GROUNDWATER BALANCE MODELLING WITH DARCY’S LAW

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May 2007

A thesis submitted for the degree of Doctor of Philosophy of The Australian National University
This thesis is my original work, except where otherwise acknowledged in the text. Some of the work in this thesis was undertaken prior to my graduate enrolment at The ANU. The steady state GAB model was developed from December 1996 to 2000 and was first published in 2000, and the Bowen model was developed during 2000 to 2002 and was first published in 2002. The development of the transient GAB model commenced in 2002. This work has not previously been submitted for a degree or diploma in any institution of higher education.

Wendy Welsh
May 2007
Acknowledgements

The work for this thesis was undertaken at the Bureau of Rural Sciences, Australian Government Department of Agriculture, Fisheries and Forestry, while I was enrolled with the Integrated Catchment Assessment and Management Centre, School of Resources, Environment and Society, The Australian National University. I thank the Bureau and the Centre for their support and for providing very stimulating working environments.

This work would not have been possible without the data provided by the Queensland Department of Natural Resources and Water, the NSW Department of Natural Resources, the SA Department of Water, Land and Biodiversity Conservation, the NT Department of Natural Resources, Environment and the Arts, the Department of Primary Industries and Resources of SA, BHP Billiton Olympic Dam Operations and the Queensland Herbarium.

Particularly, I thank my supervisory panel, consisting of Professor Anthony Jakeman (Chair), Dr Barry Croke and Professor John Norton for their guidance. Their interest, encouragement and generous support are greatly appreciated.

Special thanks go to Linda Foster, Michael Williams, Lloyd Sampson and John Hillier for facilitating access to data; to Linda Foster, Michael Williams, Lloyd Sampson, Ross S. Brodie, Leon Leach, Adrian Werner and Andrew Durick for providing feedback on this research; to Jay Punthakey for useful advice in the early stages of the GAB modelling; to John Doherty for his assistance with the use of his PEST software; to Simon Knapp for his assistance with the use of S-Plus & R software; to Selwyn Smith for his dedication to providing abundant and accurate measurements from GAB water bores in NSW; to Eloise Nation for reviewing the manuscript; and to the other graduate students for their assistance and support.

Finally, I would like to acknowledge the support of those closest to me, Don, Steven and Jono.
ABSTRACT

The sustainability of groundwater resources is important for the environment, the economy and communities where surface water is scarce. It is a hidden resource, but additional information can be extracted by combining groundwater measurements and lithological information with groundwater flow equations in groundwater models. The models convert data and knowledge about the groundwater systems into information, such as relative inflow and outflow rates and water-level predictions that can be readily understood by groundwater managers.

The development of models to effectively inform groundwater management policies is, however, a complex task that presents a fundamental scientific challenge. This thesis presents methods and results for water balances calculated using groundwater flow models. Groundwater flow modelling methods and approaches are discussed, and their capabilities and limitations are reviewed. Two groundwater systems are studied for the Great Artesian Basin (GAB) and for the irrigation area near Bowen, Queensland. Three approaches to water balance modelling are applied in comprehensive model-development frameworks that take into account model objectives, data and knowledge availability and sensitivity analysis techniques. The three models show numerical methods of increasing complexity. The Bowen study area is well-suited to the least-complex method because data collection has been a priority there. As a contrast, the GAB is a large, poorly-monitored basin for which more knowledge of the groundwater system can be gained from its simulation by the steady state and transient groundwater flow models. The Bowen impact assessment model calculates dynamic historical water balances. The GAB aquifer models are high-complexity representations of the groundwater system that include predicted responses of the system to changes in hydrological conditions. These are comprehensive and well-documented attempts to model these systems. They provide a platform for scenario investigation and future improvements.

Darcy’s Law was used in a GIS (Geographic Information System) to calculate dynamic water balances for an aquifer near the Queensland town of Bowen. This is the first time this approach has been applied to generate a complete groundwater balance. Over the period 1989-1997 the model estimates average total inflows to be 87% groundwater recharge by rainfall and irrigation return flow, 12% river recharge and 1% inflow across the study area boundary. Outflows are estimated to be 66% evapotranspiration, 28% water bore discharge, 4% discharge to the ocean and 2% groundwater loss to rivers. Analyses show that evapotranspiration is the most uncertain parameter value. The GIS method was found to be useful for calculating water balances more accurately than analytical methods, because of their simplifying assumptions, and less time consuming than the more complex numerical models developed for the GAB aquifer.
For the GAB, a steady state numerical model was developed and tested and predictive scenarios were run. The purpose of this modelling was both to gain a better understanding of the water balance of the GAB and to provide a tool that could predict water level recoveries under different bore rehabilitation scenarios. The model complexity is greater than in any previous numerical groundwater model of the GAB. In particular, the model uses more data, extends over a larger area and uses a generally finer discretisation than previous models. For the nearest surface artesian aquifer in 1960 the model estimates total inflows to be 60% groundwater recharge and 40% diffuse vertical inter-aquifer leakage. The model estimates outflows to be 53% diffuse vertical leakage, 43% water bore discharge, 3% spring discharge and 1% discharge to the ocean. Analyses show that the model is most sensitive to changes in horizontal hydraulic conductivity and recharge. The model-predicted heads match field measurements with a Scaled RMS error of 0.8%, which is well within the guideline error of 5%. The predictive scenarios show net vertical leakage into the aquifer decreasing and net vertical leakage out of the aquifer increasing, as bore flows are reduced. These estimates of inflows and outflows complement other studies of the Basin and add to our understanding of its hydrodynamics. In this way the water balance helps provide a sound basis for the development of GAB groundwater management plans and policies. Through its water level recovery predictions, the model has also been used to support the GAB Sustainability Initiative.

A transient numerical model of the GAB was also developed and tested, and predictive scenarios were run. This model builds on the steady state model, and is more complex, with a calibration period (1965-1999) that is longer than in any previous GAB model. During calibration the model observations were expressed and weighted so that the minimisation of the objective function reflected the relative importance of the model’s potential uses, these being respectively: to simulate the impact of changing bore flows, to more generally inform water management plans and to provide an estimate of the water balance. It was found that the 1960 steady state assumption was not correct. Discluding anthropogenic discharge, the model is most sensitive to recharge and hydraulic conductivity. The model-predicted heads match field measurements with a Scaled RMS error of 2.7%, which is well within the guideline error of 5%, but the increased data requirements of the transient model highlighted deficiencies in the data available for the modelling. In particular, the uneven spread of the groundwater measurements over both time and space, the questionable accuracy of measurements from both high temperature and pressure bores, and corroded bores, and the type of discharge measured (for example, maximum yield or flow-as-found), became evident during the calibration of the model. Insights and the value of this work indicates for the first time that at the start of 2005 outflows were estimated to exceed inflows by 266 GL/year, or 62% of total inflows, and, assuming that inflows through the aquifer’s boundary will not be reduced due to climate change, it will be possible to recover some of the lost groundwater pressure if all stock and
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<td>NT</td>
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<tr>
<td>PEST</td>
<td>Model-Independent Parameter Estimation (software)</td>
</tr>
<tr>
<td>PIRSA</td>
<td>Department of Primary Industries and Resources of SA</td>
</tr>
<tr>
<td>Qld</td>
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<tr>
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<td>$R^2$</td>
<td>Coefficient of determination</td>
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<tr>
<td>RMFS</td>
<td>Root Mean Fraction Square</td>
</tr>
<tr>
<td>RMS</td>
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</tr>
<tr>
<td>s</td>
<td>second</td>
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<tr>
<td>SA</td>
<td>South Australia</td>
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<tr>
<td>SMSR</td>
<td>Scaled Mean Sum of Residuals</td>
</tr>
<tr>
<td>SR</td>
<td>Sum of Residuals</td>
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<tr>
<td>SRMFS</td>
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<tr>
<td>SSQ</td>
<td>Sum of Squares</td>
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<tr>
<td>T</td>
<td>generic time unit</td>
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<tr>
<td>WEST</td>
<td>Conceptual GAB aquitard directly underlying the modelled aquifer and containing the Westbourne Formation and its co-relatives</td>
</tr>
<tr>
<td>WINT</td>
<td>Conceptual GAB aquifer two layers above the modelled aquifer and containing the Winton and Mackunda Formations and their co-relatives</td>
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