Recharge to a semi-arid, heterogeneous coastal aquifer: Uley South Basin, South Australia

submitted by

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"But I have an idea that what's written is written with all the glaring defects: and if I'd tried to deliver everything I had in mind, the result might be even more incoherent than it is." Bruce Chatwin

Dedicated to

My late grandma Isaura who is the wisest person I met in my life, and who always inspired me to achieve good things in life through hard work, honesty and intelligence.

My uncle Tójó, who we lost during this period. Tójó always encouraged the critical spirit in me, and the will to discover new things. He was the person who first spiked in me the curiosity for the Anglo-Saxon world.

May my work honour their legacy and their memory.

Declaration of Originality

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Carlos Miraldo Ordens

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Summary

Groundwater is a resource of increasing importance throughout the world, especially in arid and semi-arid regions. Prudent groundwater management is paramount for the sustainability of groundwater systems, both in terms of water quantity and quality. Reliable estimates of groundwater recharge are often a pre-requisite for such purposes, as well as for most groundwater studies. However, groundwater recharge is commonly poorly understood and recharge estimates are usually highly uncertain due to its complicated nature and the lack of data. Distributed groundwater recharge (simply termed 'recharge' in what follows) is the vertical downward movement of water through the unsaturated zone, reaching the water table, and going into storage. Recharge can occur through focused and/or diffuse mechanisms. In any assessment of recharge, these mechanisms and other important factors are described by a conceptual model, which serves as the starting point of any recharge characterisation, and is necessary for appropriate selection of recharge estimation methods. Despite the significance of a sound conceptual model of recharge processes, it is often untested in recharge evaluations.

This study explores the recharge processes within the coastal, semi-arid Uley South Basin (USB), Eyre Peninsula, South Australia, and attempts to quantify the spatial and temporal variability in recharge fluxes to the system. This aquifer presents significant management challenges, because it supplies around 70% of the Eyre Peninsula's water demand, and yet there have been historical declines in groundwater levels approaching mean sea level in places. At the time of this study, USB was managed entirely based on recharge estimates, and reliable recharge estimates remain central to the sustainable allocation of pumping from the basin. A predictive tool capable of simulating recharge across the basin is required, partly for direct management applications, but also to underpin proposed groundwater models of USB.

The carbonate terrain of USB forms a recharge environment that is especially challenging to characterise, and previous studies that have attempted to quantify USB recharge produced a wide range of basin- and time-averaged estimates (i.e. 40

to 200 mm/year). There is a need to seek plausible explanations for the lack of agreement across these studies, particularly because management requires a narrow range of uncertainty in USB recharge. Consequently, the focus of this study is to develop an improved characterisation of USB recharge, and to critically examine field-based and modelling approaches as they apply to the USB conditions. Although the investigation focuses on particular site conditions through a case study, they intend to address general research questions of relevance to many aquifers around the world. That is, guidance is offered on the development of conceptual models, and for critically combining field-based and modelling approaches of recharge estimation, especially for real-world case studies where available data are somewhat limited.

This study's first objective was to develop a conceptual understanding of the recharge mechanisms in USB using mainly existing field data. This allowed for an assessment of traditional field-based recharge estimation techniques, the groundwater chloride mass balance (CMB) and water-table fluctuation (WTF) approaches. These were critically examined as they apply to the USB conditions, and subsequently, adaptations to both methods were proposed to account for local factors. Firstly, the application of the CMB method was modified to account for (i) the spatial distribution of atmospheric chloride deposition, which decreases exponentially with distance from the coast; and (ii) up-gradient recharge areas for each well, which were approximated from chlorofluorocarbons (CFC) age dating and aquifer hydraulic properties. This provided a narrow range of temporally and spatially averaged recharge rates (53–70 mm/year), as well as a preliminary indication of the spatial distribution of recharge across the basin. Secondly, the WTF method was modified to account for pumping seasonality, which resulted in a relatively wide range of temporally and spatially averaged recharge rates (47–128 mm/year), reflecting the large uncertainty in specific yield across the basin. The primary contribution to the USB recharge characterisation from the WTF analysis was the valuable insights into the timing of recharge.

A rigorous assessment of rainfall and groundwater hydrochemistry and isotopic datasets allowed for an improved characterisation of USB recharge mechanisms. Despite that there is no runoff to the sea and that runoff is ephemeral and only persists for tens to hundreds of metres, preferential flow features seem to transmit water deeper into the unsaturated zone rather than to the water table, which is indicated by the differences in rainfall and groundwater chloride concentrations. Chloride and ^{18}O data suggest that a substantial proportion of rainfall occurring in dryer months may be completely evaporated at the surface, and that unsaturated zone water and groundwater are subject to transpiration more so than evaporation. Chloride and bromide rainfall and groundwater data seem to confirm that rainfall in USB is essentially evaporated seawater and that rainfall is the only source of recharge.

The second objective was to investigate the influence of variants of the conceptualisation of recharge processes in USB on recharge predictions based on one-dimensional (1D) unsaturated flow modelling. The study focussed particularly on different complexities of the unsaturated zone lithology and representations of preferential flow. A modified form of the code LEACHM was applied that included a simple representation of preferential flow, whereby runoff was redistributed within predefined regions of the unsaturated zone or bypassed the unsaturated zone, to allow testing of the effects of sinkholes and other preferential flow features. The model outcomes were tested against field-based timings of recharge, which indicated that only the models with preferential flow correctly reproduced the WTF-inferred timing of recharge, and that preferential flow probably redistributes runoff into the unsaturated zone rather than passing it to the water table directly. It was found that vegetation exerts the most significant control on simulated USB recharge, and a better field characterisation of vegetation parameters and distribution would be expected to reduce considerably the recharge modelling uncertainty. Because different but equally plausible conceptual models produce widely varying recharge rates, field-based recharge estimates were shown to be essential to constrain the modelling results.

The third objective was to allow for a comparison between recharge from field-based and modelling methodologies integrated across the basin. This also provided total USB recharge influxes, for later comparison to pumping and other basin-wide fluxes. Temporally and spatially averaged modelled recharge rates were in the range estimated using CMB, and consistency between modelled and fields-based timing of recharge was obtained in the simulations where surface runoff was distributed deeper into the unsaturated zone. The simulations that better matched the field-based estimations produced temporally and spatially averaged recharge rates of 69 and 74 mm/year. Modelling provided an independently-verified fine resolution of recharge distribution in both time and space domains for the basin, which are especially valuable for management purposes and for input to groundwater flow models.

The fourth objective was to evaluate two different groundwater management strategies, the flux-based management (FBM) and the trigger level management (TLM) approaches, as they apply to USB. A simple basin water balance modelling approach was used, which required transient recharge estimates from the modelling efforts. The results indicate that the addition of TLM to the presently used FBM of the system leads to (i) enhanced water availability manifested as higher allowable pumping volumes and fewer zero-pumping months; (ii) reduction in the risk of aquifer degradation and protection against recharge estimate inaccuracies; and (iii) enhanced understanding of basin functioning leading to adaptive management.

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