Trigger-level versus flux-based management approaches applied to coastal aquifers

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ABSTRACT

The control of groundwater abstraction from coastal aquifers is typically aimed at minimizing the risk of seawater intrusion (SWI), excessive storage depletion and adverse impacts on groundwater-dependent ecosystems. Published approaches to the operational management of groundwater abstraction from regulated coastal aquifers comprise elements of "trigger-level management" (TLM) and "flux-based management" (FBM). TLM relies on measured groundwater levels, groundwater salinities and/or ecosystem health indicators, which are compared to objective values (trigger levels), thereby invoking management responses (e.g. pumping cut-backs). FBM apportions groundwater abstraction rates based on estimates of aquifer recharge and discharge (including environmental water requirements). This paper evaluates coastal aquifer management paradigms using published case studies, including a recent simple modelling analysis of the Uley South (US) coastal aquifer, South Australia. There is evidence that TLM offers advantages over FBM approaches through the evaluation of real-time resource conditions and trends, allowing for management responses aimed at protecting against water quality deterioration and excessive storage depletion. However, FBM approaches are critical for planning purposes, and are required to predict aquifer responses to climatic and pumping stresses. It is recommended that TLM and FBM approaches be adopted conjunctively to minimize the risk of coastal groundwater degradation and to underpin strategies for future aquifer management and well-field operation.

INTRODUCTION

SWI is typically a very slow phenomenon and rapid interface movements are only occasionally observed (e.g. Melloul and Zeitoun 1999). As such, short-term and localised aquifer behaviour are often neglected in management approaches, which rather tend to focus on long-term trends in pumping, recharge and freshwater-saltwater interface movements. However, contamination of fresh groundwater occurs at salinity levels of only 4% of seawater, and bore contamination via saltwater up-coning can occur abruptly and is thought to be widespread across areas where pumping occurs above the freshwater-saltwater interface (Maimone *et al*. 2003).

There is presently a need to review current management practices adopted in devising operational constraints on coastal groundwater systems, with a particular focus on strategies that identify and manage storage depletion and the associated SWI threat, such as the monitor-and-react approaches suggested by Evans *et al*. (2004) for inland aquifers. Two juxtaposed approaches to the management of coastal aquifers are evaluated, namely (1) FBM and (2) TLM. The former requires estimation of aquifer fluxes and is linked to concepts of sustainable yield. FBM is the traditional approach of many developed countries (e.g. Lincoln Environmental 2000). Conversely, TLM incorporates methods that adopt a somewhat continuous monitoring-management regime, using frequently monitored field conditions leading to adjustments in allowable groundwater extraction. The primary objective of this paper is to evaluate FBM and TLM approaches by summarising published examples of coastal aquifer management, including a simplified analysis of the US Werner *et al*. (submitted).

METHODOLOGY

FBM is typically manifested as constraints on groundwater extraction volumes, which are imposed *up-front* (e.g. annual extraction volumes allocated to water users on a once-a-year basis), and these are meant to pre-empt and circumvent degradation of the groundwater resources and associated environments (e.g. Heyns 2008). FBM applied to coastal aquifers is contingent on the estimation (and prediction) of both aquifer recharge and submarine groundwater discharge in assigning water allocations; these are challenging to determine in the vast majority of circumstances (e.g. Taniguchi *et al*. 2006).

TLM relies on measured groundwater levels, groundwater salinities and/or ecosystem health indicators, which are compared to objective values (trigger levels) thereby providing resource managers with a real-time basis for controlling groundwater extraction (e.g. Werner 2010). Evans *et al*. (2004) identified recent Australian examples where water resource managers have begun implementing various forms of TLM. Although they did not show specific examples of coastal aquifers, we surmise that the conclusions of their study in terms of advantages and disadvantages of TLM are readily transferrable to the control of SWI. For example, the main advantages associated to TLM are: better reflection of the true availability of groundwater, concept is readily understood and scientific underpinning through appropriate software. On the other hand, the main TLM disadvantages are: higher risk strategy, higher management costs, difficulty in determining appropriate target levels and less flexible water accounting rules.

Recently, continental summaries of SWI and associated management approaches have been compiled (see Post and Abarca 2010). Globally, FBM approaches are by far the most common, with only isolated accounts of TLM (e.g. Barlow and Reichard 2010). Many coastal systems continue to lack any management oversight whatsoever, and these may ultimately be influenced by resource degradation that eventually limits otherwise unfettered groundwater use. In these cases, a natural form of TLM occurs whereby groundwater extraction is limited by hydrogeological and chemical constraints, e.g. excessive increases in salinity or falling watertable conditions that inhibit groundwater use.

The primary reference providing guidance for managers of coastal aquifers is arguably FAO (1997). FAO (1997) suggests that there is no early warning method for SWI and that SWI management should be based on long-term trends and investigation. They refer to safe yield concepts and as such it is inferred that they advocate FBM approaches. Few studies consider TLM approaches to coastal aquifer management. For example, Bekesi *et al*. (2009) applied TLM in a study of the coastal Gnangara groundwater system of Western Australia. Bekesi *et al*. (2009) advised that TLM corrections, equal to or less than the calculated storage depletions, should amend existing groundwater allocation limits. Bekesi *et al*. (2009) concluded that FBM allocation is inappropriate in some Gnangara groundwater sub-areas, and that TLM approaches provide an effective means for modifying groundwater allocations towards sustainable levels. Liu *et al*. (2006) devised a TLM method for adjusting pumping based on groundwater level changes on Kinmen Island, southwest China. They applied a three-tier trigger level system, with trigger levels being derived from the average and standard deviation of water level data collected over a period of 28 months. The modelling applied to USB by Werner *et al*. (Submitted) is focused on a situation where a non-adaptive pumping management regime (FBM) has been adopted historically, resulting in a steady drop in groundwater levels across a 30-year period, approaching sea level in some places. The addition of TLM to the FBM management of the system was shown through modelling to lead to: (1) enhanced water availability manifested as higher allowable pumping volumes and fewer zero-pumping months; (2) a reduction in the risk of aquifer degradation and protection against recharge estimate inaccuracies; (3) an enhanced understanding of basin functioning leading to adaptive management. These three studies suggest that TLM offers a complementary strategy to FBM for modifying groundwater allocation.

CONCLUSIONS

The prevalence of FBM over TLM is probably due to the relatively high levels of infrastructure and monitoring that are needed in TLM approaches. The application of TLM appears to be most prevalent in the protection of high-value water resources, and to minimize localized impacts. TLM is regularly adopted in modelling studies of coastal aquifers in evaluating management strategies, but this hasn't appeared to have manifested into practical applications of TLM. FBM and TLM are complementary in both temporal and spatial scales, i.e. FBM is typically associated with basin-scales and annual timeframes whereas TLM is more commonly associated with monthly periods and localised impacts. Also, TLM is aimed at protecting groundwater resources against pre-conceived levels of degradation, whereas FBM offers advantages for resource planning in the allocation of allowable volumes of extraction, i.e. for planning purposes. It follows that combining FBM and TLM paradigms (i.e. into hybrid FBM-TLM strategies) may offer water resource managers advantages gained through the joint application of both approaches; this has been demonstrated by Werner *et al*. (Submitted). Furthermore, the water levels adopted as trigger levels in TLM approaches may be supplemented by such field observations as bore salinity values (i.e. observation wells and production bores), and also water level and salinity trends can be considered rather than absolute values to better capture the nature of changes in aquifer condition.

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