CHAPTER 8
SUMMARY AND CONCLUSIONS

8.1 SUMMARY

Multiaquifer systems of alluvial or glacial deposits invariably consist of an upper water table aquifer, underlain by aquitard(s) and artesian aquifer(s). In such systems, the aquifers respond collectively for the imposed hydrologic stresses. The Minjur-Panjetty Aquifer System situated north of the city of Madras in Tamilnadu State, India is one such system with an upper water table aquifer having low hydraulic conductivity, a potential lower artesian aquifer, and an aquitard separating the two aquifers. A study of the groundwater hydrographs and their relative positions with reference to the upper and lower aquifer formations reveals that the aquifer system is subjected to nonlinear flows due to the varying water table elevation with time in the upper formation and the changing conditions of part of the lower aquifer between artesian and water table. Normally, multiaquifer systems are modelled as linear systems, ignoring the nonlinear features present in them. Such an approach is likely to result in incorrect simulation of the systems. Therefore, in this investigation, a model is developed for the MPAS, taking the nonlinear features into consideration.

The MPAS is conceptualized as a two-layer aquifer system with an upper water table aquifer, a lower artesian aquifer and an aquitard separating these two. The assumptions involved in formulating the model are stated and the governing equations of groundwater flow in the upper and lower aquifers and in the aquitard are described. The finite difference forms of the governing equations are written, using backward difference method. The final form of the model accounts for the following nonlinear features:

(i) The changes in transmissivity resulting from changes in saturated thickness of the lower aquifer
(ii) The storage coefficient changes introduced by the lower aquifer changing between artesian and water table conditions and the movement of the unconfined - confined interface

(iii) The changes in leakage brought about by the changing condition of the lower aquifer between artesian and water table, and the variation of water table elevation in the upper aquifer caused by recharge to and leakage from it.

The finite difference model uses in a time step the average of the leakage that occurs during the time-step period and also accounts for the gravity leakage. As nonlinear features are included in the model, iterative technique is used for the solution. In each iteration, the set of finite difference equations written for the governing equations of flow in the lower aquifer is solved using successive over relaxation technique.

Modelling the different types of boundary conditions, fixed head boundary, known flow boundary and impermeable/streamline boundary, are explained. The adjustments that are to be made to the aquifer parameter values at the boundary nodes to treat them in the model in the same way as those of the internal nodes, are detailed. Finally the computational procedure is described.

The digital model is validated using the analytical solutions available for the one- and two- dimensional flow problems.

Using the borehole data of the MPAS, the upper water table aquifer, the lower artesian aquifer and the aquitard separating these two are delineated and contour maps of the surfaces that delineate the formations are prepared. The areal extent of these formations and the boundary conditions are decided. The spatial variations of the thickness of the aquitard and of the lower aquifer are determined. The hydrogeologic parameters of the upper and lower aquifers and the aquitard are quantified based on the available pumping test data and the soil classifications reported in the borehole data.
A period of seven years from 1976 to 1982 is used for the simulation of the MPAS. The flows that occur in the MPAS are the recharges from rainfall, riverbed and irrigated water, the subsurface inflow and outflow and the abstractions for irrigation and industrial use. The rainfall recharge and irrigation abstraction form the major components of the flows in the system. An empirical model is used for the computation of monthly rainfall recharge. The riverbed recharge is taken as five percent of the rainfall recharge that occurs during the monsoon period of October, November and December and the subsurface inflow is taken as 20 percent of the riverbed recharge. The recharge from irrigated land is taken as 40 percent of the irrigated water.

The annual irrigation abstraction is estimated using the annual EEC data. The monthly irrigation abstraction is arrived at using monthly EEC data of a few representative villages. Tables 5.4 and 5.6 give the annual and monthly irrigation abstraction for the study period. The industrial abstractions taking place from the Minjur and Panjetty well-fields are given in Tables 5.7 and 5.8. In general, the data available are inadequate and hence the computation of the inflows and outflows involves assumptions.

The recharges occur mainly to the upper aquifer, the abstractions take place from the lower aquifer and these two aquifers are interconnected hydraulically by the leakage through the aquitard. The responses of the upper and the lower aquifers for the given flows are studied from the hydrographs of the shallow and deep observation wells, respectively.

The area of the MPAS is discretized by superposing a finite difference grid of 1km x 1km, resulting in 492 nodes including boundary nodes. The time is discretized by taking three time steps in a month with 10 days duration for the first two time steps, followed by the third step with the remaining days of the month. The flows are given for each month of the study period and during the month the flows are assumed to occur uniformly with time. The spatial distribution of each one of these flows is implemented using flow factors. The method adopted to get the initial conditions is explained. The model is run for the seven years of
flow data and calibrated. While calibrating the model, the hydrogeologic parameters and the recharges from rainfall and irrigated water are varied within reasonable limits to get better simulation of the system.

The model is tested for seven years of flow data from 1976 to 1982 and the simulated groundwater head hydrographs of the upper and lower aquifers are compared with the measured hydrographs. In deciding the validity of the proposed model, the elevation, shape and the magnitude of annual fluctuation of the groundwater hydrographs are taken as the criteria and the simulated hydrographs are visually compared with the field hydrographs. The comparison of the simulated and field hydrographs of the upper aquifer, Figures 7.1a to 7.1g, shows that the model simulates the upper aquifer fairly accurately. The comparison of the model and field hydrographs of the lower aquifer, Figures 7.2a to 7.2d, shows that the simulation of the lower aquifer is good. The proposed model predicts that 10-14 percent of area of the lower aquifer changes every year between confined and unconfined conditions. Figures 7.5a and 7.6 show the net groundwater discharge to sea and the vertical leakage between the upper and the lower aquifers, respectively. The comparison of the computed results with the field data shows that the proposed model simulates the MPAS fairly accurately.

A study on the effects of not including anyone or all of the nonlinear features of the aquifer system in the proposed model indicates the following:

(i) Ignoring the changing condition of the lower aquifer from confined to unconfined and using the confined storage coefficient values to the nodes that have changed to unconfined condition leads to larger fluctuation of groundwater head in the lower aquifer than that computed by the proposed model.

(ii) Considering the condition of the lower aquifer at each node either confined or unconfined at the beginning of every time step and using the nodal storage coefficient values as per the aquifer condition but ignoring the changes in the condition during a time step, results in the model loosing water. With the result,
the magnitude of the annual groundwater head fluctuation gets decreased, and a decline in groundwater head with year takes place. The loss of water in the model also leads to decline in the water level elevation in the upper aquifer.

(iii) Ignoring the variation of the water table elevation with time in the upper aquifer and assuming the water table to be at a constant elevation at each node leads to higher vertical leakage, decrease in the annual groundwater head fluctuation, increase in the groundwater head with time and larger discharge to sea.

(iv) Ignoring the variation of the saturated aquifer thickness and assuming a constant transmissivity between the nodes has little effect on the model results. This is because the aquifer area that changes between confined and unconfined in a year is less than 14 percent, the reduction in saturated aquifer thickness is less than 20 percent and the magnitudes of the lateral flows in the system are small.

(v) Ignoring all the nonlinear features leads to higher vertical leakage, higher groundwater head elevation, increasing trend in groundwater head elevation with time, larger flow to sea and a larger fluctuation of groundwater head in the month of September. Above all, the shape of the hydrographs differ.

The study shows that the proposed model simulates the aquifer system much better than any of the models that ignore anyone or all of the nonlinear features. One important factor to be considered here is that the differences noticed between the results of the proposed model and the models which ignore the changes in the aquifer condition between confined and unconfined are due to changes in the aquifer area of less than 14 percent. The effect of the variation of the saturated thickness of the aquifer will be significant if the variation is more and the magnitudes of the lateral flows become large. The discharge to sea does not vary appreciably between the different models except those which ignored the changes in the water table elevation in the upper formation. It is because
the net discharge to sea depends on the groundwater head distribution in the eastern part of the aquifer and the influence of the aquifer condition changing between confined and unconfined in the western part has not spread appreciably to the eastern part. The continuity condition for the whole aquifer area leads to the simulation of almost the same vertical leakage by all the models except those that assume a constant water table elevation in the upper formation.

8.2 CONCLUSIONS

The following are the main conclusions of this study:

1. The proposed model accounting for all the nonlinear features described in Chapter 3 simulates the Minjur-Panjetty aquifer system fairly satisfactorily. The model results show that about 10-14 percent of the aquifer area changes between confined and unconfined conditions in a year.

2. Any model which ignores one or more of the nonlinear features of the system is not able to simulate the system satisfactorily. The results indicate beyond doubt, that the nonlinear features in an aquifer system be taken into account while modelling it.

3. Modelling nonlinear features leads to better understanding of the flow mechanism. For example the assumption of constant water level in the upper aquifer implies infinite source of water for ever, even if there is no recharge to the aquifer. Such an inconsistency will not arise in the proposed model.

4. The fact that a model looses water while not taking into account the changing condition of the aquifer between confined and unconfined during a time step is a significant understanding that comes out of the model results. The loss of water in the model increases with increase in the length of time step.

5. The order in which the nonlinear features affect the proposed model results are:
(i) Ignoring all the nonlinear features and modelling the system as a linear one. Sometimes the nonlinear features may have opposite effects and the net result may look better than the results of a model which ignores one of the nonlinear features. The results in such circumstances do not lead to better understanding of the aquifer system (Model 5).

(ii) Ignoring the changes in the condition of the lower aquifer from confined to unconfined and using confined storage coefficient value in the model (Model 2A).

(iii) Ignoring the changes in the condition of the lower aquifer during a time step and using, at each node, the storage coefficient value that is decided based on the condition of the aquifer at the beginning of each time step (Model 2B).

(iv) Assuming a constant water level with time in the upper aquifer (Model 3) and

(v) Assuming a constant transmissivity by ignoring the variation in the saturated aquifer thickness with time (Model 4).

8.3 SUGGESTIONS FOR FUTURE WORK

The following are the suggestions for further work:

1. The model developed ignores the lateral flow in the upper aquifer. The model utility can be improved by taking into consideration the lateral flow in the upper aquifer.

2. A sensitivity analysis of the empirical model proposed for the estimation of rainfall recharge is necessary.

3. In a coastal aquifer, the sea water intrusion may have the shape of a wedge. The proposed model does not account for such an intrusion while computing the discharge to sea. The model needs improvement in this regard to estimate accurately the discharge to sea and to estimate the sea water intrusion.
4. The model application to the MPAS can be validated using the data for the period 1983 to 1986.