18 Regional Simulation of a Groundwater Flow in Coastal Aquifer, Tamil Nadu, India

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INTRODUCTION

Increasing demand for groundwater due to ever increasing population has initiated the need for effective management of available groundwater resources. During the past two decades, the water level in several parts of India has been falling rapidly due to increase in pumping of ground waters. Proper management of aquifer systems is necessary as groundwater is the major source for domestic and industrial purposes, especially in urban and semi urban areas. Groundwater modelling is a powerful management tool which can serve multiple purposes such as providing a framework for organising hydrologic data, quantifying the properties and behaviour of the systems and allowing quantitative prediction of the responses of those systems to externally applied stresses. A number of groundwater modelling studies have been carried out around the world for effective groundwater management (Corbet and Bethke, 1992; Storm and Mallory, 1995; Gnanasundar and Elango, 2000; Senthil Kumar and Elango, 2004). Such a study was carried out in the coastal aquifer located south of the city of Chennai, India. In addition to this, local residents also pump water from this aquifer. This aquifer is under stress due to pumping of groundwater to meet the ever increasing water needs of the city. The present study was carried out with the objective of developing a numerical model for this area in order to understand the behaviour of the system with the changes in hydrological stresses. The finite difference computer code MODFLOW (Modular 3-d finite difference flow) with Groundwater Modelling System (GMS) as pre- and post-processor was used to simulate the groundwater flow in this study.

DESCRIPTION OF THE STUDY AREA

The study area lies just south of Chennai city and extends from Adyar river in the north to Muttukkadu estuary in the south. It covers an area of 20 km in length and 3 km in width. The eastern side of this area is bounded by the Bay of Bengal as shown in Fig. 1. Climate of this area is characterised by an oppressive hot summer, dampness in atmosphere nearly throughout the year and good seasonal rainfall. The summer season is from April to June which is followed by the southwest monsoon season from June to September. October to December constitutes the northeast monsoon season with the associated rains being confined to November and December. Average total rainfall is about 1260 mm/year.

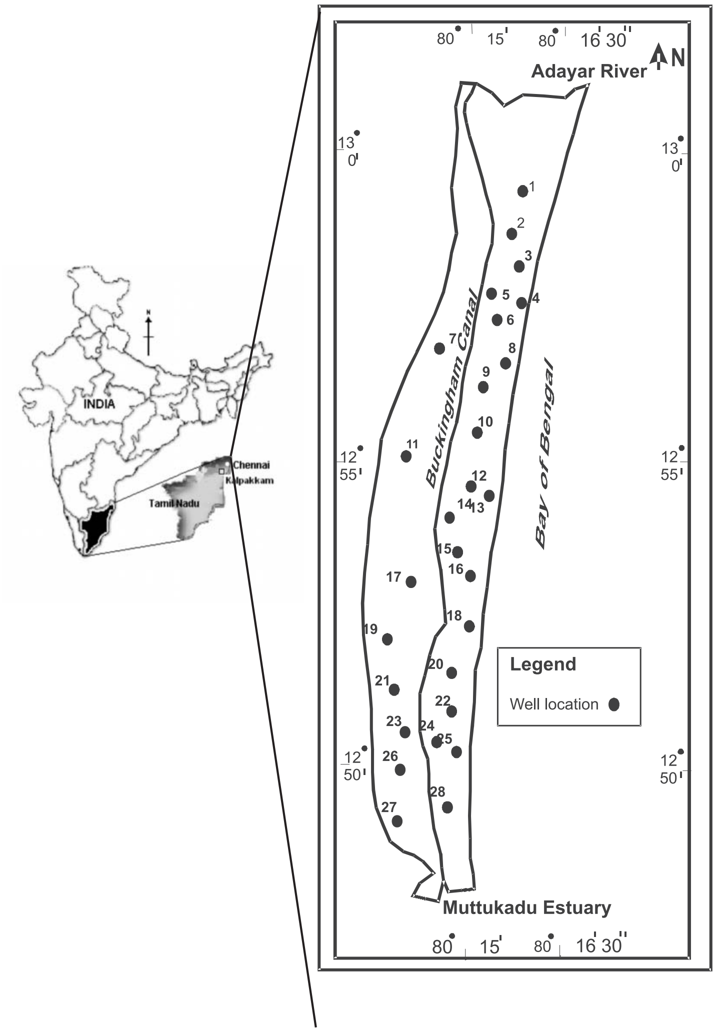

Figure 1. Study area with location of monitoring wells.

Geology and Hydrogeology

The study area exhibits varied physiographic features with elevation ranging from 1.0 to 11.5 m above MSL. The ground surface slopes towards the east and west from the central elevated portion. The region which lies towards the west of the Buckingham Canal has topographic elevation varying between 1.0 and 8.0 m above MSL. Western boundary of the study area has the highest elevation of 8.0 m above MSL. Geologically, the area comprises unconsolidated sandy formation of different depositional environments belonging to Quaternary age. The alluvial deposits are comprised of interlayered clay, silt, sand, gravel and pebble beds. These formations overlie the charnockites of Archean age. Charnockites occuring below this sandy formation function as impermeable strata or bed rock. The total depth of the aquifer system ranges between 3 and 23 m (Gnanasundar and Elango, 2000). The hydraulic conductivity of the aquifer lying west of the Buckingham Canal has values between 25 and 35 m/day, while the sub basin along the east of the canal has high hydraulic conductivity with values ranging between 45 and 75 m/day. The specific yield of the aquifer ranges from 0.17 to 0.23.

GROUNDWATER MODELLING

The computer software programme MODFLOW, Groundwater Modelling System (GMS), (McDonald and Harbaugh, 1998) developed by the United States Geological Survey was used for the present study to give input data and process the model output. This equation describes the groundwater flow under non-equilibrium and anisotropic medium, provided the principal axes of hydraulic conductivity are aligned with x-y Cartesian coordinates axes. The computer programme uses finite-difference technique and block-centered formulation to solve the groundwater flow equation for the three dimensional steady and transient flow in heterogeneous media of the South Chennai aquifer.

Model Formulation

The conceptual model of the hydrogeologic system was derived from a detailed study of the geology, borehole lithology and water level fluctuations in wells. Groundwater of the study area was found to occur in both alluvial formations and in the underlying weathered rocks. The measured groundwater head in monitoring wells, screened in the alluvial and weathered formation, is about the same. Based upon this information, the alluvial and the weathered fractured rocks can be considered as a single, unconfined layered system.

Grid Design and Boundary Conditions

The scanned map of the study area was imported in the MAP module of GMS with proper geographical registration. Boundaries and canal of this map were digitised as polygons in the MAP module. This digitised map automatically generated grid pattern for use in the MODFLOW.

The gird pattern was developed by assigning a constant spacing 400 × 600 m. This spacing resulted in dividing the area into 40 rows and 30 columns (Fig. 2). A part of the area was discretised into a relatively finer mesh size as they comprised numerous pumping wells. Vertically this region was divided into a single layer of varying thickness. The Bay of Bengal, Muttukadu Estuary and the Adyar River were taken as constant head boundaries as the water levels in these water bodies are generally at mean sea level throughout the year. The Buckingham Canal was taken as internal constant head boundary with the constant head at mean sea level. The western boundary of the area was considered as a no flow boundary as shown in Fig. 2.

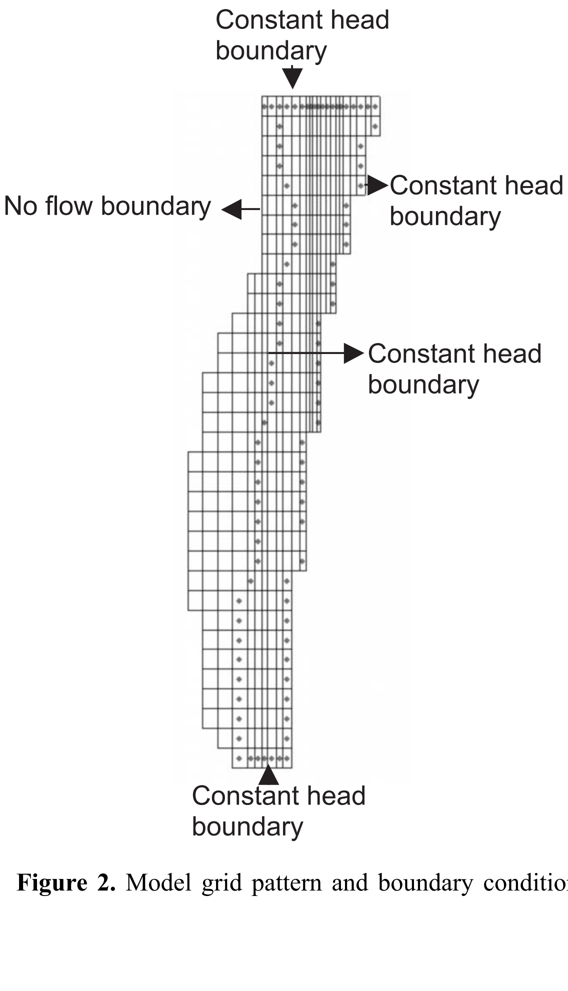

Figure 2. Model grid pattern and boundary conditions.

INPUT PARAMETERS

Aquifer Characteristics

Horizontal hydraulic conductivity of the sandy aquifer ranges between 25 and 75 m/day. Aquifer lying west of the Buckingham Canal has values between 45 and 75 m/day. The low K value along west of the canal is attributed to the presence of sandy clay and clay. The specific yield of the alluvial aquifer ranges from 0.17 to 0.23. The specific yield of the aquifer existing between the coast and the canal ranges between 0.21 and 0.23, while the other portion has values ranging between 0.17 and 0.19.

Groundwater Abstraction

The groundwater of the study area is abstracted for domestic, industrial and irrigational purposes. The average annual pumping is about 4.25 MGD. This has been obtained from the government agencies such as the Public Works Department and Metro Water. Pumping rate by private agencies was estimated through field visits. The pumping rate of wells that exist within the housing complexes in the northern part of the study area was also taken into account and pumping rates from these wells were estimated from well inventory survey by collecting data on pumping duration in a day. About 90% of the total pumping occurs within the regions lying between the Buckingham Canal and the coast. The pumping activity on western side of the canal is limited only to domestic purposes mainly for drinking and other household purposes due to poor groundwater quality.

Groundwater Recharge

The rate of rainfall recharge varies within the study area. Two recharge zones, A and B, have been demarcated based on the soil types, geomorphic pattern, land use and topography. The rainfall recharge rate in zone A is around 40-48% and in zone B it is around 25-35% as shown in Table 1. High recharge occurs in Zone A where sand and sand dunes occur. Recharge rate in the areas of zone B is quite less due to the presence of sandy clay/clayey soil.

Table 1. Recharge value incorporated in the model

Zone	*Recharge %*
Zone A (Sand)	40-48%
Zone B (Sandy clay/Clayey soil)	25-35%

Model Calibration

The calibration strategy was initially to 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 datasets. Transient state model calibration was carried out to minimize the difference between the computed and field water level conditions with the water level data of January 2000 in 28 wells distributed over the study area. Out of all the input parameters, the hydraulic conductivity and specific yield are the poorly known. Based on the data, it was decided to vary hydraulic conductivity, specific yield values up to 10% to get a good match of the computed and observed heads (Fig. 3). Table 2 shows the initial and calibrated hydraulic conductivity values of the simulated head. The root mean square error and mean error were minimised through numerous trial runs. Transient-state simulation was carried out for a period of six years from January 2000 to January 2006, with monthly stress periods and 24 hr time steps. The trial and error process by which calibration of the transient model was achieved included several trials until a good match was achieved between computed and observed heads over space and time.

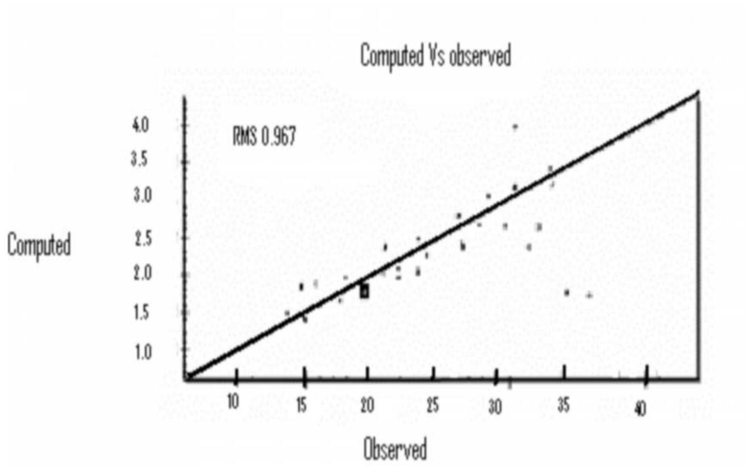

Figure 3. Computed and observed head in transient state calibration.

Table 2. Initial and calibrated hydraulic conductivity and specific yield of the simulated head

Geology of the area	*Hydraulic conductivity (m/day)*		*Specific yield*	
	Initial	*Calibrated*	*Initial*	*Calibrated*
Sand	75	81	0.22	0.31
Clayey sand	25	21	0.17	0.23

SIMULATION RESULTS

The model was simulated with the regional groundwater head and it was compared with the observed data of 28 wells. The predicted regional head generally follows the observed regional groundwater head. The regional groundwater head for the months of January 2000 and January 2006 is shown in Figs 4 and 5 respectively. In general, the simulated results indicate that this aquifer system is stable under the present pumping rate, excepting for a few locations along the coast where groundwater level has gone up to 1 m above sea level. The regional groundwater flow direction is towards east. There is fairly good agreement between the computed and observed heads. A comparison between the observed and computed head values for the observation well no. 8 is shown in Fig. 8. The computed head values mimic the observed head values.

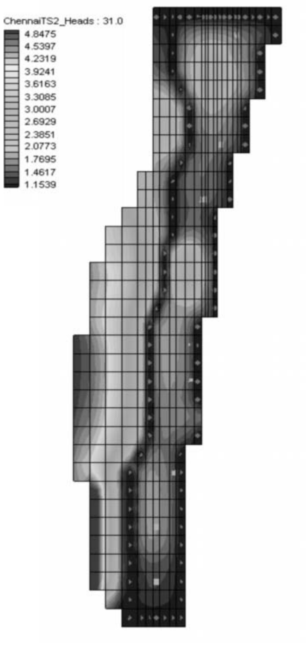

Figure 4. Computed regional groundwater head (Jan 2000).

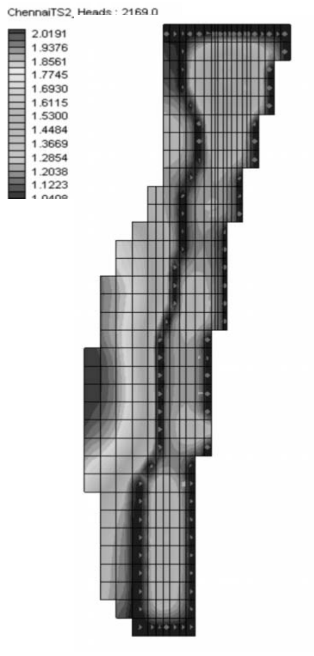

Figure 5. Computed regional groundwater head (Jan 2006).

Increase in Pumping

As groundwater is the major source of water for the cities from this region, there has been increase in pumping over the years. Hence, it is essential to know the behaviour of the system under increased hydrological stress. The model was simulated for the increase in pumping of 10% along the coastal region. The regional groundwater heads for the months of January 2000 and January 2006 are shown in Figs 6 and 7, respectively. A comparison between the observed and computed head values for the observation well no. 8 is shown in Fig. 9. In well No. 8, the groundwater head is lowered by 0.5 to 1.5 m. The result clearly indicates that the aquifer is not stable and increase in 10% pumping in the coastal region does affect this aquifer system.

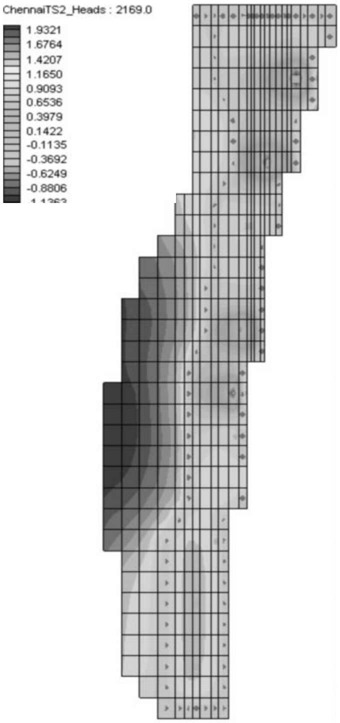

Figure 6. Computed regional groundwater head after 10% increase in pumping (Jan 2000).

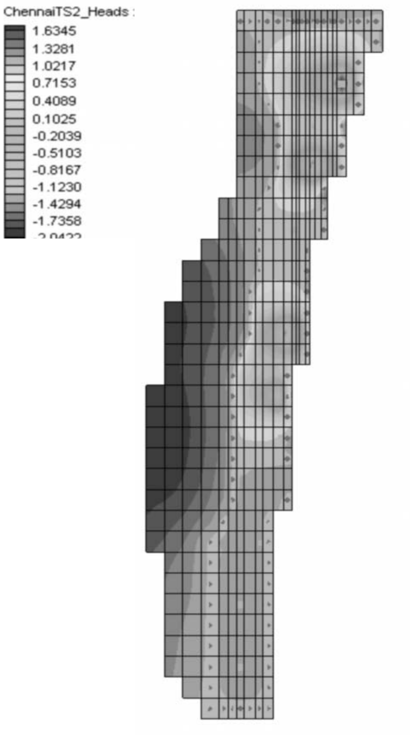

Figure 7. Computed regional groundwater head after 10% increase in pumping (Jan 2006).

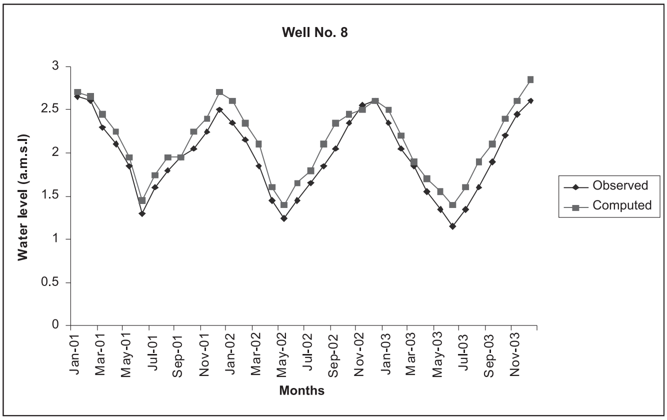

Figure 8. Computed and observed water heads at normal pumping in well no. 8.

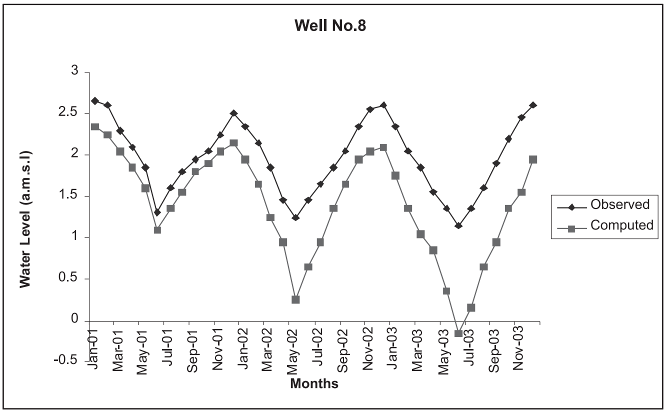

Figure 9. Computed and observed water heads at 10% increase in pumping in well no. 8.

CONCLUSION

Simulation of groundwater flow by three-dimensional mathematical model indicates that this aquifer system is stable under the present pumping rate. The computed groundwater head over space and time matches reasonably with the observed groundwater head with a difference of 0.4 m. Sensitivity analysis revealed that the developed model is very sensitive to recharge and, to some extent, hydraulic conductivity and specific yield. Increase in 10% pumping rate will lead to lowering of the groundwater head by 0.5 to 1.5 m. This will result in seawater intrusion in coastal regions of this aquifer system. The study indicates that the total abstraction from this aquifer has to be restricted to 4.25 mgd to prevent seawater intrusion.

REFERENCES

Corbet, T.F. and Bethke, C.M., 1992. Disequilibrium fluid pressures and ground water flow in western Canada sedimentary basin. *J. Geophys. Res.*, **97(B5):** 7203-7217.

Gnanasundar, D. and Elango, L., 2000. Groundwater flow modelling of a coastal aquifer near Chennai city, India. *Journal of Indian Water Resources Society*, **20(4):** 162-171.

McDonald, M.G. and Harbaugh, A.W., 1998. User's documentation for MODFLOW-98, an update to the U.S. Geological Survey modular finite-difference ground-water flow model, U.S. Geological Survey Open-File Report 96-485, pp56 ISBN 90 54 10 942 4.

Storm, E.W. and Mallory, M.J., 1995. Hydrogeology and simulation of groundwater flow in the Eutaw-Mcshan aquifer and in the Tuscaloosa aquifer system in northeastern Mississippi: U.S Geological Survey Water Resources Investigations Report 94-4223, 83.

Senthilkumar, M. and Elango, L., 2004. Three-dimensional mathematical model to simulate groundwater flow in the lower Palar River basin, southern India. *Hydrogeology Journal*, **12(4):** 197-208.