# 8. DISCUSSION AND CONCLUSIONS

Discussions with regard to a specific topic are detailed in each of the preceding chapters of the dissertation and conclusions have also been drawn at the end of each chapter. Therefore, the main aim of this chapter is to discuss points which require further detail, to compare some features of the hydrosalinity module of *ACRU* against other existing hydrosalinity models and to present a general conclusion based on the results of the research project.

In the last few decades increasing demands on limited water resources and increasing pollution of these resources (especially in terms of salinity) have been great cause for concern in many arid and semi-arid areas of the world, including South Africa (Cowan and Skivington, 1993). The sustainability of agriculture and the preservation of soil and water resources in these areas require an appropriate balance between the potentially negative on-site and off-site effects of salinity. In order to achieve these goals, catchment modelling plays an important role in assessing future trends in salt load and land salinisation as well as the impacts of different management options. However, this in turn requires an understanding of the different sources and processes involved in hydrosalinity. In order to understand the main sources and controlling processes of hydrosalinity and to explore some modelling techniques employed to describe the interaction between the various sources and hydrosalinity processes, an extensive literature review was undertaken in Chapters 2 and 3.

The various sources and processes of hydrosalinity are interrelated. The salinity hazard posed on a given land and water resource is influenced by various processes that are responsible for the release, transport, and deposition of salts related to each source. Hence, modelling of hydrosalinity processes requires a comprehensive approach that takes into account salt inputs from various sources such as atmospheric deposition, irrigation water and fertilizer application; salt uptake by plants and precipitation; release of salts from weathered soil and rock materials as well as transportation mechanisms through the soil profile to receiving streams and reservoirs. Therefore, catchment managers and other practitioners generally need to consider the interaction between factors such as climate, hydrology and catchment characteristics, including land use practices, for proper management of their land and water resources. Despite the fact that most of the sources and processes of hydrosalinity are highly interrelated, knowledge about the main sources and the manner in which the dominating processes influence water salinity is vitally important for the development of hydrosalinity models.

As noted by Jayatilaka and Connel (1995), different modelling approaches can each play a role in some hydrological simulation. However, in developing a model or when applying an existing model to handle a particular problem, it is important to consider several factors that determine model suitability. Some of these factors are: the scale of the problem (be it field or catchment), the type of simulation (event or continuous) and the accuracy of the output required. In addition, the availability of data, both for model calibration and for verification, needs to be taken into account. Therefore, the basic types of water quality and quantity models are reviewed in Chapter 3 followed by how the various hydrosalinity processes are represented in these models, with special emphasis on soil salt balance and movement. Review of the various hydrosalinity models has shown that most of these models operate in lumped mode. However, hydrosalinity studies at a catchment scale usually require discretisation of the catchment into a number of (usually relatively homogenous) sub-catchments in order to accurately model the salinity level and salt loading in bigger catchments or in catchments with complex land uses and soils. Therefore, there is a research need to develop catchment based distributed hydrosalinity models. The hydrosalinity module of *ACRU, viz. ACRUSalinity,* can simulate TDS concentrations and salt loading both in single catchment (lumped mode) and in multiple sub-catchments (distributed mode), with salt transport occurring from one sub-catchment to another based on the direction of flow as determined by the cascading sub-catchment configuration. Therefore it is hoped that, the development of *ACRUSalinity* will make a significant contribution towards filling the abovementioned research needs in the facet of hydrosalinity modelling.

*ACRUSalinity* is developed in the object-oriented version of *ACRU, viz. ACRU2000*. This version has a modular structure, where new modules can be added to the model with little or no interference with the existing modules. The modular structure of *ACRU2000* has facilitated the development of *ACRUSalinity* because, with the new structure, any new module can easily inherit much of the basic structure and many of the objects of *ACRU2000*. This is possible in *ACRU2000* since it is implemented with an object-oriented programming technique. Therefore, the role of object-oriented programming tools such as the Java programming language and Rational Rose Software were important in the development of *ACRUSalinity,* both when building new objects and when defining the relationship of these objects with the existing hydrological modules of *ACRU2000* for an easy flow of information and data between the various objects.

Although the object-oriented programming technique has significant merits over the procedural programming languages such as BASIC and FORTRAN, it is not without limitations. Some of the problems encountered during the development of *ACRUSalinity* were the low speed of execution and problems related with precision limits. It was noticed that *ACRU2000* takes a longer time for execution than the FORTRAN based *ACRU 300*. The second problem is attributed mainly to rounding errors. As described in Chapters 4 and 5, certain data objects such as *DWaterFluxRecord* and *DSaltFluxRecord* serve not only to store data, but also to conduct internal water and salt balance computations with the help of their parent classes. Therefore, if a new process under development attempts to transport salt from one component to another, and if the salt loading in the supplying (owner) component is lower than the salt load requested for transfer, then an error message is sent and execution halts. Such problems were encountered mainly during the distribution of the salt load from adjunct impervious and non-irrigated areas to a reservoir and to channel reaches in the presence of an internal reservoir. Therefore, in these processes dealing with salt load distribution, an attempt was made to avoid this type of problem through introduction of a "correction value" of plus or minus the difference between the quantity of salt stored in the owner component and the requested quantity of salt load for transport to a destination component. However, this correction value is added to, or subtracted from, the owner/destination component if, and only if, the difference ("correction value") is between -0.001 mg and 0.001 mg, since a difference outside of this limit might also be caused due to incorrect computer coding.

The subsurface TDS balance in *ACRUSalinity* generally adopts the technique employed by the DISA hydrosalinity model (Görgens *et al.*, 2001). However, subsurface salt movement is based primarily on the principle of conservation of mass and thus it depends mainly on the water balance and the direction of flow as conceptualised in the hydrological modules of *ACRU*. For example, subsurface salt movement associated with saturated upward and downward soil water flow depends mainly on the quantity and direction of flow as determined by the hydrological modules of *ACRU*. The subsurface component of a non-irrigated land is represented in *ACRU* with two soil horizons (topsoil and subsoil) and an intermediate/groundwater store. The subsurface system of an irrigated land is represented with only a single soil horizon and a groundwater store. Therefore, the Lagrarian salt lagging approach used in the DISA model to account the impact of a difference in TDS concentration of percolation water entering into a layer and whose origin is from more than one overlying layers, is not employed in *ACRUSalinity*. This is based on the assumption that since the soil profile is divided into only two layers (in the case of non-irrigated lands), the depth of water percolating to the groundwater system on a particular day is less than the soil moisture content of the subsoil at the end of the previous day. Thus, the origin of the daily percolation water into the groundwater store is assumed to be only from its immediate overlying layer (i.e. the subsoil).

The process of salt generation in the DISA model is described by an empirical equation (Chapter 3, Section 3.4.3.1). However, this equation was reported not to be entirely successful in a realistic simulation of subsurface salt generation processes (Görgens *et al.*, 2001). Therefore, an attempt was made in *ACRUSalinity* to find an alternative equation that could describe this process. The first order rate kinetics equation was employed by Ferguson *et al.* (1994) to describe an enrichment of individual solute species in soil water. This equation was adopted in *ACRUSalinity* to describe salt generation in subsurface components. It describes the salt generation process in the soil and groundwater system fairly well. The problem in using this equation is, however, to obtain values for its parameters from physical measurements. Values of these parameters for most of the individual solute species can be obtained from literature (Ferguson *et al.*, 1994). However, no such data are available for total dissolved solutes, since this is probably the first research of its kind to apply this equation on total dissolved solutes. Estimated values of these parameters can be determined if time series of soil salinity data are available for the area. The rate constant, $k$, may be estimated from fitting a regression equation to observed data measured at below drained upper limit (DUL), i.e. when there is no significant mixing taking place due to percolation from an upper layer. Below DUL, drainage ceases and the water remaining is held by capillary forces which are sufficient enough to resist gravity (Schulze *et al.*, 1995b). Similarly, the equilibrium concentration of respective horizons may be estimated from salinity data recorded after a long spell of dry weather.

Runoff salinity depends on the volume and TDS concentration of stormflow and baseflow. Therefore, runoff TDS concentration is determined in *ACRUSalinity* based on an instantaneous mixing of surface and subsurface flows. The value of baseflow salinity is determined from the consideration of the combined effects of water and salt balance in the subsurface system. However, stormflow is assumed to have the same TDS concentration as the average salinity of rainfall in the catchment. This is based on the report from some researchers who have indicated that stormflow salinity is not expected to show a significant difference when compared to TDS concentration of the rain falling on the land, or the applied irrigation water (for example, Rhoades *et al.*, 1997; Mironenko and Pachepsky, 1998). The assumption that stormflow salinity as having the same TDS concentration as the rainfall salinity may not hold true in areas characterised with significant salt crusts. In such areas the stormflow salinity may initially rise with the rising limb of a hydrograph on the first flush of rainfall following a prolonged dry spell.

The salt load associated with runoff water is distributed to channel and/or reservoir reaches depending on the catchment configuration. In general, the determination of baseflow and stormflow salinity, as well as runoff salinity and salt loading and the subsequent salt allocation to a destination reach, is based on physical processes. Thus, the hydrosalinity module of *ACRU* is suitable for testing various "what if" scenarios to assess the impact of changes in land use, climatic and hydrologic as well as water resources developments such as construction of reservoirs, on future catchment TDS balance including surface and subsurface TDS concentration and salt export to downstream reaches.

The module evaluation phase of this research has involved code validation and verification against observed data. The code validation was undertaken mainly to detect errors emanating from incorrect computer coding through using the principle of mass conservation. The code validation has proved that the main algorithms describing the various hydrosalinity processes in *ACRUSalinity* are safe from such errors, except for minor rounding errors. The verification result through comparison of model simulation against observed streamflow TDS concentrations at Camden (U1H005) gauging weir in the Upper Mkomazi Catchment has shown good results. Both the graphical and the statistical analysis of observed and simulated values have indicated that the simulated streamflow salinity values mimic the observed values remarkably well.

A sensitivity analysis was carried out to assess model responses to changes in the values of the major hydrosalinity input parameters. From the sensitivity tests, it was noticed that runoff water salinity was less sensitive to changes in salt uptake rate constant (*k*) than baseflow salinity, although both parameters have also shown low sensitivity to changes in the value of *k*. However, a significant difference in sensitivity of TDS concentration of various subsurface components to changes in *k* was observed with an increasing sensitivity from topsoil down to the groundwater store. A similar result was also obtained from a sensitivity test on the impact of changes in value of the salt saturation (equilibrium) parameter on surface and subsurface components. The model has also shown a relatively high sensitivity to changes in initial subsurface TDS concentration for the first three months of the simulation period, but thereafter, the value of this parameter had little impact on surface and subsurface TDS concentrations. The model has shown low sensitivity to changes in initial reservoir water TDS concentrations. Therefore, no single input parameter dominantly impacts the surface and subsurface water TDS concentrations. Rather, TDS concentration in these components is a function of all the water quantity and salinity related parameters.

Because these are general observations from the sensitivity analysis, it is difficult to assume results from these sensitivity tests as being conclusive and applicable under all conditions. Rather, the sensitivity result for most of the parameters is expected to change, depending on climatic, hydrological and catchment conditions of an area. For example, results from an assessment of the impact of initial subsurface and reservoir TDS concentration on daily TDS concentration vary, depending on such factors as the volume and timing of rainfall events. If a high rainfall event occurs at the beginning of the simulation period then the initial TDS concentration is expected to have little impact on the subsequent days' TDS concentration, whereas, in the absence of any dilution by rainfall or irrigation water, in the case of subsurface components, the subsurface water salinity increases according to the first order rate kinetics and thus the model response would be high to changes in value of the initial subsurface water salinity.

Although, for a more accurate simulation and improved applications of the module, it is necessary to conduct further research and additions to the module, the present hydrosalinity module of *ACRU* comprises several process objects that can be used to provide a reasonable first order approximation in a number of hydrosalinity studies. The present applications of the new module include for an assessment of:

- the impact of changes in future climatic and hydrological changes on TDS concentration and salt loading
- the impact of forest plantations or clearing of forests on dryland salinity
- the on-site and off-site impacts of irrigation on surface and subsurface water salinity as well as its impact on downstream TDS concentrations in streamflow and salt loading
- the impact of water resources developments, such as a reservoir, on downstream TDS concentration or
- the impact of different management options on reservoir TDS concentration and salt loading.

In general, the new module generates a number of output information that could be used in the above-mentioned and other applications, whereas, the input information specific to the new module are very few compared to the extent of output information (Appendix A). Therefore, considering the module's intended use as a catchment scale hydrosalinity simulation tool mainly for application in developing countries where limited data is a major problem, the module is designed so that it can run using the minimum input information and yet provide reasonably adequate information for use in planning, design and management of land and water resources with the purpose of preventing land and water salinisation. Further research to enhance the performance of the newly developed hydrosalinity module is recommended in the next chapter.