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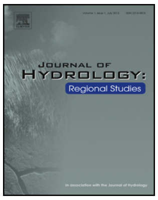

A national inventory of seawater intrusion vulnerability for Australia

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ABSTRACT

Study region: Twenty-eight coastal aquifer case study areas across Australia.
Study focus: Seawater intrusion causes degradation of groundwater resources in coastal areas. The characterization of seawater intrusion is difficult and expensive, and there is therefore a need to develop methods for rapid assessment of seawater intrusion as part of large-scale screening studies in order to guide future investment. We use a steady-state analytic approach to quantify seawater extent and propensity for change in seawater extent under different stresses, in combination with findings from a previous qualitative investigation, which relies on a data-based assessment of regional trends.
New hydrological insights for the region: The combination of methods identified areas of highest risk to SWI including unconfined aquifers at Derby (WA) and Esperance (WA), and confined aquifers at Esperance (WA) and Adelaide (SA). The combination of analytic and qualitative approaches offers a more comprehensive and less subjective seawater intrusion characterization than arises from applying the methods in isolation, thereby imparting enhanced confidence in the outcomes. Importantly, active seawater intrusion conditions occur in many of Australia's confined coastal aquifers, obviating the use of the analytical solution, and suggesting that offshore groundwater resources provide significant contributions to these systems.

1. Introduction

Coastal aquifers are important sources of freshwater supply in Australia (Werner, 2010). Seawater intrusion (SWI), which is the inland encroachment of seawater, has been highlighted as a risk to Australia's coastal aquifers in all states and the Northern Territory due to pressures associated with, for example, increased water demand and climate change (Voice et al., 2006; Werner, 2010). Developing a national-scale evaluation of SWI has been identified as a necessary step towards prioritizing efforts to manage these resources sustainably (Ivkovic et al., 2012).

Around the vast Australian coastline, there is extensive variability in geology, climate, land use, surface water effects, tidal ranges and groundwater use that produces a wide range of coastal aquifer situations. This poses a significant hindrance to the development of a national overview of the state of coastal aquifers with respect to SWI, particularly given the complex nature of the density-dependent flow and transport processes accompanying SWI. In addition, the extent of monitoring

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and investigations specific to SWI are highly variable, with detailed SWI investigations (e.g., nested-piezometer monitoring of the freshwater–seawater interface, hydrochemical analyses to elucidate salinity sources, three-dimensional models of dispersive, density-dependent flow and transport, etc.) having occurred for only a few areas (Werner, 2010). Hence, methods that rely on relatively limited information are needed to produce a national overview of SWI in Australia. To achieve this, the method should identify current and emerging risk areas, while taking into account coastal aquifer responses to changes in the key drivers of SWI. This information can then be used to prioritize areas requiring more detailed SWI investigations in the future.

SWI is a complex process and this makes SWI assessment relatively difficult and expensive (Werner et al., 2013). As a result, large-scale reviews of SWI for North America (Barlow and Reichard, 2010), South America (Bocanegra et al., 2010), Europe (Custodio, 2010) and Africa (Steyl and Dennis, 2010) have involved particularly simple methodologies, leading to largely subjective descriptions of hydrogeological settings, and the scales and modes of SWI. There is a lack of quantitative and systematic characterization of individual aquifers, for the purposes of ranking and comparison, within large-scale reviews of SWI. This precludes repeatability of the assessment, and prevents comparison between different field sites. Efforts to standardize the investigation of large-scale SWI vulnerability (defined here as the propensity for SWI to occur) have used methods such as the GALDIT (Chachadi and Lobo-Ferreira, 2007; Lobo-Ferreira et al., 2007; Santha Sophiya and Syed, 2013; Recinos et al., 2015) and CVI (SLR) (Ozyurt, 2007) approaches. Werner et al. (2012) highlight that these methods lack theoretical underpinnings, require subjective rankings, and are based on only a subset of the key factors that influence SWI. For example, SWI vulnerability arising from changes in sea-level, recharge and/or extraction is not captured directly, if at all, and aquifer fluxes are not directly considered.

Recently, an alternative large-scale method has been developed by Werner et al. (2012), who proposed a set of SWI vulnerability indicators for continental unconfined and confined aquifer systems. The method is based on the steady-state, sharp-interface equations of Strack (1976, 1989), and consequently incorporates the main physical mechanisms of SWI, albeit under idealized conditions. The basic premise is that partial derivative equations quantify the propensity for SWI as rates of change in SWI extent for a range of different stresses, e.g., increased extraction, reduced recharge and sea-level rise (SLR). Using this approach, SWI vulnerability can be easily and rapidly quantified. A relatively small number of hydrogeological parameters are required for the method and this makes it suitable for application within data-poor areas. Further, SWI vulnerability to different stresses can be easily compared due to the simple nature of the underlying equations. The method was applied by Werner et al. (2012) to four coastal aquifer systems, where detailed SWI assessments have been carried out, and there was general agreement between their approach and the vulnerability determinations obtained from more detailed investigations. Morgan et al. (2013) applied the Werner et al. (2012) method as part of a first-order assessment of SWI vulnerability for the multi-layered Willunga Basin aquifer system in South Australia, and found that the approach offered useful insights into the relative vulnerability of aquifers at that site. Recently, Morgan and Werner (2014) extended the Werner et al. (2012) vulnerability indicators method to freshwater lens systems in strip islands.

Werner et al. (2012) recommended that additional case studies should be evaluated to produce an extensive database of SWI vulnerability indicators. This would allow for the conversion of vulnerability indicators to descriptive vulnerability definitions (i.e., high, moderate, low) and allow rankings of other SWI cases, thereby offering guidance to future large-scale studies of SWI vulnerability. The aim of this investigation is to address this knowledge gap by applying the methods of Werner et al. (2012) and Morgan and Werner (2014) to aquifers in 28 case study areas across Australia, where seawater intrusion was considered a threat by national groundwater leaders (Ivkovic et al., 2012). The degree to which Australian aquifers are currently vulnerable to SWI, and potentially vulnerable in the future as a consequence of over-extraction and anticipated climate change impacts, will be considered. Conceptualization and parameterization of each case study site were carried out by Ivkovic et al. (2013), and the resulting parameter values are adopted in the current analysis.

It is important to recognize that the approaches of Werner et al. (2012) and Morgan and Werner (2014) have a number of limitations arising from the simplification of the conceptual system and the assumptions inherent in the analytical model. For example, key elements of SWI vulnerability are not captured, including temporal factors (e.g., seasonality and inter-annual climate events such as droughts), spatial variations (e.g., in recharge, pumping, aquifer properties and geometry), physical processes (e.g., land-surface overtopping, outflow face at the shoreline to accommodate submarine groundwater discharge, tidal impacts) and other important elements (e.g., the salinity of individual pumping wells, previous incidences of SWI, management practices, and the degree of knowledge and understanding of coastal aquifer processes). In order to overcome a number of these limitations, this study will use the results from a previous qualitative investigation of SWI vulnerability by Ivkovic et al. (2012), which relies on a data-based assessment of regional and temporal trends. Results from the two approaches will be used to provide a complementary evaluation of SWI vulnerability. To be clear, our goal is not to compare results of the two approaches, rather it is to carry out a national-scale assessment of SWI vulnerability for Australia using two separate methodologies that provide information on differing elements of SWI vulnerability. While the analytic approach of Werner et al. (2012) and Morgan and Werner (2014) offers insight into the theoretical extent of seawater within an aquifer, the qualitative approach of Ivkovic et al. (2012) evaluates regional and temporal trends in factors that are thought to increase SWI vulnerability.