

## Editorial

# *Chances and challenges in the conservation of groundwaters and their dependent ecosystems*

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## INTRODUCTION

Most conservation efforts in aquatic ecosystems focus on surface waters. This is understandable given their public visibility, accessibility and, in many parts of the world, stark evidence of their vulnerability to human impact. On the other hand, programmes to protect and conserve groundwaters, and the ecosystems that rely wholly or partially on access to groundwater, are far less common. Contaminated groundwater is less obvious to the public than a blue-green algal bloom or the floating corpses from a fish kill. Increasingly, as surface waters become polluted, groundwater resource use is intensifying in many parts of the world, often mining resources faster than they are replenished (Danielopol *et al.*, 2003). We are realizing that groundwater is not an inert, lifeless resource, but instead can harbour considerable biodiversity of invertebrates and microbes (Marmonier *et al.*, 1993; Danielopol *et al.*, 2000) whose activities provide crucial ecosystem services in nutrient transformation and biological filtration (Boulton, 2000; Hancock, 2002). There are growing numbers of examples of catastrophic crashes in groundwater ecosystems due to saline intrusion (Ergil, 2000) and over-extraction (Kromm and White, 1992) while in other areas, contaminants such as heavy metals are rendering groundwater toxic to millions of humans (Nickson *et al.*, 1998; Sengupta *et al.*, 2001).

The key issue is one of public and political education about the conservation values, ecosystem services, and subsurface–surface linkages of groundwaters. While knowledge gaps still exist, I suggest that we know enough to be able to advise policy-makers and governments about the benefits of conservation of groundwaters and their dependent biota. Recent editorials in this journal have highlighted the ecological significance of hydrologic connectivity (Pringle, 2003) and restoration science at large scales (Ormerod, 2004). My contribution builds on these to provoke research and debate about conservation of groundwaters and their linkages at suitable scales, potentially requiring restoration of groundwater quality and water regime to benefit significant groundwater-dependent ecosystems (GDEs).

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## BURIED TREASURES: BIODIVERSITY AND ECOSYSTEM SERVICES

Groundwater underpins the global hydrological cycle. Fed by atmospheric water that reaches the Earth's surface and infiltrates the ground, groundwater flows in voids ranging from large spaces in fissured rocks to the pore spaces of unconsolidated sediments, finally to exfiltrate into terrestrial or marine environments, sometimes many thousands of years later (Winter *et al.*, 1998). As a result, groundwater ecosystems are 'open' systems through which water and energy flows, matter is processed in various ways and, depending on the length of the subsurface flow path and residence time, exfiltrating groundwater can influence the ecology of surface ecosystems such as rivers (Hancock, 2002) or wetlands (Winter *et al.*, 1998). This relationship between groundwater and surface ecosystems has differing degrees of dependency from obligate (e.g. aquatic fauna resident in aquifer ecosystems; Humphreys, 2001) to facultative (e.g. some riparian tree species), giving rise to recognition of various types of GDEs. These GDEs (from Evans and Clifton, 2001) include:

- (i) terrestrial ecosystems that rely seasonally or episodically on groundwater;
- (ii) river base-flow systems, including aquatic, hyporheic, and riparian ecosystems that depend on groundwater input, especially during dry periods;
- (iii) aquifer and cave ecosystems, often containing diverse and unique fauna;
- (iv) wetlands dependent on groundwater influx for all or part of the time; and,
- (v) estuarine and nearshore marine ecosystems that rely on groundwater discharge.

In many countries, some of these GDEs are of national and international significance. For example, groundwater-fed lakes and wetlands can support crucial populations of rare and endangered waterbirds, while many cave and aquifer ecosystems harbour extraordinary endemic biodiversity and large proportions of relictual species (Danielopol *et al.*, 2000; Humphreys, 2001). 'Buried treasures' of groundwater biodiversity hotspots and relictual endemics have been described from many parts of the world (reviews in Boulton, 2001; Danielopol *et al.*, 2003) but little is known of the ecosystem services performed by this biota. In subterranean systems, lack of light truncates the functional diversity of producers and grazers (Gibert and Deharveng, 2002) but dissolved organic matter and biofilms typically support a complex foodweb dominated by detritivores that play key roles in biological filtration. The fundamental ecosystem service of filtration (including physical and chemical processes) results in one of the most important goods for humans — drinking water — and is perhaps the main utilitarian argument for conservation of groundwater ecosystems and their services. Other groundwater ecosystem services valued by humans include benefits to fisheries, agriculture, forestry, and river base-flows to name a few.

The condition or 'health' of GDEs relies on timing and availability of groundwater but the response functions of these ecosystems are seldom known and this provides a major challenge for managers. Although the health of some GDEs, such as alpine bogs, might show a linear response to groundwater availability, other ecosystems such as salt marshes may respond in a stepped fashion with minimal change in condition until a threshold of water availability is reached (Evans and Clifton, 2001). There are relatively few studies of the shapes of these response functions over several years, especially for entire ecological communities (Murray *et al.*, 2003), severely hampering management recommendations for groundwater extraction rates and volumes.

## THREATS TO GROUNDWATERS AND GDES

One of the most pressing threats to groundwaters and GDEs is a change in groundwater regime that exceeds the natural bounds of variation. The groundwater regime in a certain area includes depth to

groundwater, variability in groundwater table at several temporal scales (days to decades or longer), groundwater pressure, and flow rate. There are numerous examples of severe impacts on GDEs from excessive rates of groundwater extraction and 'mining' where water is removed at far greater rates than recharge. For example, the Ogallala Aquifer underlying some 450 000 km<sup>2</sup> of the US supplies almost a third of the country's irrigation water and is being withdrawn nearly 10 times faster than its recharge rate (Kromm and White, 1992). In many places, not only has the water table dropped below economically feasible extraction levels, some streams and rivers have dried and only flow during floods (e.g. Arkansas River; Kromm and White, 1992). Often, the visible responses by GDEs to over-extraction are relatively slow because of the low groundwater flow rates, and even after groundwater extraction ceases, the condition of the dependent ecosystem may continue to deteriorate. Higher than usual groundwater levels can be equally catastrophic, especially when coupled with salinization and vegetation clearance (Evans and Clifton, 2001).

Disruption of the hydrological linkages between groundwaters and their dependent ecosystems also poses a severe threat. For example, in rivers where the hyporheic zone provides vital filtration and nutrient transformation services, siltation of the bed sediments can sever the linkages and impair ecological processes in both the surface and subsurface ecosystems (Hancock, 2002). Alternatively, changes in overlying vegetation can alter hydrological linkages and water levels in caves and their aquatic ecosystems with devastating impacts on their fauna. In particular, transport of dissolved and particulate organic matter, critical as an energy source for these subterranean foodwebs, is impeded by changes in hydrological linkages and vegetation cover (review in Boulton *et al.*, 2003).

Another major threat is contamination by salts, excess nutrients, manufactured products (e.g. pesticides, petrochemicals) or heavy metals. For example, sea-water intrusion threatens aquifers of Cyprus and has already rendered the eastern Magusa aquifer unusable on this semi-arid island (Ergil, 2000). In Bangladesh, more than 20 million people drink groundwater containing arsenic exceeding five times the WHO's recommended limits (Nickson *et al.*, 1998) and arsenic poisoning is affecting more than 80 million people exposed to the naturally occurring heavy metal in water from wells sunk into the alluvium of the Ganges delta (Sengupta *et al.*, 2001). Beyond these alarming impacts on humans, changes to groundwater quality also impact on GDEs. For example, sediments, petrochemicals, and agricultural contaminants from surface ecosystems have been detected in limestone cave streams in Derbyshire, England, where there has been a general deterioration in water quality (Gunn *et al.*, 2000). In many Australian caves and karstic systems, inappropriate rubbish disposal and substandard effluent management also threaten their biota and water quality (Boulton *et al.*, 2003).

## CHANCES AND CHALLENGES TO CONSERVING GROUNDWATERS AND GDES

Out of sight, out of mind? To me, the biggest challenge to conservation efforts is heightening public and political awareness of the importance of groundwaters and their dependent ecosystems, the threats facing them, and the need for applied research on groundwater processes and response functions to help managers assess groundwater resource use. Political attention primarily focuses on surface waters, many of which are dependent on groundwater but whose vertical linkages are not always fully appreciated by managers (Winter *et al.*, 1998; Boulton, 2000). Frequently, volumes of extraction of surface waters are closely monitored by water resource agencies, whereas groundwater, even from alluvial aquifers linked to nearby surface sources, may be less regulated; only recently have there been tighter controls on sinking boreholes and extracting groundwaters in many parts of the world. Part of the problem relates to the difficulties of assessing groundwater volumes, recharge rates and sources, and groundwater quality. A second issue has been the relatively slow recognition of the linkages between groundwater and many surface water ecosystems described above. A third dilemma is the lack of public visibility of groundwaters and the long

lag-time between changes in groundwater regime or quality and the response by surface GDEs so that impacts tend to be gradual and often subtle (Boulton *et al.*, 2003).

However, there are still many relatively intact groundwater ecosystems remaining, providing chances for scientists and managers to collaborate to protect and manage these systems and their GDEs. Managers of water resources are becoming familiar with the challenges of dealing with large spatial areas and although their perceptions of hydrologic connectivity are generally lateral and longitudinal (Pringle, 2003), the importance of vertical connectivity is slowly being appreciated (Boulton, 2000). There are some encouraging signs that groundwaters and their dependent ecosystems are attracting attention for conservation and protection. For example, the recent enactment in Europe of the EC Water Framework Directive (European Commission, 2000) includes provisions to protect groundwaters from pollution, and to ensure that groundwater abstraction does not threaten dependent terrestrial or wetland ecosystems. The IUCN World Conservation Congress, held in November 2004 in Thailand, included groundwater-dependent ecosystems in their recommendations for establishing protected areas representative of all freshwater ecosystems ([www.iucn.org](http://www.iucn.org)) but there are few guidelines available for how best to do this. A review of environmental water requirements of GDEs in Australia (Evans and Clifton, 2001) was part of this country's National River Health Program, and illustrated the wide variety of GDEs as well as their ecological importance. It has led to increased research and interest in GDEs (Murray *et al.*, 2003) and specific consideration of groundwater ecosystems in water resource development plans in several Australian states.

With growing interest in ecohydrology and hydroecology, recognition of the vertical dimension of hydrologic connectivity (Pringle, 2003), and acceptance that many surface aquatic ecosystems rely on groundwater to varying degrees, conservation and management of this linked resource will become increasingly important. Perhaps the 'golden age of river restoration' (Ormerod, 2004) will include specific restoration of groundwater-surface linkages in some rivers. As we learn more about the relationships between groundwater regime and the requirements of their GDEs, groundwater environmental allocations will become more of a science and less of a guess. Most significantly, public awareness of this subliminal 'buried treasure' will sharpen, providing greater impetus to efforts to protect and even restore examples of this critical resource.

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