Groundwater Dependent Wetlands

159

Ray Froend and Pierre Horwitz

Contents

Abstract

Groundwater-dependent wetlands (GDW) are no different to other wetlands in their need for management particularly under circumstances where hydrological changes threaten the conservation of wetland values. However, GDW have two important characteristics that make their management challenging. They derive a significant proportion of their annual inflow from hydrological pathways obscured by subterranean geology and geomorphology, and therefore understanding their response to altered groundwater regimes can be perceptually difficult. This same context creates a spatial and temporal "disconnect," where delays and thresholds need to be understood before cause and effect can be established. Accordingly, GDW are best approached from a starting point of complexity and uncertainty using management frameworks appropriate for the task.

R. Froend (✉)
Centre for Ecosystem Management, Edith Cowan University, Perth, WA, Australia
e-mail: r.froend@ecu.edu.au

P. Horwitz (✉)
Centre for Ecosystem Management, School of Science, Edith Cowan University, Joondalup, WA, Australia
e-mail: p.horwitz@ecu.edu.au

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What Is Unique About GDW Management?

Groundwater-dependent wetlands (GDW) are no different to other wetlands in their need for management particularly under circumstances where hydrological changes threaten the conservation of wetland values. However, GDW have two important characteristics that make their management challenging. They derive a significant proportion of their annual inflow from hydrological pathways obscured by subterranean geology and geomorphology, and therefore understanding their response to altered groundwater regimes can be perceptually difficult. This same context creates a spatial and temporal "disconnect," where delays and thresholds need to be understood before cause and effect can be established. Accordingly GDW are best approached from a starting point of complexity and uncertainty using management frameworks appropriate for the task.

Questions arise about the management of GDW in the context of nearby/underlying (assumed) aquifers that may be used for water supply or are impacted by land use change. In cases where changes to groundwater inflow can be controlled (at least in principle), such as through abstraction from aquifers supporting GDWs or land use changes impacting aquifer recharge, adaptive management is the favored approach (Peterson 2005). However, in situations where there is neither control nor certainty, approaches such as scenario planning and resilience-building are more appropriate.

Integrated Management and Social Learning Processes

Choosing the most appropriate process to plan or implement an intervention in some instances will be at least as important as the desired outcome of the intervention itself (Horwitz et al. 2015). For example, plans aimed at reducing groundwater abstraction will require the appropriate participation of different users within local communities during the planning and implementation phases. Falkenmark and Folke (2002) emphasize the importance of social learning and therefore the roles of participation, empowerment, communication and education in water-related matters, and directing attention away from seeing these matters as merely technical issues. Ivey et al. (2004) propose five questions that will help elucidate a community's capacity to deal with these matters (specifically climate-induced water shortages):

- Are community stakeholders aware of the potential impacts of water shortages on human and ecological systems?
- Are local water management agencies perceived by community stakeholders as legitimate?

- Do local water management agencies and related organizations communicate, share information, and coordinate their activities?
- Is there an agency providing leadership to local water management organizations?
- Are members of the public involved in water management decision-making and implementation of activities?

Since surface and groundwater interactions are involved in the hydrological maintenance of the GDW, and both have "catchments" involving a range of different sectors with different perspectives, interests, and public mandates, an integrated catchment management approach is required. This should ensure that each sector can be engaged in the process of understanding, and deciding, where the trade-offs will need to be made. The most obvious case is where groundwater abstraction for water supply is considered a potential threat to the GDW, where water utilities, water resource management, environmental protection, and local and regional government, at least, will all need to be involved (MacFarlane et al. 2012).

An adaptive approach, aimed at building better understanding of the ecological importance of groundwater to a wetland, will continually seek to improve knowledge of the connectivity between wetland and groundwater, and the aquifers in question, through a social learning process (Holling 1978). This would include a participatory process to document and understand the different users of the groundwater and the trade-offs that are made (Horwitz et al. 2015) for each management scenario.

Conceptualizing the Relevance of Groundwater to the Wetland

Conceptual models of hydrological connectivity (surface and groundwater) can be applied as tools for identifying knowledge gaps and uncertainties. They can also be helpful in demonstrating the relative importance of groundwater as a hydrological input to the wetland (and also as a possible output or throughflow) (for instance, see Lloyd et al. 1993). Models can be used to formalize current understanding of the spatial and temporal connectivity between groundwater and the wetland. Furthermore, a model will assist with understanding the complexity (Gentile et al. 2001; Ogden et al. 2005; Richardson et al. 2011) by describing the wetland's hydrology and hydrogeology and biotic and abiotic components and processes. Hydrogeological processes including aquifer-to-aquifer interactions and surface water-to-groundwater interactions should be considered, including recharge, discharge, and storage processes and mixing and direction of groundwater flow. Although interactions between aquifers can be difficult to describe where data are limited, it is important to recognize the uncertainty. Similarly, understanding the spatial and temporal patterns of groundwater processes (seasonal and interannual) and how they relate to the ecology of the system are important aspects of hydrology-ecology interactions. These linkages should be described in a way that emphasizes the characteristics of the groundwater regime that supports the GDW. A critical groundwater service may include water provision for habitat or use, artesian (or other) pressure, thermal water supply, nutrient supply, or some other modifier of water quality critical to ecosystem function. In data-limited environments it is important that any assumptions made in the development of a conceptual model must be stated, along with an indication of the degree of uncertainty around these assumptions.

Measurement and Monitoring GDW Ecological Processes

Monitoring and evaluation, as an integral part of an adaptive management process, will build upon conceptual models for GDWs. Measurement programs can be used to provide a sound scientific basis for developing our understanding of the wetland system in question and informing proactive management objectives or responding to reactive changes in the wetland (Lyons et al. 2008). The ideal understanding of GDW response to altered groundwater flow would be based on quantified and validated relationships between the ecosystem and the groundwater source in question. It should be noted that, unless there is evidence to suggest otherwise, it is safer to assume the aquifer used for water supply, or affected by land use change within the catchment of the wetland, is the same as (or hydraulically connected to) the groundwater source important in maintaining the GDW. Through assessment and monitoring, these assumptions can be supported or disproved and contribute toward revising the conceptualization of interactions over time.

Each monitoring program will differ in their objectives and the components and processes of interest; however, a common requirement in GDW monitoring is the need to understand the connectivity and importance of groundwater (quality and quantity) to the wetland. Ideally, monitoring to achieve this will occur before planned impacts on the groundwater resource take place. However, in many cases this is not possible as groundwater inflow is already impacted by multiple stressors, currently and historically. Under these circumstances it is likely that there will be high uncertainty regarding the groundwater-wetland interaction. It is therefore important to have an adaptive management process in place that incorporates knowledge from biophysical monitoring into an improved conceptual model of the GDW. Furthermore, the process of learning should involve all sectors to ensure mutual understanding of the system and the trade-offs involved with changes to groundwater inflow.

For the purposes of assessing the level of dependency of a wetland on groundwater and how the ecosystem responds to changes in the groundwater system, long-term monitoring is very valuable (Parsons et al. 2011). Well-designed monitoring programs and hypothesis testing also add to the broader scientific knowledge base, which assists in the revision of conceptual models developed within the adaptive and consultative management process.

Adapting to Groundwater Change

A significant challenge in the management of GDWs is found in systems that are undergoing a hydrological transition (Kløve et al. 2011). In these scenarios, certainty in groundwater interaction with wetlands tends to be poor, and control over stressors impacting aquifers may be low (or at least varied), particularly where climate-related hydrological change is suspected (MacFarlane et al. 2012). Often, there is uncertainty regarding the relative importance of different (if recognized) stressors in altering groundwater inflow to wetlands.

In situations where groundwater inflow to a GDW is predicted to vary over the long term (e.g., rainfall reduction due to climate change or catchment land use change reducing recharge rates), questions are asked about the likely ecological responses to reduced or increased groundwater availability over time. Furthermore, it is unlikely there are sufficient data on the nature of future groundwater interactions to give accurate estimates of hydrological let alone ecological responses. The use of groundwater models to develop predictions on levels and potential inflow can be of benefit to the management process; however, it is important to maintain transparency of measurement error and integration of uncertainty when using modeled scenarios. Furthermore, all models should be subject to a process of continuous improvement based on outcomes from monitoring and research.

Adapting to changing groundwater conditions will require the regular revision of resource management objectives to determine if they are realistic under the altered groundwater regime. This should include assessment of previous hydrological, ecological, and social predictions and assumptions on which management objectives are based. In cases where changes to the groundwater resource have or are predicted to exceed management criteria for acceptable impacts or trade-offs, consideration should be given to the feasibility of supplementing (or replacing) groundwater use with an alternative source, subject to appropriate analysis of impacts.

Some GDWs are more susceptible to climatic variability and change than others and will require different management responses (Richardson et al. 2011). Aquifers with a low storage-to-recharge ratio (e.g., local groundwater flow system) are more hydrologically responsive to recharge reduction processes such as climatic variability. Although the biotic components of these hydrologically less robust systems will more likely have adaptive strategies to deal with natural variability (Shafroth et al. 2000), the novel environment created by the hydrological change may be outside the known response capacity of the wetland system. Questions should be raised about the suitability of such aquifers for development in light of the environmental trade-offs. Those wetlands associated with more robust aquifers (high storage-to-recharge ratio), and subject to low hydrological variability, are less likely to include biota with drought resilience traits. This can make these ecosystems more vulnerable to change over long periods even though the hydrogeological system supporting them is less likely to be affected by climatic variability.

Future Challenges

The cumulative pressures from increasing use of groundwater resources and reduced rainfall recharge due to climate change represent significant future challenges to managing GDW. Where declines in aquifer storage threaten the persistence of known GDW interactions, an integrated, risk-adverse approach to management is required. However, this is not always possible due to uncertainty in (or absence of) groundwater information/modeling on recharge and discharge processes or disagreement between stakeholders on management objectives and acceptable trade-offs. Developing trade-offs in favor of GDW conservation may be challenging where water for consumption becomes scarce as a consequence of increasing population and climate change. If threshold responses in GDW are to be avoided, integrated approaches will be required along with mitigation or avoidance of resource development practices that exacerbate climate or land-use-driven reduction in recharge.

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