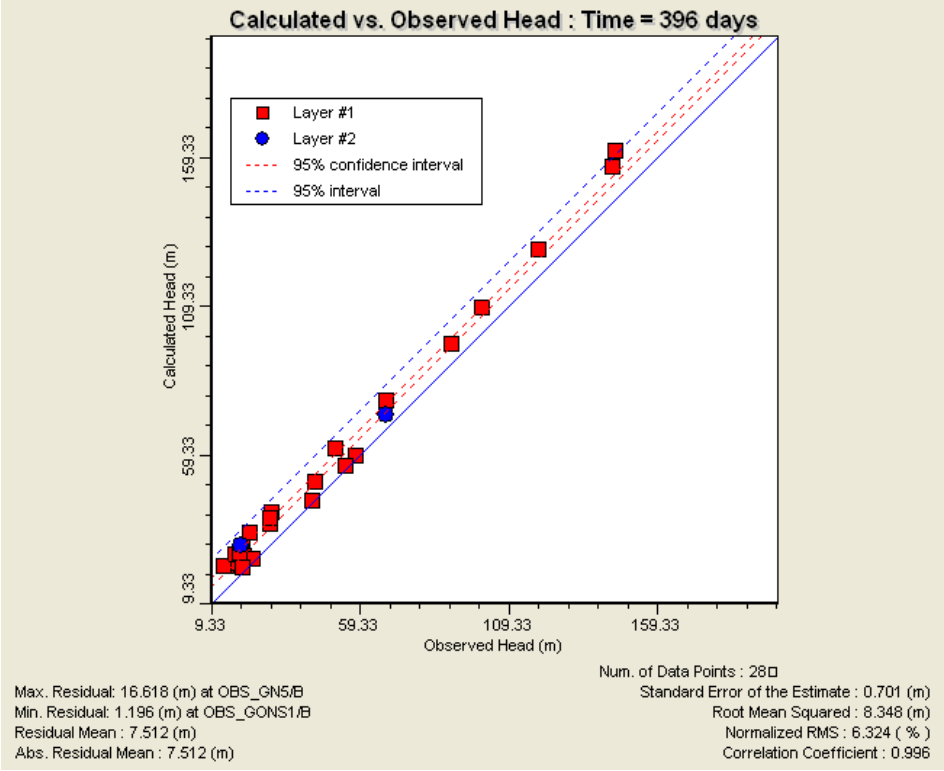

Figure 14b: Comparison of computed & observed GW head under transient state condition

25.0 MODEL SIMULATION RESULTS

The model was simulated in transient condition for a period of 8 years from Jan 2010 to Dec 2018. There was fairly good agreement between the computed and observed heads **(Figure15).** A study of the simulated potentiometric surface of the aquifer indicates that the highest heads are found on the western side of the study area, which is a general reflection of the topography. The regional groundwater flow direction is from west to east. Simulated groundwater head for the Chennai aquifer system (Figure 15) shows that groundwater flow in the hard rock regions are different from the groundwater flow in the alluvial formation in the east. Northcentral and western part of the study area have dry cells.

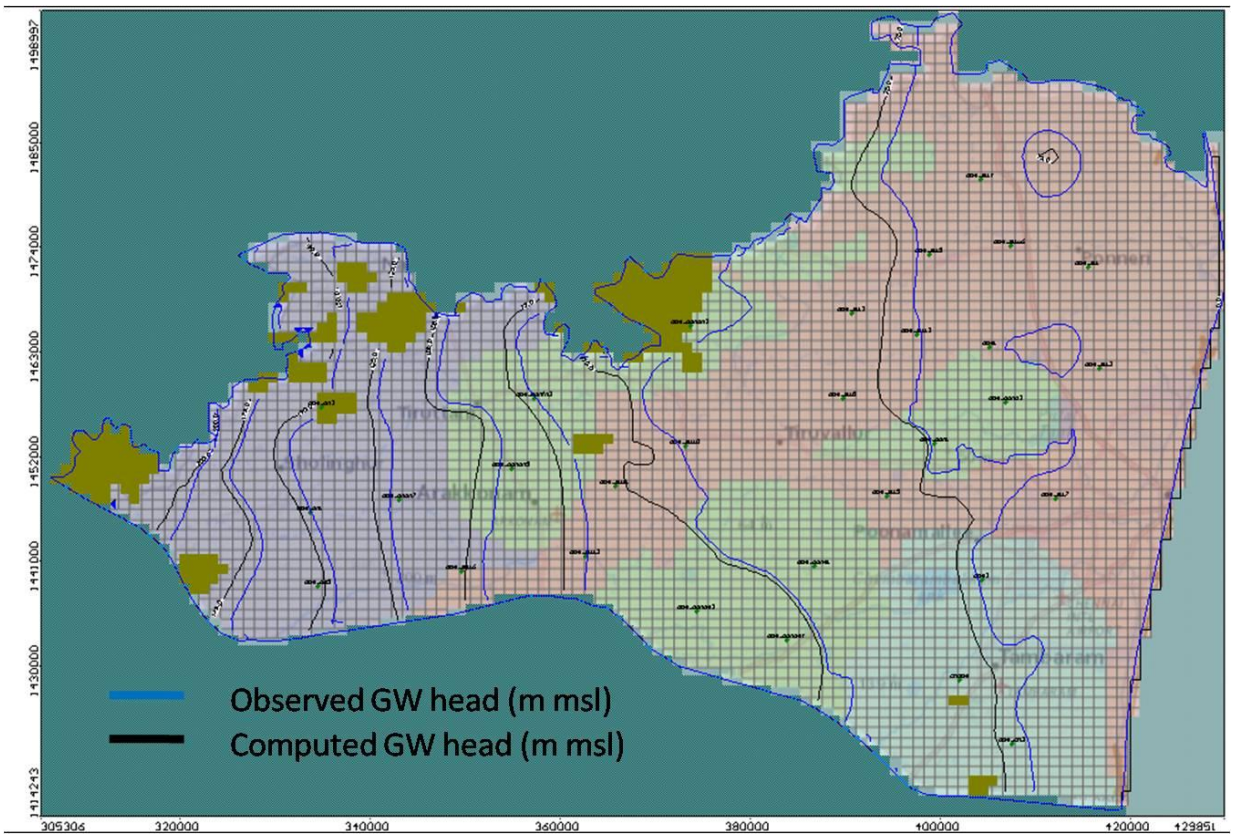

Figure15: Simulated and observed groundwater head during May 2014.

The aquifer system is under tremendous stress due to the heavy groundwater withdrawal. The groundwater flow vectors for the month of July & December **Figure 16a & b**. These vectors clearly indicate the irregular pattern of the vectors during the month of December and regular flow vector during the summer period **(Figure 16a & b).** Eastern portion the flow towards the sea is also observed from the groundwater vectors. Reversal of flow vectors is also observed in the May month which is an indication of the seawater intrusion in the eastern part of the Chennai aquifer system.

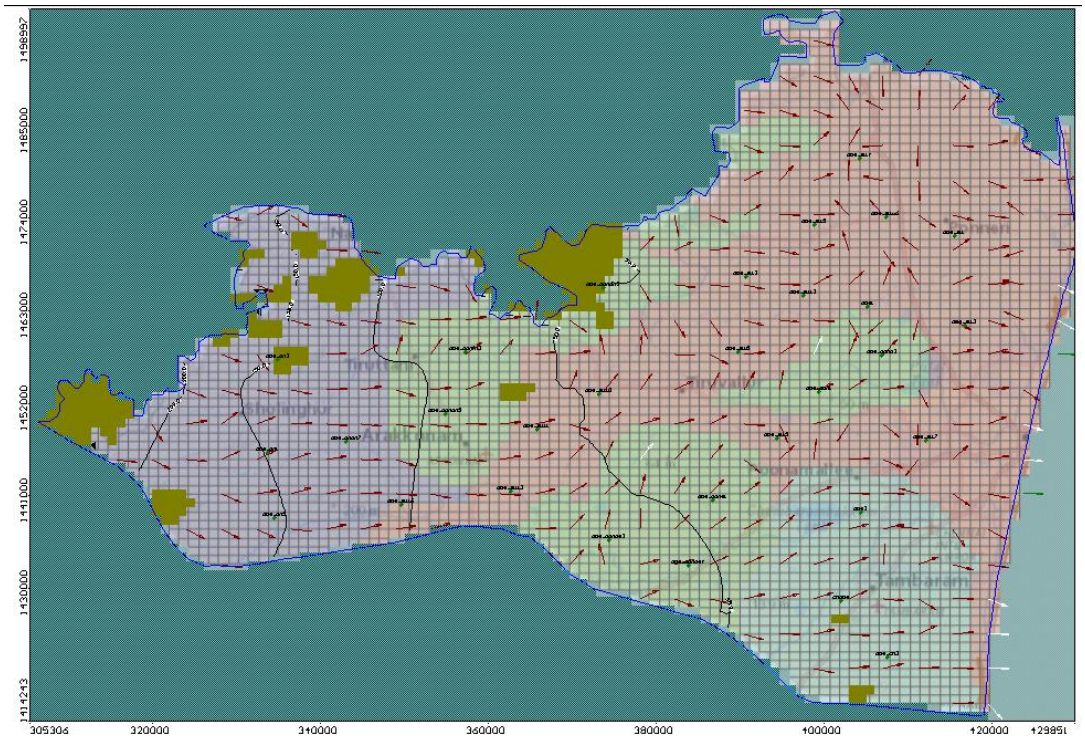

Figure16a: Groundwater flow vectors during May 2014.

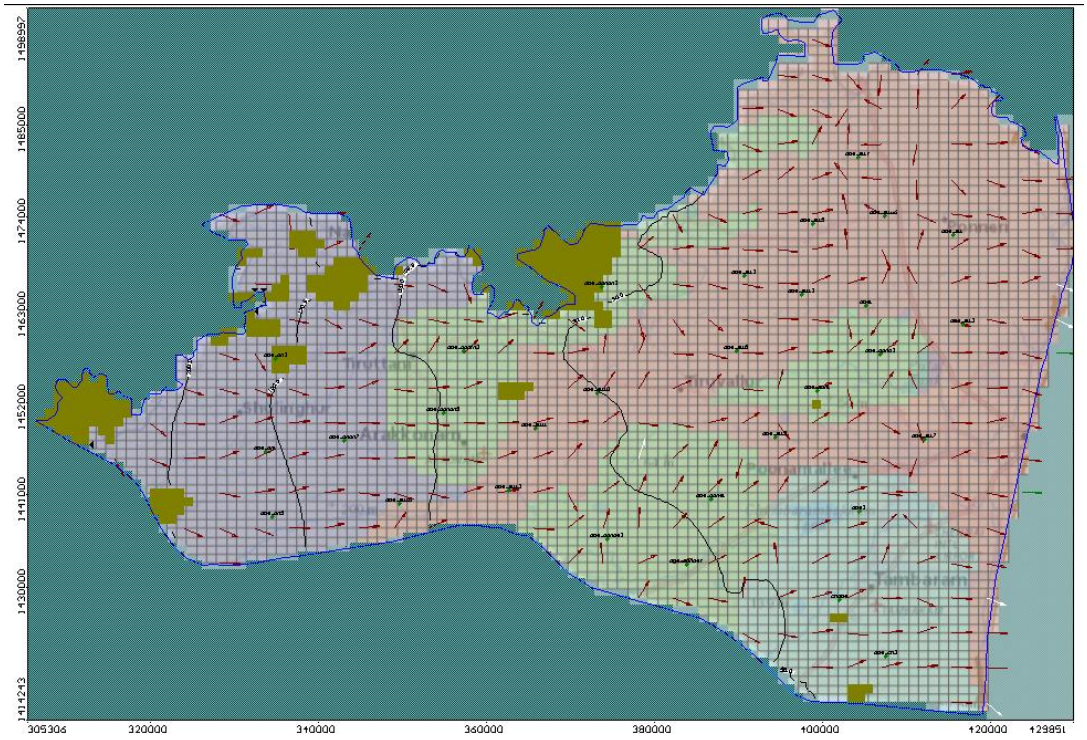

Figure16b: Groundwater flow vectors during December 2014.

Cross-section view of the groundwater flow and heads along the west to east is represented in **Figure17**. The groundwater head follows the topography. High groundwater heads are

observed in the western part of the Chennai aquifer system and gradually low heads in the eastern part.

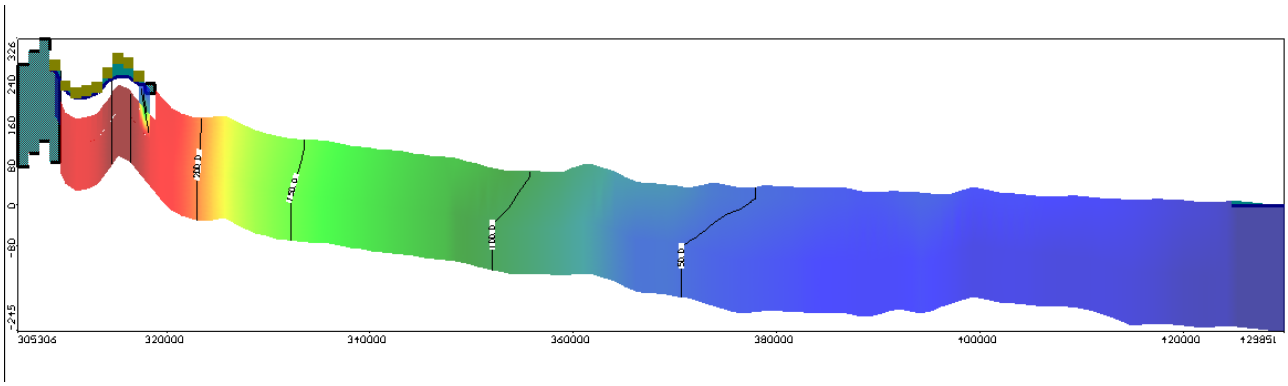

Figure 17. Cross section view of GW heads from West to East.

26.0 MODEL FORECAST AND AQUIFER MANAGEMENT PLAN FORMULATION

The aquifer response for different input and output fluxes was studied in order to sustainably manage the aquifer system. The model was run for a further period of 07 years from 2018 to 2025. Before commencement of this simulation, the data of average rainfall, abstraction, water bodies, river flow and recharge was provided to the model upto 2025.

Four prediction runs were planned to evolve optimal management schemes for the Chennai aquifer system, they are

- Projected groundwater head by 2025 with present pumping conditions
- Projected groundwater head by 2025 with increase of 10 % & 25 % pumping
- Projected groundwater head by 2025 with supply side interventions suggested. Increase in 54 mcm of recharge annually.
- Projected groundwater head by 2025 with 120 days flow in rivers and construction of a canal connecting two river Arani and Korratalaiyar

Normal rainfall and present pumping condition

The model was run to predict the regional groundwater head in this area until the year 2025. For these runs the monthly average rainfall calculated from 40 years rainfall data was used. The present level of groundwater abstraction was considered for this simulation. The simulated regional groundwater head for September 2025 is shown in **Figure18.** There is not much increase or decrease in water level (Figure 18). Such observation is made in most of the locations.

Increase in pumping

As groundwater is the major source of water for the agriculture, industries and domestic water supply located in this region, there has been an increase in pumping over the years. Hence, it is essential to know the behaviour of the system under increased hydrological stress. There are two major anticipated changes in the pumping pattern in future, the first being the possible increase in pumping 10% to meet the increasing demand for the expansion of its

activities, and the second being the increase in 25 % pumping for various uses over the entire area **(Table 5).**

Table 5: Projected increase in groundwater withdrawal for various sectors

Aquifer unit	Present GW draft (mcm/yr)	10 % increase in GW draft by 2025 (mcm/yr)	25 % increase in GW draft by 2025 (mcm/yr)
Aquifer 1	745	820	930
Aquifer II	154	170	192
Total draft	899	990	1122

Figure 18 clearly shows the impact of the increase in pumping by 10 % and 25 % by the year 2025. Black coloured contour line representing the projected groundwater head with present pumping condition for 2025, maroon coloured contour line representing 10 % and red contour line representing 25 % increase in groundwater pumping by 2025. The western movement of the contour line clearly indicates the decrease in groundwater head in alluvial regions of the Chennai aquifer system. With east side having a coastal boundary and already seawater intrusion is observed in the study area (Senthilkumar, 2018). Increase in groundwater draft by 25 % by 2025 will be more devastating and contour also indicate the western movement. This will further increase in the inward movement of saline water during the summer periods. Further, increase in groundwater abstraction should be regulated, demand side interventions should be implemented in the region for sustainable management of the available groundwater resources.

Supply side interventions through recharge measures

On the basis of aquifer mapping report of the Chennai aquifer system supply side interventions were formulated for the 38 OE firkas of the Chennai aquifer system. Based on the water level monitoring in different seasons across the basin, as well as after having better understanding of the disposition and extent of the aquifer system through exploratory drilling, pumping tests etc., the potential volume of void space available within the weathered zone of first aquifer of the basin has been estimated as 470 MCM. But the annual uncommitted runoff is only 242 MCM which is less than 50% of required water to fill the available void space of Aquifer-I. Artificial recharge and Water conservation plan is prepared for the over exploited firkas of the basin area through harnessing just less than 40% of the annual uncommitted runoff of 54 MCM only with a total out lay of 56Crore rupees.

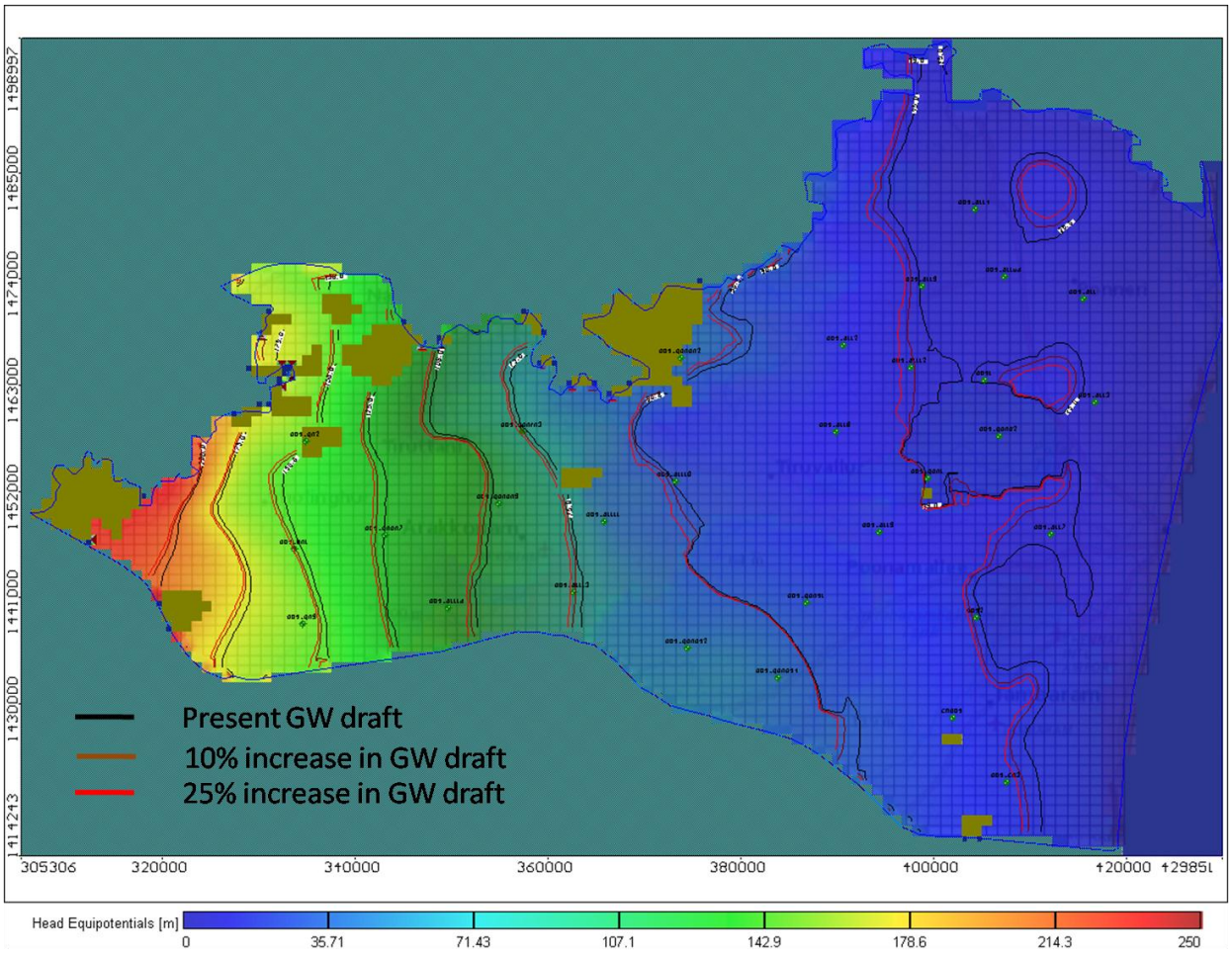

Figure18. Projected GW heads during 2025 with present and increase in GW draft.

The suggested artificial recharge structures are mainly Nala bunds, Check Dams and Recharge Shafts in addition to removal of silt in the surface tanks. Selection of the site locations of these structures are based on the critical analysis of the hydrogeological, geophysical and exploration data of the basin. Particularly geomorphological and drainage aspects are being given more weightage in selection of the Artificial Recharge structures.

A total number of 23 check dams, 166 nala bunds and 372 recharge shafts are proposed in the OE and critical firkas of the basin. A total number of 273 Recharge Rejuvenation ponds are selected for desilting followed by construction of recharge shafts within the tanks. The expected recharge through these artificial recharge structures is in the order of 54 MCM.

54 MCM recharge component was applied in the calibrated model to understand the effects on the groundwater flow system. Figure 19 clearly shows that the eastern part of the Chennai aquifer system is highly impact by the recharge in the groundwater by 54 mcm. Red contour line **(Figure19)** is observed to move towards the eastern side. The impact is more prominent in the alluvial regions than in the hard rock regions. Eastern movement in an positive indication for pushing the saline water intrusion seaward side.

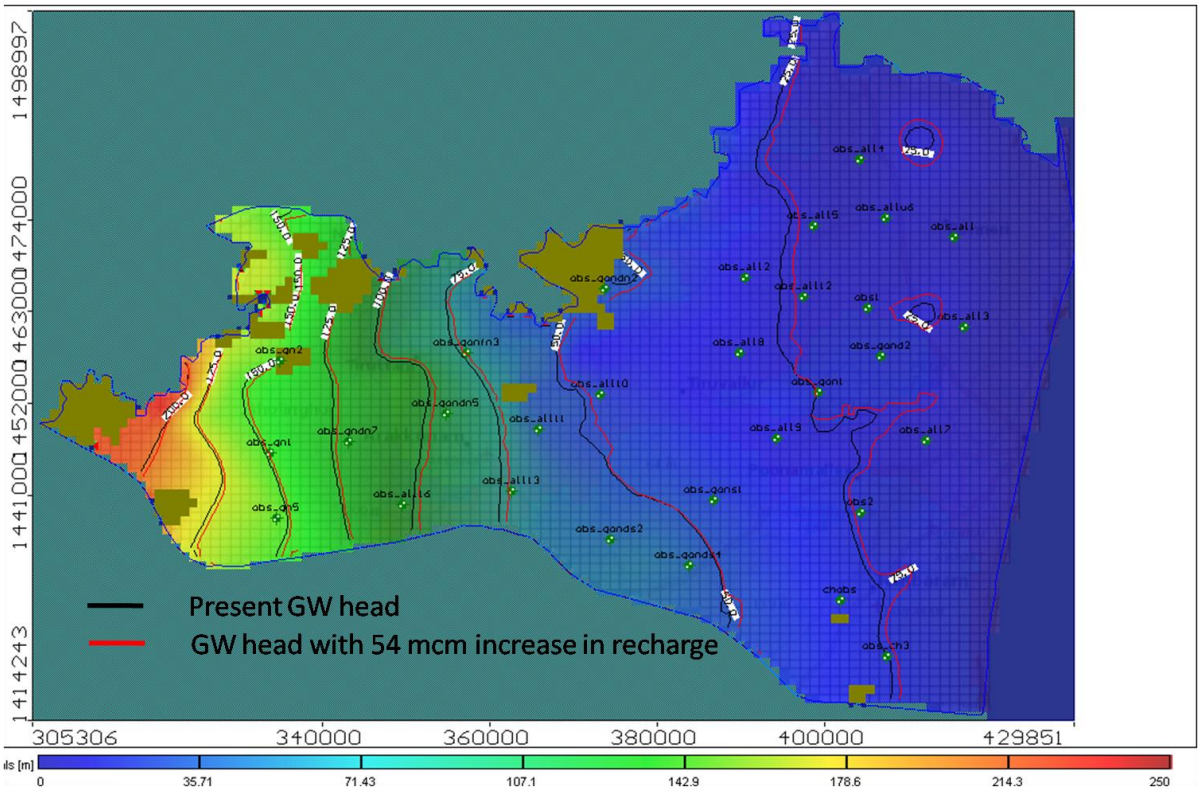

Figure 19. Projected GW heads with 54 mcm increase in recharge during 2025.

Projected groundwater head by 2025 with 120 days flow in rivers and construction of an unlined canal connecting two rivers *Arani* and *Korratalaiyar*

The model was projected until 2025 with two new interventions that could assist in pushing the saline water interface towards seaward side. The 10 % increase in groundwater draft was considered in this prediction model. The water flow in the 4 rivers are very minimal maximum 10 to 15 days with a river head of 0.1 to 0.25 m. Considering the same river head and if flow in the river is maintained for 120 days, the impact on the groundwater head in the Chennai aquifer system was projected. An unlined canal of 10 m width in the proposed location connecting the *Arani* and *Korattalaiyar* river (**Figure 20**). Both the rivers at this point tend to move in opposite direction.

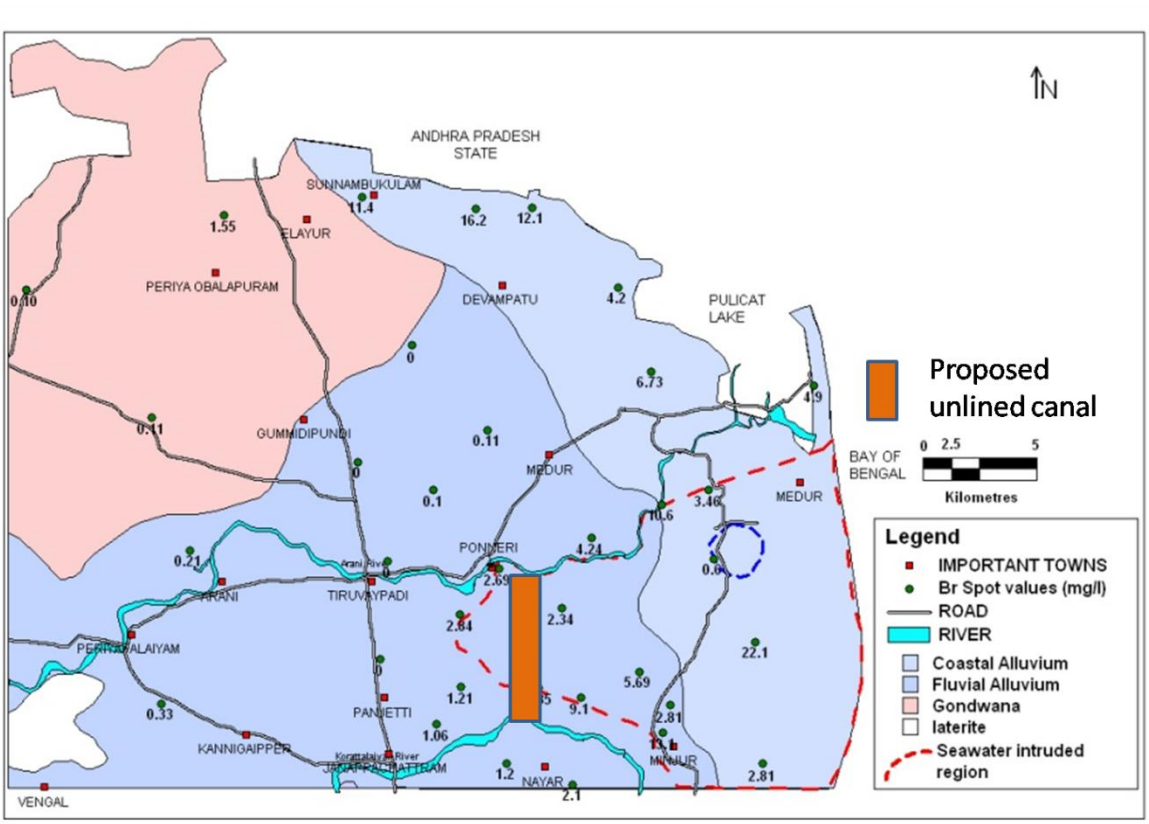

Figure 20: Proposed location for construction of canal connecting Arani and Korratalaiyar R.

The calibrated model predicted the behavior of the groundwater heads with 120 days flow in the rivers and also predicted the impact of unlined canal connecting the two rivers Arani and Koratalaiyar **(Figure 21).** The figure clearly shows the increase in the groundwater head in the eastern side and movement of the white coloured contours lines (Figure 21) towards the eastern side. The impact is more prominent in the alluvial regions than in the hard rock regions. Development of the groundwater mounds in the eastern part are positive signatures for pushing the saline water towards the seaward side.

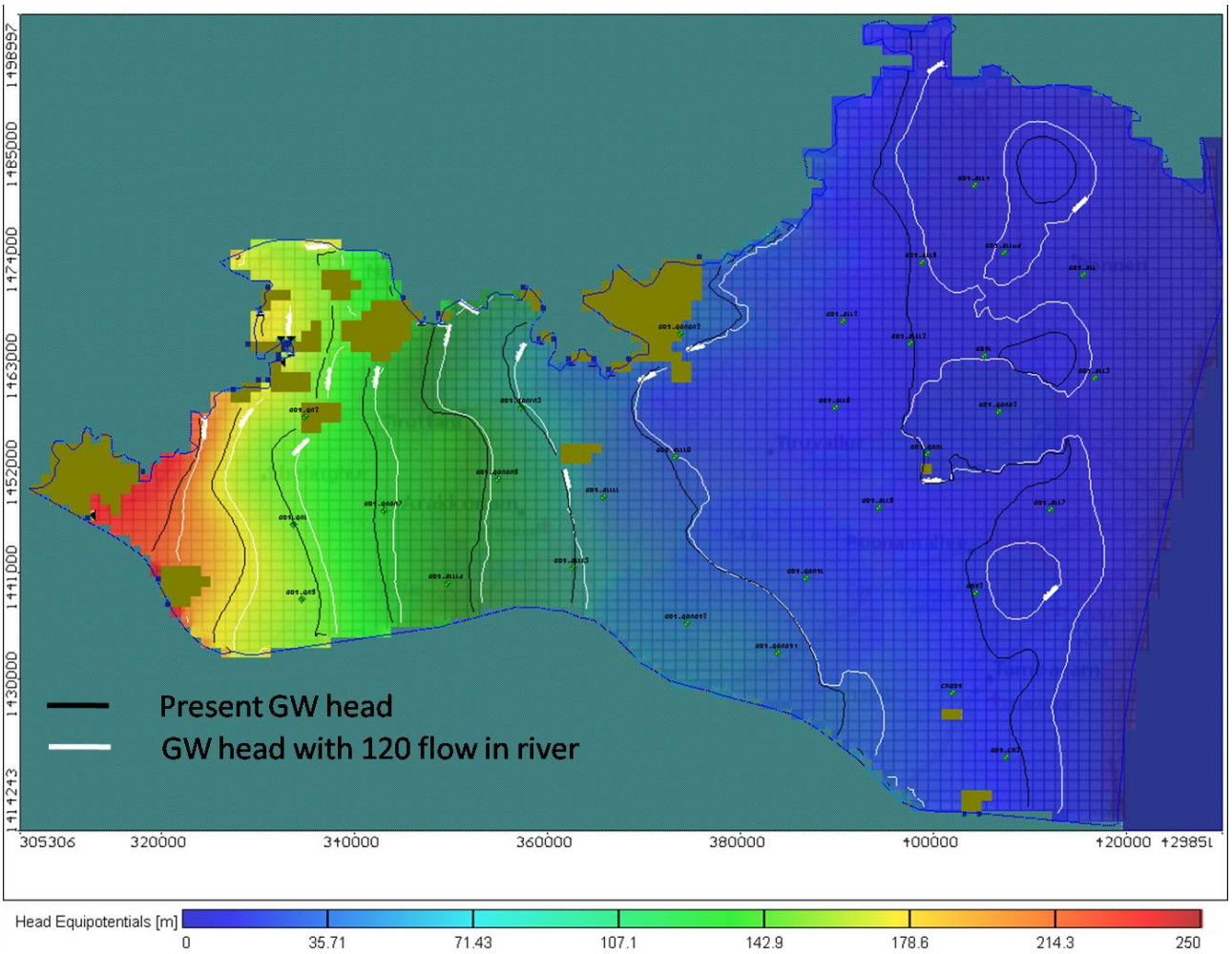

Figure 21: Projected GW heads with 120 days flow in rivers and construction of canal connecting Arani and Korratalaiyar river during 2025.

27.0 ASSUMPTIONS USED IN THE CONCEPTUAL MODEL

Certain assumptions about the Chennai aquifer and boundary condition specifications were required to be made for the mathematical representation of the aquifer. These include

The Chennai aquifer is represented by two layer model upto 300 meters below ground level though it includes many stratigraphic units with varying hydraulic properties within a vertical section. Aquifer parameters data are available but not spatially distributed. Hydraulic connection between the aquifer units I and II where assumed in locations. The southern hard rocks along the western boundary is considered as no-flow boundary though minimal inflow. The data of the river flows were not available. Based on field observations and discussions with state agencies and villages the river head and number of days of flow was assumed.

28.0 CONCLUSION

Three-layered finite-difference flow model was used to simulate the groundwater head in the parts of the Chennai aquifer basin for a period of 9 years (Jan 2010 to De 2018) for better understanding of the aquifer system.

- The simulated results indicate that this aquifer system is under tremendous stress of groundwater withdrawal of 899 MCM annually.
- The groundwater head follows the topography. The groundwater water flows from the western part towards the eastern part. Seawater intrusion is observed in the eastern part. Vectors clearly indicate the reversal of flows in the north eastern and eastern parts of the Chennai aquifer system. The River flow is very minimum and they contribute to the recharge of the aquifer system. There is flow of groundwater from the aquifer system to the eastern sea boundary during the monsoon months in few locations, this flow prevents the inward movement of sea water intrusion.
- The model predicts the changes in ground water head with changes in hydrological conditions like normal run for another 08 years i.e., until year 2025 with few major changes. The aquifer system becomes unstable with 25% increase in groundwater withdrawal by 2025. The groundwater heads move towards the western side further increasing the inward movement of the saline water.
- Model also predicted the supply side interventions recommended. 54-MCM/yr increase in recharge has a clear impact in the groundwater model. The contour lines move towards the easterly directions.
- Model also predicted behavior of the groundwater heads with 120 days flow in the rivers and also predicted the impact of unlined canal connecting the two rivers Arani and Koratalaiyar. The increase in the groundwater head in the eastern side. Development of the groundwater mounds in the eastern part is positive signatures for pushing the saline water towards the seaward side.

Annexure -I

Details Of Rainfall Stations and 50 Years normal average Rainfall								
S.No.	Name of the RF Station	Coordinates		SWM	NEM	Winter	Summer	Annual
		Latitude	Longitude					
1	Sholingar	13 07 00	79 26 00	445	391	31	84	952
2	Ramakrishnarajpet	13.167	79.439	362	320	13	79	773
3	Pallipet	13.336	79.442	404	361	19	111	895
4	Minnal	13 05 00	79 33 00	445	398	361	91	959
5	Arakonam	13 05 00	79 40 00	468	479	43	80	1070
6	Kesavaram	13 02 00	79 46 00	484	486	18	92	1080
7	Poondi	13 11 50	79 53 00	601	600	27	65	1292
8	Thiruvallore	13.135	79.911	424	545	46	73	1088
9	Chembarambakkam	13 07 00	79 55 00	418	620	24	83	1145
10	Sriperumbudur	12.967	79.792	418	547	36	66	1068
11	Tamaraipakkam Anicut	13 12 00	80 12 00	420	619	26	67	1131
12	Tambaram	12 55 00	80 07 00	513	809	22	80	1424
13	Poonthamallee	13 02 00	80 07 00	408	702	49	64	1223
14	Sholavaram	13 14 00	80 10 00	438	733	26	91	1289
15	Meenambakkam	13 00 00	80 11 00	433	768	37	86	1324
16	Redhills	13 10 00	80 11 00	342	614	24	90	1070
17	Korattur Anicut	13 05 30	79 59 30	402	543	24	72	1041
18	Ponneri	13 19 30	80 12 00	361	749	45	69	1223
19	Saidapet	13 03 00	80 14 00	405	759	52	70	1286
20	Nungambakkam	13 04 00	80 15 00	363	750	43	60	1215
21	Valliyur	13 12 50	79 59 15	409	720	30	103	1262
22	Athipet	13 15 38	80 17 00	328	750	42	56	1176
23	Chepauk	13 04 00	80 16 00	378	622	26	86	1112
24	Tiruthani	13 09 20	70 32 40	456	466	44	82	1047
25	Thiruvetriyur *	13.133	80.283	355	707	56	14	1132
26	Tharamani *	12 59 30	80 14 55	489	789	41	58	1377
27	Kaveripakkam	12 54 00	79 29 00	431	927	33	80	1471
28	Panappakkam	12 56 00	79 36 00	508	416	36	125	1085
29	Thiruvalangadu *	13.167	79.75	534	651	42	56	1283
30	Pattabiramam *	13.12	80.11	490	572	48	57	1167
31	Elavur	13 29 00	80 09 00	434	694	48	26	1202
	Note: * These Rainfall Stations were installed during recent years, and average has been arrived only for actiual years of data available.							

DISTRICT : CHENNAI											Rainfall (mm)		
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1994	0.10	9.70	0.00	0.50	74.50	54.05	77.15	102.75	36.75	273.30	518.75	225.25	1372.80
1995	158.60	0.00	32.60	0.00	319.15	17.65	103.10	256.75	183.65	248.45	256.40	10.10	1586.45
1996	1.20	0.00	0.00	17.35	7.50	538.00	58.95	70.85	285.20	466.05	309.60	450.50	2205.20
1997	8.15	0.00	0.00	54.65	0.00	51.15	43.50	91.00	172.55	282.60	820.50	406.90	1931.00
1998	2.80	0.00	0.00	14.95	18.70	38.85	108.55	108.30	65.65	189.35	318.05	168.65	1033.85
1999	0.00	0.00	0.00	10.55	6.40	78.75	88.00	176.05	167.15	318.10	154.80	49.20	1049.00
2000	0.00	0.00	0.00	15.90	15.60	93.50	104.10	60.80	123.70	147.90	179.50	45.25	786.25
2001	0.70	0.00	0.00	82.77	13.93	29.70	221.47	54.53	151.03	409.87	351.35	261.88	1577.22
2002	64.75	2.57	0.00	0.00	16.08	26.55	67.93	85.44	147.38	412.53	440.00	21.03	1284.25
2003	0.00	0.00	3.75	0.00	3.55	13.00	101.35	96.35	126.82	97.88	78.88	65.22	586.80
2004	18.57	0.00	0.00	0.60	203.20	28.49	40.13	31.90	230.60	205.75	336.70	3.83	1099.76
2005	0.50	6.08	0.00	116.20	41.33	18.65	142.80	63.43	107.78	936.20	646.17	478.47	2557.60
2006	0.88	0.00	15.15	6.65	18.93	41.16	76.60	121.37	153.94	684.86	253.97	19.02	1392.51
2007	0.00	3.15	9.77	9.82	0.03	88.89	241.93	228.15	186.37	298.42	134.41	262.04	1462.98
2008	62.90	11.00	135.90	6.72	2.70	101.08	40.00	118.00	87.73	356.47	487.02	8.13	1417.65
2009	25.02	0.00	0.50	0.00	11.63	10.63	44.42	83.35	86.75	68.40	561.00	249.33	1141.02
2010	9.27	0.00	0.00	0.00	181.30	118.13	137.75	215.65	121.13	134.67	229.83	279.80	1427.53
2011	12.25	59.30	0.00	23.20	9.60	79.58	72.58	278.75	211.83	221.15	425.75	148.77	1542.75
2012	14.62	0.00	0.40	0.35	0.05	43.17	56.95	106.25	183.25	412.28	39.50	153.48	1010.30
2013	0.00	11.58	22.83	9.75	2.90	50.18	132.80	183.93	219.97	185.13	166.23	61.77	1047.05
2014	0.00	4.17	0.00	0.00	26.50	104.38	45.80	191.35	105.03	467.80	228.93	176.90	1350.85
2015	7.55	0.00	0.00	61.05	7.03	27.55	165.48	137.35	78.78	143.32	1039.43	484.32	2151.85
2016	0.40	0.00	0.00	0.00	196.95	98.90	68.35	46.88	273.55	26.20	56.38	19.60	787.20
2017	3.28	0.00	0.00	0.00	1.33	41.47	82.35	274.27	90.47	321.95	721.20	67.92	1604.25
2018	3.03	0.40	2.63	0.00	0.00	53.38	89.03	220.28	63.43	153.30	229.23	49.65	864.36

DISTRICT : Tiruvallur											Rainfall (mm)		
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1994	0.33	4.86	0.00	0.00	24.55	22.88	99.66	128.59	60.85	299.69	401.90	102.59	1145.92
1995	28.34	0.00	8.42	0.00	132.21	71.72	101.45	228.08	161.02	208.42	175.14	0.29	1115.09
1996	0.12	0.85	0.00	34.56	3.14	418.35	65.41	112.74	218.78	241.25	258.00	380.75	1733.94
1997	13.25	0.00	0.00	4.79	25.95	83.59	58.61	74.34	229.77	164.59	489.74	286.76	1431.40
1998	0.00	4.06	0.17	4.31	3.97	36.62	96.54	141.11	126.54	182.42	332.67	160.39	1088.79
1999	4.47	0.00	0.00	25.44	40.55	39.76	66.14	134.22	77.18	199.71	195.13	54.43	837.02
2000	0.00	159.53	0.00	7.26	34.79	65.26	65.01	141.28	61.39	145.71	115.14	100.98	896.36
2001	1.68	0.00	0.94	131.12	30.53	27.98	95.11	76.52	179.64	336.96	210.15	178.22	1268.84
2002	41.81	0.44	0.00	0.00	36.46	32.67	73.33	82.15	124.58	247.44	217.17	27.57	883.63
2003	0.00	0.00	18.34	8.17	4.95	43.90	174.72	117.96	108.53	178.41	57.95	43.11	756.03
2004	10.69	0.00	0.00	7.59	205.46	60.54	53.33	24.45	196.69	215.14	239.77	1.13	1014.78
2005	0.00	0.00	7.78	38.59	14.00	12.50	91.13	104.88	181.61	502.16	390.61	321.39	1664.64
2006	0.80	0.00	22.27	20.07	27.65	85.79	47.26	102.50	180.90	341.68	166.59	63.05	1058.56
2007	0.00	4.08	0.00	17.86	28.45	80.72	159.53	200.63	158.47	242.16	105.13	241.16	1238.19
2008	47.52	13.53	87.50	1.62	34.24	75.70	84.25	87.04	105.73	220.83	419.10	10.89	1187.98
2009	3.27	0.00	0.12	0.55	11.19	33.44	53.89	137.72	86.85	57.67	306.57	146.67	837.95
2010	1.36	0.00	0.00	0.00	134.11	99.57	248.19	249.01	144.22	137.96	231.81	188.22	1434.44
2011	2.00	43.33	0.00	47.52	28.78	79.32	125.56	249.67	148.96	162.01	360.42	110.19	1357.76
2012	7.54	0.00	0.40	12.98	2.51	38.22	120.84	120.14	140.13	246.52	101.24	123.41	913.92
2013	0.00	39.56	4.96	5.62	4.28	62.50	72.67	84.92	167.51	121.86	83.47	7.87	655.22
2014	0.00	0.00	0.00	0.00	28.68	95.39	59.32	126.53	120.66	175.07	108.26	84.23	798.13
2015	0.00	0.00	1.00	50.71	48.71	51.63	145.14	183.12	102.56	189.96	821.52	292.31	1886.65
2016	0.04	0.00	0.00	0.00	143.19	163.79	64.42	19.68	179.00	15.77	22.61	19.80	628.32
2017	10.90	0.00	5.34	0.00	20.02	65.66	105.41	236.41	129.44	274.69	291.67	61.35	1200.89
2018	0.44	7.71	13.96	0.00	10.19	51.71	67.36	108.99	106.23	87.47	181.31	51.40	686.77

Annexure II

Table. Results of the pumping test analysis

Location	Thickness of the aquifer	Type of the aquifer	Type of Formation	Transmi-ssivity	Storage Coefficient/ Sp.yield	Remarks
	m			m^2/d		
Attipattu	26.2	SC/C	SR	2483.855	1.5×10^{-4}	UNDP studies
NE of minjur	31.5	SC/C	SR	2794.337	1.75×10^{-4}	UNDP studies
Vallur	12.5	SC/C	SR	807.2529	1.85×10^{-3}	UNDP studies
W of Minjur	11.5	SC/C	SR	1987.084	1.0×10^{-4}	UNDP studies
E of Ponneri	4.3	SC/C	SR	149.0313	-	UNDP studies
E of Ponneri	20.0	SC/C	SR	1117.735	2.1×10^{-4}	UNDP studies
Kattur	13.1	SC/C	SR	894.1878	3.1×10^{-3}	UNDP studies
Duranallur	15.7	SC/C	SR	1018.381	6.2×10^{-4}	UNDP studies
Panjetty	35.8	SC/C	SR	3974.168	2.8×10^{-3}	UNDP studies
Ponneri	9.0	UNC	SR	28	0.07	CGWB- HP-PDS studies
Minjur	9.0	UNC	SR	1328	0.20	CGWB- HP-PDS studies
Kannigaipair	9.0	UNC	SR	63.6	0.14	CGWB- HP-PDS studies
Velliyur	12.0	UNC	SR	615	0.15	CGWB- HP-PDS studies
Kadambattur	12.0	UNC	SR	2.38	0.01	CGWB- HP-PDS studies
Yellareddi Kandigai	15.0	SC	SR	3924	1.2×10^{-3}	CGWB
Panjetti	26.0	SC	SR	2217	7.55×10^{-4}	CGWB
Neidavoyal	10	UNC	SR	2115.0	-	CGWB
Parikkipattu	22	UNC	SR	763	-	CGWB
Velapakkam	12	SC	SR	4180	-	CGWB
Alamadhi	41	C	SR	1.16	-	CGWB
Puduvoyal	76	C	SR	6.94	-	CGWB
Verapuram	-	C	SR	5.90	-	CGWB
Avadi	70	C	SR	21.81	-	CGWB
Chengadu	12	SC/C	SR	103	5.67×10^{-2}	CGWB
ArcotKuppam	5 fractures	UNC/SC	HR	45.88	8.6×10^{-3}	CGWB
Athimanjarpet	2	UNC	HR	3.57	-	CGWB

Location	Thickness of the aquifer m	Type of the aquifer	Type of Formation	Transmi-ssivity m^2/d	Storage Coefficient/ Sp.yield	Remarks
	Fractures					
K.K.Nagar	2 Fractures	UNC	HR	5.66	-	CGWB
Kilpauk	19.0	SC	SR	871	4.5×10^{-3}	CGWB
Koyambedu	21.0	SC	SR	84.93	1.2×10^{-3}	CGWB
Thiruman-Galam	52	C	SR	135	1.9×10^{-4}	CGWB
Ammur	2 Fractures	UNC	HR	78.3	-	CGWB
Vallimalai	1 Fractures	UNC	HR	1.92	1.59×10^{-4}	CGWB
Guttakandur	3 Fractures	UNC/SC	HR	66.0		CGWB
Appukal	3 Fractures	UNC/SC	HR	18	-	CGWB
Odugattur	2 Fractures	UNC/SC	HR	31	-	CGWB
Kalliyur	5 fractures	UNC/SC	HR	134	-	CGWB
Andiappanur	5 Fractures	UNC/SC	HR	29	9.2×10^{-2}	CGWB
Thoplagunda	5 Fractures	UNC/SC	HR	29.2	5.7×10^{-5}	CGWB
Punganur	3 Fractures	UNC/SC	HR	21.4	1.87×10^{-3}	CGWB

Annexure IIIa

GW Draft computation for Aquifer unit I — Annexure-3a — Annexure-3a

Sl No	Firka	District	Total Geographical area in ha	population	Hilly area in ha	Paddy	Scane	Banana	TOTAL AREA IRRG	Canal	Tank	TW-IRRG	BW-IRRG	DCB-IRRG	DW-IRRG	TW-DOM	BW-DOM	DCB-DOM	DW-DOM	TW-IND	BW-IND	DCB-IND	DW-IND	Aq-I-IRR-DW-Df (m3)	Aq-I-Dom-Df (m3)	Aq-1-Ind-Df (m3)
1	Govindavadi	KANCHEEPURAM	5001.59		0.00	1597.63	61.98	0.74	1767.88	0.00	1084.69	523.00	90.00	38.00	652.00	0.00	12.00	0.00	21.00	0.00	0.00	0.00	0.00	3278880.00	166320.00	0.00
2	Karumpakkam	KANCHEEPURAM	3114.73		420	1071.97	0.00	0.20	1162.87	0.00	825.15	0.00	0.00	0.00	646.00	40.00	2.00	15.00	75.00	0.00	0.00	0.00	0.00	3069792.00	665280.00	0.00
3	Kattankulathur	KANCHEEPURAM	5327.00		1222	376.14	0.00	0.18	400.34	0.00	213.55	44.00	0.00	0.00	700.00	2.00	30.00	4.00	219.00	3.00	2.00	2.00	21.00	3326400.00	128520.00	60480.00
4	Kelambakkam	KANCHEEPURAM	6289.08		524	104.05	0.00	1.50	195.12	0.00	104.26	14.00	0.00	0.00	160.00	343.00	48.00	0.00	549.00	26.00	0.00	0.00	0.00	7603200.00	473760.00	56160.00
5	MANAMBATHY	KANCHEEPURAM	2600.32		317	806.59	0.00	0.00	869.90	0.00	644.66	30.00	0.00	0.00	417.00	13.00	0.00	0.00	35.00	0.00	0.00	0.00	0.00	1981584.00	241920.00	0.00
6	Mamallapuram	KANCHEEPURAM	2387.74		0.00	1453.00	243.00	0.00	15.00	327.00	16.00	0.00	0.00	0.00	1700.50	1219.00	0.00	492.54	687.25	344.43	152.00	187.00	1.29	8080776.00	12089851.20	1478998.85
7	Nellikuppam	KANCHEEPURAM	2387.74		0.00	1453.00	243.00	0.00	15.00	327.00	16.00	0.00	0.00	0.00	1700.50	1219.00	0.00	492.54	687.25	344.43	175.00	199.00	1.29	8080776.00	12089851.20	1554598.85
8	Parandur	KANCHEEPURAM	157.53		148	2436.61	0.00	1706.78	440.00	110.00	2.00	829.00	11.00	18.00	0.00	14.00	0.00	0.00	0.00	0.00	2219.54	1706.78	0.00	855360.00	705600.00	8480842.56
9	Paiyanur	KANCHEEPURAM	4409.2		279	1105.07	8.50	0.00	1365.87	0.00	873.21	0.00	0.00	0.00	735.00	57.00	0.00	0.00	120.00	0.00	0.00	0.00	0.00	3492720.00	892080.00	0.00
10	Serappanacheri	KANCHEEPURAM	9860.50		910	769.98	2.02	0.29	821.90	0.00	650.07	135.00	0.00	0.00	759.00	19.00	2.00	0.00	159.00	0.00	0.00	0.00	0.00	3606768.00	907200.00	0.00
11	Singaperumal kovil	KANCHEEPURAM	3844.38		726	261.14	0.00	1.66	285.44	0.00	171.42	15.00	1.00	0.00	802.00	3.00	0.00	0.00	479.00	0.00	0.00	0.00	0.00	3811104.00	242928.00	0.00
12	Sukuvanchatiram	KANCHEEPURAM	7354.81		24	1485.68	0.00	0.82	1668.38	0.00	1464.90	475.00	0.00	0.00	481.00	4.00	0.00	0.00	408.00	0.00	0.00	0.00	0.00	2285712.00	207648.00	0.00
13	THIRUPPU KUZHI	KANCHEEPURAM	5636.47		0.0	1460.02	57.91	7.44	1778.87	0.00	1219.87	1383.00	0.00	0.00	1859.00	32.00	6.00	0.00	59.00	3.00	0.00	0.00	0.00	8833968.00	488880.00	64800.00
14	Tiruporur	KANCHEEPURAM	10382.8		2098	1172.98	1.38	5.30	1565.09	0.00	1010.38	34.00	0.00	0.00	981.00	893.00	0.00	3.00	583.00	1.00	0.00	36.00	0.00	4661712.00	745416.00	79920.00
15	Tambaram	KANCHEEPURAM	2567.29		0.00	39.77	0.00	0.32	44.55	0.00	44.55	0.00	0.00	0.00	30.00	1018.00	0.00	0.00	2837.00	0.00	0.00	0.00	0.00	142560.00	19429200.00	0.00
16	Thandalam	KANCHEEPURAM	7874.53		81.7	102.07	0.00	0.00	154.45	0.00	108.16	111.00	0.00	0.00	118.00	0.00	0.00	0.00	118.00	0.00	0.00	0.00	0.00	560736.00	594720.00	0.00
17	Vandalur	KANCHEEPURAM	5547.50		906	167.77	0.00	0.57	214.46	0.00	155.45	0.00	0.00	0.00	591.00	1872.00	38.00	19.00	569.00	101.00	0.00	0.00	28.00	2808432.00	12589920.00	2786400.00
18	Vallam(K)	KANCHEEPURAM	7356.52		199	362.52	0.00	0.00	436.36	0.00	404.86	41.00	6.00	0.00	43.00	0.00	0.00	0.00	64.00	0.00	0.00	0.00	0.00	204336.00	322560.00	0.00
19	Alanthur	KANCHEEPURAM	1291.39		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1545.00	0.00	0.00	12.00	0.00	0.00	0.00	0.00	0.00	7847280.00	0.00
20	Chitlapakkam	KANCHEEPURAM	2056.73		0.00	12.90	0.00	0.00	12.90	0.00	12.90	0.00	0.00	0.00	45.00	2009.00	0.00	0.00	2642.00	0.00	0.00	0.00	0.00	213840.00	23441040.00	0.00
21	Guduvancheri	KANCHEEPURAM	6559.58		1610	440.63	0.00	0.00	504.52	0.00	502.60	0.00	0.00	0.00	789.00	270.00	0.00	6.00	1043.00	6.00	2.00	0.00	9.00	3749328.00	6647760.00	3672000.00
22	Kunrathur	KANCHEEPURAM	9847.63		258	517.90	0.00	15.34	630.04	0.00	560.05	73.00	0.00	0.00	225.00	20.00	0.00	0.00	121.00	25.00	0.00	0.00	1.00	1069200.00	7106400.00	5616000.00
23	Madambakkam	KANCHEEPURAM	1476.26		0.00	327.33	0.00	0.00	341.14	0.00	341.14	3.00	0.00	0.00	164.00	38.00	0.00	0.00	224.00	0.00	0.00	0.00	0.00	779328.00	1320480.00	0.00

24	MADURAMANGALAM	KANCHEEPURAM	6525.08		0.00	1586.82	94.68	15.94	1815.24	0.00	1299.19	537.00	0.00	0.00	765.00	37.00	0.00	0.00	721.00	0.00	0.00	0.00	0.00	363528.00	382032.00	0.00
25	Mangadu	KANCHEEPURAM	3712.43		36.75	169.93	0.00	25.52	238.85	0.00	127.80	134.00	0.00	0.00	342.00	236.00	30.00	0.00	273.00	17.00	19.00	0.00	2.00	162518.00	271656.00	82080.00
26	Medavakkam	KANCHEEPURAM	3121.85		0.00	134.94	0.00	0.00	140.12	0.00	136.63	0.00	0.00	0.00	27.00	1335.00	0.00	0.00	228.00	0.00	0.00	0.00	0.00	128304.00	787752.00	0.00
27	Padappai	KANCHEEPURAM	6431.42		188.9	821.88	0.24	8.05	987.26	0.00	874.73	60.00	0.00	0.00	251.00	16.00	0.00	0.00	199.00	2.00	0.00	0.00	0.00	119275.00	108360.00	4320.00
28	Pallavaram	KANCHEEPURAM	1697.33		0.00	16.56	0.00	0.00	16.56	0.00	16.56	0.00	0.00	0.00	0.00	805.00	0.00	0.00	1535.00	0.00	0.00	0.00	0.00	0.00	117936.00	0.00
29	Pallikaranai	KANCHEEPURAM	4364.79		0.00	29.06	0.00	0.28	57.91	0.00	41.24	0.00	0.00	0.00	428.00	4867.00	0.00	0.00	2358.00	0.00	0.00	0.00	20.00	203385.00	364140.00	43200.00
30	Pammal	KANCHEEPURAM	2163.98		0.00	28.02	0.00	0.21	71.63	0.00	71.63	0.00	0.00	0.00	64.00	1074.00	3.00	0.00	46.00	0.00	0.00	0.00	0.00	304128.00	565992.00	0.00
31	Sholinganallur	KANCHEEPURAM	3009.36		0.00	4.65	0.00	0.00	16.75	0.00	16.75	0.00	0.00	0.00	27.00	425.00	0.00	0.00	1362.00	60.00	0.00	0.00	4.00	128304.00	900648.00	13824.00
32	Sriperumpudur	KANCHEEPURAM	8083.05		142.5	1376.30	0.00	0.21	1465.85	0.00	1385.16	53.00	0.00	0.00	135.00	15.00	0.00	0.00	149.00	0.00	0.00	0.00	0.00	641520.00	826560.00	0.00
33	Tambaram	KANCHEEPURAM	2567.29		0.00	39.77	0.00	0.32	44.55	0.00	44.55	0.00	0.00	0.00	30.00	1018.00	0.00	0.00	2837.00	0.00	0.00	0.00	0.00	142560.00	194292.00	0.00
34	Thandalam	KANCHEEPURAM	7874.53		81.7	102.07	0.00	0.00	154.45	0.00	108.16	111.00	0.00	0.00	118.00	0.00	0.00	0.00	118.00	0.00	0.00	0.00	0.00	560736.00	594720.00	0.00
35	Vallam(K)	KANCHEEPURAM	7356.52		198.9	362.52	0.00	0.00	436.36	0.00	404.86	41.00	6.00	0.00	43.00	0.00	0.00	0.00	64.00	0.00	0.00	0.00	0.00	204336.00	322560.00	0.00
	Ambatttur	THIRUVALLUR	11087.5		0.00	54.60	0.03	0.00	70.74	0.00	0.00	205.00	0.00	0.00	55.00	5012.00	1605.00	0.00	0.00	734.00	6.00	0.00	0.00	261360.00	333496.00	15984.00
38	Ammanambakkam	THIRUVALLUR	5942.66		248.1	1242.56	4.05	4.49	1900.20	0.00	387.88	739.00	55.00	0.00	1.00	70.00	0.00	0.00	0.00	17.00	0.00	0.00	0.00	4752.00	352800.00	36720.00
39	Arani	THIRUVALLUR	5611.53		0.00	2462.50	17.58	239.25	3830.05	0.00	860.52	427.00	40.00	0.00	100.00	1045.00	0.00	0.00	165.00	25.00	0.00	0.00	0.00	475200.00	609840.00	54000.00
	Avadi	THIRUVALLUR	4421		0.00	687.21	0.00	5.00	738.82	0.00	0.00	0.00	136.00	0.00	0.00	58.00	60.00	0.00	15.00	0.00	28.00	0.00	0.00	0.00	670320.00	60480.00
40	BALAPURAM	THIRUVALLUR	6588.16		335.2	958.10	531.38	8.24	2007.38	0.00	0.00	316.00	168.00	244.00	680.00	24.00	44.00	8.00	3.00	0.00	0.00	0.00	0.00	439084.00	398160.00	0.00
41	Cherukkanoor	THIRUVALLUR	9413.05		198.0	1042.64	700.36	0.82	3507.19	0.00	381.39	348.00	45.00	0.00	883.00	217.00	8.00	0.00	32.00	3.00	0.00	0.00	1.00	419601.00	129528.00	8640.00
42	Elavur	THIRUVALLUR	11340.3		205.7	3169.87	14.99	42.28	4820.40	0.00	1844.48	475.00	4.00	73.00	170.00	864.00	0.00	0.00	465.00	22.00	0.00	0.00	0.00	115473.00	669816.00	47520.00
43	Erumbi	THIRUVALLUR	4680.53		215.3	672.23	204.29	10.57	1357.58	0.00	0.00	174.00	82.00	250.00	257.00	103.00	52.00	0.00	0.00	0.00	0.00	0.00	0.00	240926.00	781200.00	0.00
44	Gnayiru	THIRUVALLUR	6807.77		0.00	3318.08	8.94	166.24	4611.24	0.00	256.50	676.00	9.00	0.00	42.00	1004.00	0.00	0.00	185.00	3.00	0.00	0.00	5.00	199584.00	599256.00	17280.00
45	Gummidipoondi	THIRUVALLUR	8487.06		121.2	2250.29	61.40	42.29	2580.10	30.70	1629.23	334.00	32.00	0.00	250.00	585.00	48.00	0.00	95.00	20.00	0.00	0.00	0.00	118800.00	366912.00	43200.00
46	Kadambathur	THIRUVALLUR	10181.4		114.9	3734.40	73.40	8.01	4576.87	0.00	1968.91	327.00	122.00	47.00	161.00	659.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	988416.00	334656.00	0.00
47	Kanagammachattram	THIRUVALLUR	7334.67		30.5	1220.72	290.79	4.80	3445.83	0.00	0.00	458.00	87.00	77.00	289.00	214.00	0.00	0.00	34.00	6.00	0.00	0.00	0.00	173923.00	124992.00	12960.00
48	Kannigaipair	THIRUVALLUR	6408.25		0.00	2933.72	25.30	37.54	3331.48	0.00	0.00	730.00	0.00	0.00	0.00	104.00	0.00	0.00	0.00	38.00	0.00	0.00	0.00	0.00	524160.00	82080.00
49	Kattur	THIRUVALLUR	10930.3		554.9	2591.11	0.00	0.25	3126.67	124.35	827.36	549.00	0.00	4.00	0.00	225.00	0.00	0.00	9.00	0.00	0.00	0.00	4.00	19008.00	117936.00	8640.00
50	Kolur	THIRUVALLUR	9302.89		0.00	3336.87	0.00	0.00	3661.74	0.00	1341.58	689.00	0.00	0.00	8.00	368.00	2.00	0.00	25.00	0.00	0.00	0.00	0.00	38016.00	199080.00	0.00
51	MADHARPAKKAM	THIRUVALLUR	11475.0		398.3	3264.02	22.45	0.08	4499.52	0.00	2494.24	186.00	25.00	7.00	321.00	836.00	0.00	5.00	94.00	8.00	0.00	0.00	19.00	155865.00	471240.00	58320.00
52	Madhavaram	THIRUVALLUR	6180.35		0.00	113.46	0.00	25.73	213.61	0.00	137.96	65.00	0.00	0.00	0.00	8930.00	0.00	0.00	1093.00	296.00	0.00	0.00	0.00	0.00	505159.00	63936.00
	MADURAVOIL	THIRUVALLUR	4582.13		0.00	120.59	0.00	4.45	174.27	0.00	5.23	86.00	65.00	22.00	0.00	6910.00	1363.00	0.00	1980.00	218.00	0.00	6.00	0.00	104544.00	516751.00	48384.00

53	Manavor	THIRUVALLUR	4624.01		13.88	1192.51	14.49	0.00	1534.17	0.00	137.00	160.00	43.00	0.00	206.00	191.00	12.00	0.00	19.00	3.00	1.00	0.00	0.00	978912.00	111888.00	8640.00
54	Mappedu	THIRUVALLUR	7516.82		53.42	1245.54	0.31	0.12	2686.40	0.00	2638.07	79.00	0.00	0.00	13.00	301.00	0.00	0.00	25.00	14.00	12.00	0.00	2.00	61776.00	164304.00	60480.00
55	Minjur	THIRUVALLUR	8109.30		133.9	1054.58	3.45	9.43	1888.62	322.58	137.07	338.00	0.00	0.00	0.00	1217.00	0.00	0.00	238.00	26.00	0.00	0.00	12.00	0.00	733320.00	82080.00
56	Morai	THIRUVALLUR	6421.32		0.00	1923.82	6.05	0.56	2365.36	0.00	168.50	455.00	11.00	6.00	0.00	3072.00	67.00	0.00	64.00	110.00	0.00	0.00	0.00	28512.00	161431.00	23760.00
57	Pallipattu	THIRUVALLUR	7896.23		547.3	892.69	1089.34	7.85	2604.14	0.00	0.00	951.00	0.00	0.00	267.00	334.00	0.00	5.00	10.00	0.00	0.00	0.00	0.00	126878.00	175896.00	0.00
58	Pandur	THIRUVALLUR	7787.63		368.4	1109.91	35.60	0.00	1779.12	0.00	0.00	299.00	0.00	5.00	127.00	67.00	4.00	1.00	14.00	4.00	0.00	0.00	0.00	627264.00	433440.00	8640.00
59	Pennalurpett	THIRUVALLUR	9492.09		739.7	1080.52	18.37	0.00	1709.45	0.00	290.40	309.00	15.00	0.00	287.00	64.00	0.00	0.00	77.00	4.00	0.00	0.00	9.00	136382.00	710640.00	28080.00
60	PERIYAPALAYAM	THIRUVALLUR	6110.81		80.08	2171.08	60.53	45.87	2875.50	0.00	373.49	617.00	8.00	0.00	0.00	68.00	0.00	0.00	0.00	31.00	0.00	0.00	0.00	0.00	342720.00	66960.00
61	Ponneri	THIRUVALLUR	6451.63		0.00	4134.23	186.77	18.44	5738.93	764.67	2383.78	738.00	0.00	4.00	5.00	1111.00	0.00	0.00	258.00	15.00	0.00	0.00	5.00	42768.00	689976.00	43200.00
	POONAMALLEE	THIRUVALLUR	3670		0.00	664.02	0.00	0.00	679.02	0.00	0.00	0.00	168.00	0.00	0.00	2147.00	410.00	0.00	322.00	152.00	82.00	0.00	0.00	0.00	145101.00	50544.00
62	Poondi	THIRUVALLUR	8701.45		621.0	1096.89	48.31	0.49	1652.16	43.47	104.28	233.00	131.00	73.00	149.00	73.00	19.00	11.00	55.00	0.00	0.00	0.00	1.00	105494.00	796320.00	2160.00
63	Poonimangadu	THIRUVALLUR	6066.71		184.2	494.54	1001.80	0.41	2591.91	0.00	0.00	252.00	115.00	105.00	392.00	175.00	20.00	0.00	20.00	0.00	3.00	0.00	0.00	236174.00	108360.00	6480.00
64	Poovalambedu	THIRUVALLUR	10190.2		418.9	2937.07	9.61	34.93	3672.90	0.00	2131.45	395.00	34.00	36.00	224.00	339.00	2.00	2.00	46.00	10.00	0.00	0.00	1.00	123552.00	196056.00	23760.00
65	Pothattur pettai	THIRUVALLUR	8745.77		797.9	609.15	1549.62	3.30	2519.45	0.00	0.00	733.00	0.00	0.00	218.00	239.00	0.00	0.00	25.00	0.00	0.00	0.00	0.00	103593.00	133056.00	0.00
66	R.K.Pet	THIRUVALLUR	6326.3		224.3	749.36	557.48	1.20	1997.37	0.00	0.00	242.00	213.00	145.00	585.00	41.00	45.00	0.00	4.00	0.00	0.00	0.00	0.00	346896.00	453600.00	0.00
67	Redhills	THIRUVALLUR	5499.64		0.00	130.26	0.00	48.54	179.80	0.00	83.15	60.00	14.00	0.00	0.00	9187.00	232.00	0.00	320.00	206.00	12.00	6.00	10.00	0.00	490845.00	50544.00
68	Sholavaram	THIRUVALLUR	6484.7		51.9	2100.11	0.00	98.48	3185.70	0.00	0.00	642.00	0.00	13.00	0.00	862.00	0.00	0.00	98.00	0.00	16.00	0.00	0.00	61776.00	483840.00	34560.00
69	Thirumazhisai	THIRUVALLUR	5524		75.7	2350.03	0.00	0.00	2486.65	0.00	0.00	189.00	242.00	0.00	0.00	162.00	83.00	0.00	62.00	0.00	0.00	0.00	0.00	0.00	154728.00	0.00
70	THIRUNINRAVUR	THIRUVALLUR	4218		126.4	990.61	0.00	0.00	1026.89	0.00	0.00	0.00	235.00	0.00	0.00	425.00	50.00	14.00	153.00	80.00	0.00	0.00	5.00	0.00	323568.00	18360.00
71	Thirupalaivanam	THIRUVALLUR	11368.8		0.00	2914.31	28.90	0.00	3752.33	0.00	1337.85	447.00	14.00	0.00	7.00	126.00	0.00	0.00	44.00	0.00	0.00	0.00	0.00	33264.00	856800.00	0.00
72	Thiruvalangadu	THIRUVALLUR	8222.58		83.80	1139.50	200.68	0.34	2524.27	0.00	641.68	224.00	48.00	0.00	290.00	251.00	30.00	7.00	37.00	5.00	0.00	0.00	0.00	137808.00	163800.00	10800.00
73	Thiruvallur	THIRUVALLUR	6868.32		0.00	781.51	9.45	27.57	1014.21	0.00	70.42	512.00	61.00	0.00	6.00	554.00	0.00	0.00	84.00	14.00	0.00	0.00	0.00	28512.00	321552.00	30240.00
74	Tirur	THIRUVALLUR	6868.32		0.00	781.51	9.45	27.57	1014.21	0.00	70.42	512.00	61.00	0.00	6.00	554.00	0.00	0.00	84.00	14.00	0.00	0.00	0.00	28512.00	321552.00	30240.00
75	Tiruttani	THIRUVALLUR	9196.43		385.20	876.38	343.27	1.35	2142.84	0.00	0.00	363.00	47.00	170.00	571.00	257.00	5.00	0.00	72.00	14.00	2.00	0.00	6.00	352123.00	168336.00	47520.00
76	Uthukkottai	THIRUVALLUR	6625.27		34.77	3656.02	161.71	4.12	4664.60	0.00	0.00	1598.00	0.00	0.00	18.00	305.00	0.00	0.00	0.00	21.00	0.00	0.00	0.00	85536.00	153720.00	45360.00
77	Velakapuram	THIRUVALLUR	7317.07		121.20	1770.47	252.10	2.11	2552.16	0.00	29.80	912.00	20.00	0.00	0.00	124.00	0.00	0.00	24.00	0.00	0.00	0.00	3.00	0.00	745920.00	6480.00
78	VELLIYUR	THIRUVALLUR	5242.90		0.00	1633.91	13.34	94.37	2276.10	0.00	758.09	884.00	160.00	0.00	11.00	249.00	56.00	2.00	19.00	4.00	32.00	0.00	0.00	52272.00	164304.00	77760.00
79	Vengathur	THIRUVALLUR	8851.70		83.85	738.07	13.42	13.11	3392.84	0.00	2259.55	98.00	20.00	18.00	98.00	626.00	24.00	0.00	362.00	18.00	23.00	5.00	0.00	551232.00	510048.00	99360.00
80	Arakonam(North)	VELLORE	9470.06		0.00	1503.60	107.79	0.86	1772.25	0.00	21.00	11.00	172.00	40.00	1140.00	19.00	33.00	2.00	106.00	0.00	0.00	54.00	0.00	560736.00	806400.00	11664.00
81	Arakonam(South)	VELLORE	9674.67		0.00	1330.37	143.57	6.18	1786.97	10.00	10.00	12.00	350.00	123.00	1059.00	38.00	2715.00	137.00	6077.00	0.00	0.00	80.00	0.00	561686.00	451936.00	17280.00

82	Banavaram	VELLORE	1275 2.5		0.00	1801 .80	175. 15	0.24	2616 .70	0.00	0.00	25.0 0	298. 00	373. 00	2327 .00	62.00	56.0 0	28.0 0	105. 00	0.00	0.00	147. 00	0.0 0	128304 00.00	126504 0.00	31752 0.00
83	Kaveripakkam	VELLORE	8668 .87		0.00	2031 .13	162. 97	441. 54	2899 .80	0.00	383. 00	36.0 0	251. 00	540. 00	2499 .00	74.00	68.0 0	7.00	91.0 0	0.00	0.00	49.0 0	0.0 0	144413 28.00	120960 0.00	10584 0.00
84	Nemili(v)	VELLORE	1043 0.4		0.00	2155 .38	134. 67	0.00	2876 .30	0.00	0.00	78.0 0	468. 00	526. 00	1908 .00	10.00	15.0 0	0.00	102. 00	0.00	0.00	118. 00	0.0 0	115663 68.00	640080. 00	25488 0.00
85	Pallur	VELLORE	1042 0.6		0.00	1807 .04	77.1 0	3.83	2433 .82	0.00	0.00	123. 00	329. 00	434. 00	1988 .00	6.00	40.0 0	0.00	76.0 0	0.00	0.00	187. 00	0.0 0	115093 44.00	614880. 00	40392 0.00
86	Panapakkam	VELLORE	8835 .80		0.00	2774 .50	78.9 2	2.01	3274 .56	0.00	0.00	124. 00	332. 00	181. 00	1765 .00	14.00	55.0 0	0.00	77.0 0	0.00	0.00	51.0 0	0.0 0	924739 2.00	735840. 00	11016 0.00
87	Paranji	VELLORE	1283 3.8		0.00	1365 .94	417. 06	0.00	2848 .58	0.00	0.00	30.0 0	237. 00	440. 00	2620 .00	222.0 0	62.0 0	59.0 0	60.0 0	0.00	0.00	175. 00	0.0 0	145411 20.00	203112 0.00	37800 0.00
88	SHOLINGHUR	VELLORE	7521 .91		0.00	1221 .21	243. 23	1.59	1747 .59	0.00	0.00	2.00	6.00	0.00	1501 .00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0 0	713275 2.00	0.00	0.00
89	VELAM	VELLORE	8698 .22		0.00	1381 .53	532. 04	3.76	2402 .60	0.00	0.00	2.00	16.0 0	8.00	1381 .00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0 0	660052 8.00	0.00	0.00
90	EGMORE - NUNGAMBAKKAM--I	CHENNAI	465. 697	26405 5												5947 9.86								0.00	187361 5.55	0.00
91	EGMORE - NUNGAMBAKKAM--II	CHENNAI	236. 889	13431 8												3025 6.00								0.00	148254 4.00	0.00
92	EGMORE - NUNGAMBAKKAM--III	CHENNAI	235. 374	13345 9												3006 3.00								0.00	147308 7.00	0.00
93	EGMORE - NUNGAMBAKKAM-IV	CHENNAI	409. 127	40438 7												9109 0.63								0.00	446344 0.85	0.00
94	KOTTAI - THONDIARPET-I	CHENNAI	393. 974	91284												2080 3.97								0.00	101939 4.58	0.00
95	KOTTAI - THONDIARPET-II	CHENNAI	392. 459	90933												2072 3.96								0.00	101547 3.84	0.00
96	KOTTAI - THONDIARPET-III	CHENNAI	506	17402 6												3966 0.90								0.00	194338 4.29	0.00
97	KOTTAI - THONDIARPET-IV	CHENNAI	281. 338	65186												1485 6.17								0.00	727952. 29	0.00
98	MAMBALAM - GUINDY-I	CHENNAI	534. 895	11027 8												2764 5.87								0.00	135464 7.44	0.00
99	MAMBALAM - GUINDY-II	CHENNAI	342. 959	70707												1611 4.30								0.00	789600. 49	0.00
100	MAMBALAM - GUINDY-III	CHENNAI	514. 692	10611 3												2660 1.64								0.00	130348 0.40	0.00
101	MAMBALAM - GUINDY-IV	CHENNAI	651. 572	13433 3												3367 6.27								0.00	165013 7.11	0.00
102	MYLAPORE - TIRUVALLIKENI--I	CHENNAI	44.4 483	14161												3264. 10								0.00	159940. 90	0.00
103	MYLAPORE - TIRUVALLIKENI--II	CHENNAI	817. 244	26037 6												6001 4.93								0.00	294073 1.55	0.00
104	MYLAPORE - TIRUVALLIKENI--III	CHENNAI	191. 936	61151												1409 4.98								0.00	690653. 89	0.00
105	MYLAPORE - TIRUVALLIKENI--IV	CHENNAI	724. 306	23076 6												5318 9.99								0.00	260630 9.67	0.00
106	PURASAWALKAM - PERAMBUR-I	CHENNAI	480. 345	23858 9												6796. 19								0.00	333013. 36	0.00
107	PURASAWALKAM - PERAMBUR-II	CHENNAI	534. 895	26568 4												7568. 00								0.00	370831. 91	0.00
108	PURASAWALKAM - PERAMBUR-III	CHENNAI	436. 907	21701 3												6181. 60								0.00	302898. 59	0.00
109	PURASAWALKAM - PERAMBUR-IV	CHENNAI	276. 792	13748 3												3916. 21								0.00	191894. 13	0.00

Annexure III b*

GW Draft computation for Aquifer unit II

Annexure-IIIb

SlNo	Firka	District	Total Geographical area in ha	TW-IRRG	BW-IRRG	DCB-IRRG	DW-IRRG	TW-DOM	BW-DOM	DCB-DOM	DW-DOM	TW-IND	BW-IND	DCB-IND	DW-IND	Aq-II Irr-Dft (m3)	Aq-II-Total Dft (m3)
1	Govindavadi	KANCHEEPURAM	5001.595	523	90	38	652	0	12	0	21	0	0	0	0	5825952	5825952
2	Karumpakkam	KANCHEEPURAM	3114.73	0	0	0	646	40	2	15	75	0	0	0	0	0	0
3	Kattankulathur	KANCHEEPURAM	5327.008	44	0	0	700	2	30	4	219	3	2	2	21	418176	418176
4	Kelambakkam	KANCHEEPURAM	6289.08	14	0	0	160	343	48	0	549	26	0	0	0	133056	133056
5	MANAMBATHY	KANCHEEPURAM	2600.325	30	0	0	417	13	0	0	35	0	0	0	0	285120	285120
6	Mamallapuram	KANCHEEPURAM	2387.745	0	0	0	1701	1219	0	493	687	344	152	187	1	0	0
7	Nellikuppam	KANCHEEPURAM	2387.745	0	0	0	1701	1219	0	493	687	344	175	199	1	0	0
8	Parandur	KANCHEEPURAM	157.53	829	11	18	0	14	0	0	0	0	2220	1707	0	7983360	7983360
9	Paiyanur	KANCHEEPURAM	4409.2	0	0	0	735	57	0	0	120	0	0	0	0	0	0
10	Serappanacheri	KANCHEEPURAM	9860.506	135	0	0	759	19	2	0	159	0	0	0	0	1283040	1283040
11	Singaperumal kovil	KANCHEEPURAM	3844.382	15	1	0	802	3	0	0	479	0	0	0	0	152064	152064
12	Sukuvanchatiram	KANCHEEPURAM	7354.815	475	0	0	481	4	0	0	408	0	0	0	0	4514400	4514400
13	THIRUPPU KUZHI	KANCHEEPURAM	5636.47	1383	0	0	1859	32	6	0	59	3	0	0	0	13144032	13144032
14	Tiruporur	KANCHEEPURAM	10382.81	34	0	0	981	893	0	3	583	1	0	36	0	323136	323136
15	Tambaram	KANCHEEPURAM	2567.29	0	0	0	30	1018	0	0	2837	0	0	0	0	0	0
16	Thandalam	KANCHEEPURAM	7874.53	111	0	0	118	0	0	0	118	0	0	0	0	1054944	1054944
17	Vandalur	KANCHEEPURAM	5547.505	0	0	0	591	1872	38	19	569	101	0	0	28	0	0
18	Vallam(K)	KANCHEEPURAM	7356.52	41	6	0	43	0	0	0	64	0	0	0	0	446688	446688
19	Alanthur	KANCHEEPURAM	1291.395	0	0	0	0	1545	0	0	12	0	0	0	0	0	0
20	Chitlapakkam	KANCHEEPURAM	2056.73	0	0	0	45	2009	0	0	2642	0	0	0	0	0	0
21	Guduvancheri	KANCHEEPURAM	6559.58	0	0	0	789	270	0	6	1043	6	2	0	9	0	0
22	Kunrathur	KANCHEEPURAM	9847.63	73	0	0	225	20	0	0	121	25	0	0	1	693792	693792

23	Madambakkam	KANCHEEPURAM	1476.265	3	0	0	164	38	0	0	224	0	0	0	0	28512	28512
24	MADURAMANGALAM	KANCHEEPURAM	6525.08	537	0	0	765	37	0	0	721	0	0	0	0	5103648	5103648
25	Mangadu	KANCHEEPURAM	3712.439	134	0	0	342	236	30	0	273	17	19	0	2	1273536	1273536
26	Medavakkam	KANCHEEPURAM	3121.85	0	0	0	27	1335	0	0	228	0	0	0	0	0	0
27	Padappai	KANCHEEPURAM	6431.425	60	0	0	251	16	0	0	199	2	0	0	0	570240	570240
28	Pallavaram	KANCHEEPURAM	1697.335	0	0	0	0	805	0	0	1535	0	0	0	0	0	0
29	Pallikaranai	KANCHEEPURAM	4364.795	0	0	0	428	4867	0	0	2358	0	0	0	20	0	0
30	Pammal	KANCHEEPURAM	2163.98	0	0	0	64	1074	3	0	46	0	0	0	0	0	0
31	Sholinganallur	KANCHEEPURAM	3009.36	0	0	0	27	425	0	0	1362	60	0	0	4	0	0
32	Sriperumpudur	KANCHEEPURAM	8083.055	53	0	0	135	15	0	0	149	0	0	0	0	503712	503712
33	Tambaram	KANCHEEPURAM	2567.29	0	0	0	30	1018	0	0	2837	0	0	0	0	0	0
34	Thandalam	KANCHEEPURAM	7874.53	111	0	0	118	0	0	0	118	0	0	0	0	1054944	1054944
35	Vallam(K)	KANCHEEPURAM	7356.52	41	6	0	43	0	0	0	64	0	0	0	0	446688	446688
	Ambatttur	THIRUVALLUR	11087.55	205	0	0	55	5012	1605	0	0	734	6	0	0	1948320	1948320
38	Ammanambakkam	THIRUVALLUR	5942.665	739	55	0	1	70	0	0	0	17	0	0	0	7546176	7546176
39	Arani	THIRUVALLUR	5611.53	427	40	0	100	1045	0	0	165	25	0	0	0	4438368	4438368
	Avadi	THIRUVALLUR	4421	0	136	0	0	58	60	0	15	0	28	0	0	1292544	1292544
40	BALAPURAM	THIRUVALLUR	6588.165	316	168	244	680	24	44	8	3	0	0	0	0	4599936	4599936
41	Cherukkanoor	THIRUVALLUR	9413.05	348	45	0	883	217	8	0	32	3	0	0	1	3735072	3735072
42	Elavur	THIRUVALLUR	11340.38	475	4	73	170	864	0	0	465	22	0	0	0	4552416	4552416
43	Erumbi	THIRUVALLUR	4680.535	174	82	250	257	103	52	0	0	0	0	0	0	2433024	2433024
44	Gnayiru	THIRUVALLUR	6807.77	676	9	0	42	1004	0	0	185	3	0	0	5	6510240	6510240
45	Gummidipoondi	THIRUVALLUR	8487.065	334	32	0	250	585	48	0	95	20	0	0	0	3478464	3478464
46	Kadambathur	THIRUVALLUR	10181.47	327	122	47	161	659	0	0	5	0	0	0	0	4267296	4267296
47	Kanagammachattram	THIRUVALLUR	7334.67	458	87	77	289	214	0	0	34	6	0	0	0	5179680	5179680
48	Kannigaipair	THIRUVALLUR	6408.25	730	0	0	0	104	0	0	0	38	0	0	0	6937920	6937920
49	Kattur	THIRUVALLUR	10930.33	549	0	4	0	225	0	0	9	0	0	0	4	5217696	5217696
50	Kolur	THIRUVALLUR	9302.89	689	0	0	8	368	2	0	25	0	0	0	0	6548256	6548256
51	MADHARPAKKAM	THIRUVALLUR	11475.06	186	25	7	321	836	0	5	94	8	0	0	19	2005344	2005344
52	Madhavaram	THIRUVALLUR	6180.355	65	0	0	0	8930	0	0	1093	296	0	0	0	617760	617760

	MADURAVOIL	THIRUVALLUR	4582.13	86	65	22	0	6910	1363	0	1980	218	0	6	0	1435104	1435104
53	Manavor	THIRUVALLUR	4624.01	160	43	0	206	191	12	0	19	3	1	0	0	1929312	1929312
54	Mappedu	THIRUVALLUR	7516.824	79	0	0	13	301	0	0	25	14	12	0	2	750816	750816
55	Minjur	THIRUVALLUR	8109.305	338	0	0	0	1217	0	0	238	26	0	0	12	3212352	3212352
56	Morai	THIRUVALLUR	6421.325	455	11	6	0	3072	67	0	64	110	0	0	0	4428864	4428864
57	Pallipattu	THIRUVALLUR	7896.23	951	0	0	267	334	0	5	10	0	0	0	0	9038304	9038304
58	Pandur	THIRUVALLUR	7787.63	299	0	5	127	67	4	1	14	4	0	0	0	2841696	2841696
59	Pennalurpett	THIRUVALLUR	9492.095	309	15	0	287	64	0	0	77	4	0	0	9	3079296	3079296
60	PERIYAPALAYAM	THIRUVALLUR	6110.81	617	8	0	0	68	0	0	0	31	0	0	0	5940000	5940000
61	Ponneri	THIRUVALLUR	6451.63	738	0	4	5	1111	0	0	258	15	0	0	5	7013952	7013952
	POONAMALLEE	THIRUVALLUR	3670	0	168	0	0	2147	410	0	322	152	82	0	0	1596672	1596672
62	Poondi	THIRUVALLUR	8701.455	233	131	73	149	73	19	11	55	0	0	0	1	3459456	3459456
63	Poonimangadu	THIRUVALLUR	6066.715	252	115	105	392	175	20	0	20	0	3	0	0	3487968	3487968
64	Poovalambedu	THIRUVALLUR	10190.26	395	34	36	224	339	2	2	46	10	0	0	1	4077216	4077216
65	Pothattur pettai	THIRUVALLUR	8745.77	733	0	0	218	239	0	0	25	0	0	0	0	6966432	6966432
66	R.K.Pet	THIRUVALLUR	6326.3	242	213	145	585	41	45	0	4	0	0	0	0	4324320	4324320
67	Redhills	THIRUVALLUR	5499.645	60	14	0	0	9187	232	0	320	206	12	6	10	703296	703296
68	Sholavaram	THIRUVALLUR	6484.7	642	0	13	0	862	0	0	98	0	16	0	0	6101568	6101568
69	Thirumazhisai	THIRUVALLUR	5524	189	242	0	0	162	83	0	62	0	0	0	0	4096224	4096224
70	THIRUNINRAVUR	THIRUVALLUR	4218	0	235	0	0	425	50	14	153	80	0	0	5	2233440	2233440
71	Thirupalaivanam	THIRUVALLUR	11368.85	447	14	0	7	126	0	0	44	0	0	0	0	4381344	4381344
72	Thiruvalangadu	THIRUVALLUR	8222.58	224	48	0	290	251	30	7	37	5	0	0	0	2585088	2585088
73	Thiruvallur	THIRUVALLUR	6868.32	512	61	0	6	554	0	0	84	14	0	0	0	5445792	5445792
74	Tirur	THIRUVALLUR	6868.32	512	61	0	6	554	0	0	84	14	0	0	0	5445792	5445792
75	Tiruttani	THIRUVALLUR	9196.435	363	47	170	571	257	5	0	72	14	2	0	6	3896640	3896640
76	Uthukkottai	THIRUVALLUR	6625.275	1598	0	0	18	305	0	0	0	21	0	0	0	15187392	15187392
77	Velakapuram	THIRUVALLUR	7317.07	912	20	0	0	124	0	0	24	0	0	0	3	8857728	8857728
78	VELLIYUR	THIRUVALLUR	5242.905	884	160	0	11	249	56	2	19	4	32	0	0	9922176	9922176
79	Vengathur	THIRUVALLUR	8851.704	98	20	18	98	626	24	0	362	18	23	5	0	1121472	1121472
80	Arakonam(North)	VELLORE	9470.06	11	172	40	1140	19	33	2	106	0	0	54	0	1739232	1739232

81	Arakonam(South)	VELLORE	9674.675	12	350	123	1059	38	2715	137	6077	0	0	80	0	3440448	3440448
82	Banavaram	VELLORE	12752.56	25	298	373	2327	62	56	28	105	0	0	147	0	3069792	3069792
83	Kaveripakkam	VELLORE	8668.875	36	251	540	2499	74	68	7	91	0	0	49	0	2727648	2727648
84	Nemili(v)	VELLORE	10430.41	78	468	526	1908	10	15	0	102	0	0	118	0	5189184	5189184
85	Pallur	VELLORE	10420.65	123	329	434	1988	6	40	0	76	0	0	187	0	4295808	4295808
86	Panapakkam	VELLORE	8835.805	124	332	181	1765	14	55	0	77	0	0	51	0	4333824	4333824
87	Paranji	VELLORE	12833.86	30	237	440	2620	222	62	59	60	0	0	175	0	2537568	2537568
88	SHOLINGHUR	VELLORE	7521.91	2	6	0	1501	0	0	0	0	0	0	0	0	76032	76032
89	VELAM	VELLORE	8698.225	2	16	8	1381	0	0	0	0	0	0	0	0	171072	171072
90	EGMORE - NUNGAMBAKKAM--I	CHENNAI	465.6978					59480								0	0
91	EGMORE - NUNGAMBAKKAM--II	CHENNAI	236.8896					30256								0	0
92	EGMORE - NUNGAMBAKKAM--III	CHENNAI	235.3744					30063								0	0
93	EGMORE - NUNGAMBAKKAM-IV	CHENNAI	409.1271					91091								0	0
94	KOTTAI - THONDIARPET-I	CHENNAI	393.9742					20804								0	0
95	KOTTAI - THONDIARPET-II	CHENNAI	392.459					20724								0	0
96	KOTTAI - THONDIARPET-III	CHENNAI	506					39661								0	0
97	KOTTAI - THONDIARPET-IV	CHENNAI	281.338					14856								0	0
98	MAMBALAM - GUINDY-I	CHENNAI	534.8958					27646								0	0
99	MAMBALAM - GUINDY-II	CHENNAI	342.9596					16114								0	0
100	MAMBALAM - GUINDY-III	CHENNAI	514.692					26602								0	0
101	MAMBALAM - GUINDY-IV	CHENNAI	651.5728					33676								0	0
102	MYLAPORE - TIRUVALLIKENI--I	CHENNAI	44.44838					3264								0	0
103	MYLAPORE - TIRUVALLIKENI--II	CHENNAI	817.244					60015								0	0
104	MYLAPORE - TIRUVALLIKENI--III	CHENNAI	191.9362					14095								0	0
105	MYLAPORE - TIRUVALLIKENI--IV	CHENNAI	724.3065					53190								0	0
106	PURASAWALKAM - PERAMBUR-I	CHENNAI	480.3455					6796								0	0
107	PURASAWALKAM - PERAMBUR-II	CHENNAI	534.8958					7568								0	0
108	PURASAWALKAM - PERAMBUR-III	CHENNAI	436.9073					6182								0	0
109	PURASAWALKAM - PERAMBUR-IV	CHENNAI	276.7922					3916								0	0

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