Springs of the Great Artesian Basin – Oases of Life in Australia’s Arid and Semi-arid Interior

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Abstract
Springs of the Great Artesian Basin (GAB) are among the most revered, structurally complex, ecologically diverse and threatened groundwater-dependent ecosystems in Australia. In 2018, the Council of The Royal Society of Queensland recognised the need for consolidated knowledge to support evidence-based management and conservation of these unique, endangered ecosystems. Recent developments make this Special Issue of papers on GAB springs, their cultural values, endemic biota, and the challenges of management and conservation, especially timely. Two decades have passed since formal listing in 2001 of “The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin” as endangered under the Commonwealth’s Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act, 1999). This formal designation was followed by the preparation of the Recovery Plan for the GAB endangered community. Similarly, two decades have passed since the publication of the original national strategic management plan for the basin. These two national initiatives are now being renewed with greater vigour and focus on the importance of saving water, a major factor in improving spring health. Papers in the Special Issue contribute to the broad objectives of the Recovery Plan and the Great Artesian Basin Sustainability Initiative from a range of sectors, individuals and perspectives. We anticipate that papers in this volume will stimulate new research, novel insights across all forms of expertise, and greater commitment to the wise use and protection of these miraculous oases of life and cultural history in Australia’s Great Artesian Basin.

Keywords: Great Artesian Basin, springs, hydrogeology, groundwater-dependent ecosystems, endemic species, cultural history and values, stewardship and governance models, conservation and management frameworks

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Introduction
Beneath some of the most arid areas of the world’s driest inhabited continent lies a vast reservoir of subterranean water – the Australian Great Artesian Basin (GAB). This ancient groundwater resource is one of the world’s largest and one of the few that is still characterised by artesian conditions for large portions of the basin – where water may discharge to surface under hydrostatic pressure. The basin covers about 22% of the Australian mainland, including large areas of Queensland, New South Wales, South Australia and the Northern Territory.

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Some of its waters date from the Pleistocene up to 2.5 million years ago. Modern recharge, from infiltration of rainfall around the eastern and western margins and from episodic river flows, is significantly less than discharge (Smerdon et al., 2012).

The GAB is a multilayered aquifer system, comprising a geological sequence of aquifers – water-bearing formations – and aquitards, which limit the movement of groundwater. The groundwater system is predominantly recharged where aquifers are exposed to the surface, along the eastern and western margins of the GAB (Habermehl, 2020).

Groundwater flow directions are complex, particularly around the periphery of the basin where local groundwater flow directions can differ substantially from the regional trend.

In some locations, the GAB waters rise to the surface under hydrostatic pressure through geological faults and folds in the strata that overlie the aquifer (Figure 1).

Figure 1. The GAB with sub-basins, major regional clusters of springs (spring supergroups, shown in blue) (Fensham & Fairfax, 2003), local (hatch) and regional recharge areas (dark grey around the GAB periphery), regional flow directions (orange arrows) (Ransley et al., 2015). Source: Flook et al. (2020).
These natural discharge points form vents, seepages and more discrete waterbodies of astonishing variety – the GAB springs. Some springs form bubbling pools no larger than a paddling pool (e.g. Blanche Cup and The Bubbler in Wabma Kadarbu Mound Springs Conservation Park on the Oodnadatta Track, South Australia). The bubbling water represents the convulsions of the dying Rainbow Serpent after an altercation with a Kuyani ancestor (Friends of Mound Springs, https://www.friendsofmoundsprings.org.au/featured-mound/bubbler-and-blanche-cup/). At Edgbaston Reserve, north-east of Longreach in Central Queensland, there are 100 individual springs, but many of them form little more than damp areas and ankle-deep wetlands. Yet some Edgbaston (Byarri) springs are just deep enough to support one of Australia’s most remarkable and critically endangered fish species (Fairfax et al., 2007; Kerezsy, 2020). The largest GAB springs are longer than 100 m and deeper than 3 m. At Dalhousie Springs (Witjira National Park, South Australia), large, deep, warm waters form the natural Dalhousie ‘swimming pool’ (Zeidler & Ponder, 1989). Throughout this volume, original photographs of these and many other GAB springs offer a window on their features and remarkable variety.

Due to the geographic extent of the GAB, these oases of life are found across arid, semi-arid and northern tropical landscapes (Figure 1), but the majority, and certainly the most well-researched springs, are located in the more arid areas of these landscapes. Originally, 11 groups of springs were identified (Habermehl, 1982), and later defined as supergroups by Ponder (1986). Subsequently, the two most northern groups were recognised and most maps show the 13 supergroups named in Figure 1. Ponder (1986) proposed the basic spring terminology, ranging from the different parts and vents of individual springs, to the association of springs in groups, to spring complexes and, ultimately, the large groups of springs known as supergroups (Figure 1). Spring groups are also commonly based on the hydrostatic conditions under which they occur. Artesian springs are those which are fed by a deeper aquifer, with water travelling upwards through an overlying aquitard to reach the surface. Recharge or outcrop springs are those that are fed by a local groundwater system, with water travelling only a short distance through an unconfined aquifer at outcrop.

Australia’s GAB springs offer a unique focal point for the intersection of many types of knowledge. There is the knowledge Aboriginal Peoples generated over thousands of years of living close to springs, passed down through origin stories, and expressed today in continuing cultural practices and stewardship. Colonial impressions and understandings obtained from early exploration, pastoral settlement and expansion also represent a source of knowledge of GAB springs, and testify to the heritage significance of springs. As Australian society grew more aware of the value of groundwater last century, technical knowledge of spring hydrogeology, ecohydrology and biodiversity also expanded (e.g. Ponder et al., 1989). Springs came to be recognised and regulated as groundwater-dependent ecosystems of great cultural, ecological, socio-economic and conservation significance, as concern about threatening processes grew and attention turned to ways in which society could more carefully monitor and manage springs. Reducing the sheer waste of groundwater from the GAB has motivated many of those committed to sustainable management over recent decades.

This compilation of papers on springs of the Great Artesian Basin is one of a long line of Special Issues of the Proceedings of The Royal Society of Queensland, devoted to themes of particular interest, and often with a regional focus. In 2018, the Council of the Royal Society recognised the need for consolidated knowledge to support evidence-based management and conservation of these unique, endangered groundwater-dependent ecosystems. Unlike previous special editions, however, the size of the basin means that the experience of authors and scope of the papers fittingly reach beyond Queensland state borders. Under the guidance of Dr Renee Rossini, a recent doctoral graduate with a passion for spring invertebrates (Rossini et al., 2018), the GAB springs project was duly launched in August 2018. A dedicated editorial panel came together to guide the formal call for papers, their review by independent experts, editing, cross-checking and final collation into Volume 126 of the Royal Society’s Proceedings.

Recent developments make this volume of papers on GAB springs, their groundwater-dependent
ecosystems and the challenges of management and conservation especially timely. Two decades have passed since formal listing in 2001 of “The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin” as endangered under the Commonwealth’s *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act, 1999). This formal designation was followed by the preparation of the Recovery Plan for the GAB endangered community (Fensham et al., 2010). It provided a platform to galvanise action on issues of special significance to the management and conservation of springs and their communities of rare and endangered species. The bold objective of the Recovery Plan is to maintain or enhance groundwater supplies to GAB discharge spring wetlands, maintain or increase spring wetland habitat area and ecological health, and increase populations of all endemic organisms.

Similarly, two decades have passed since the publication of the original national strategic management plan for the basin (GABCC, 2000). Importantly, activities geared towards drafting the national plan resulted in the first nationally coordinated basin infrastructure funding program, the Great Artesian Basin Sustainability Initiative (GABSI), commencing in 1999. These two national initiatives are now being renewed with greater vigour and focus on the importance of saving water, a major factor in improving spring health.

Papers in the Special Issue contribute to the broad objectives of the Recovery Plan and the Great Artesian Basin Sustainability Initiative from a range of sectors, individuals and perspectives. In this introductory paper, we place each contribution in context but defer a synthesis of knowledge gaps and future directions for research, management and conservation of GAB springs until the final paper of the volume (Rossini et al., 2020).

The Special Issue begins with an account of the importance of groundwater to Australian Aboriginal people, by Moggridge (2020) who researched this theme for his Masters thesis. In the beginning – the Dreamtime – springs were created by Aboriginal cultural heroes and revered as reliable watering points in harsh desert country, serving as sites of ceremony, oral instruction and settlements along major trade networks (Ah Chee, 2002; Harris, 2002). Rituals and ethics of caring for the land, water and all living beings illuminate our understanding of Aboriginal knowledge and affirm our profound cultural inheritance as new Australians. This awareness comes with an obligation to enter into respectful partnerships that aid recovery and restoration of Aboriginal practices and knowledge of spring country. Yet the cultural significance of many GAB springs, and the tacit knowledge held by Aboriginal Peoples from a vast area of Australia, remains poorly documented even after a recent surge in interest from scientists and water managers (Brake, 2020; Peck, 2020; Pointon & Rossini, 2020; Silcock et al., 2020).

In the time since European settlement, studies dating back over 140 years testify to the dedication of individuals and agencies committed to documenting, researching and monitoring springs. Papers in this volume provide comprehensive reviews of the hydrogeology and hydrochemistry of GAB springs, their modes of origin, the geography and biophysical attributes of springs, and understanding of processes needed to inform management and recovery of GAB springs affected by groundwater use and drawdown (Habermehl, 2020; Flook et al., 2020; Keppel et al., 2020). Recent surveys are still yielding new information in the less well-studied parts of the GAB, such as the Mulligan River Springs (Silcock et al., 2020), the only permanent surface water in this dry area on the edge of the Simpson Desert in far-western Queensland (Figure 1).

Discharge springs form oases of life extending in an arc around the margins of the GAB, primarily in arid and semi-arid landscapes. These patchy and largely isolated groundwater-dependent ecosystems differ from the surface-water wetlands of overlying catchments such as the Lake Eyre Basin. In these ‘boom and bust’ ecosystems, riverine freshwater species usually flourish during wet times but cling to life in ecological refuges during drier times. In these systems, aquatic species generally have wide distributions and excellent dispersal capabilities, allowing them to erupt from the disconnected waterholes that were their refuges during drought (Bunn et al., 2006). Although existing in the same landscapes, GAB springs create very different habitats for aquatic life. They form isolated islands of wetland in a sea of arid land, are rarely connected, relatively environmentally stable and hydrochemically unique (Ponder, 1995). While
springs are often utilised by surface-water species, GAB springs are exceptional in the high proportion of species that are endemic to these groundwater-dependent ecosystems (Fensham et al., 2011). They function as evolutionary refugia – permanent or semi-permanent groundwater-dependent habitats supporting rare and endemic species of plants and animals adapted over millennia (Davis et al., 2013; Murphy et al., 2015). Many species are restricted to a single spring complex (Rossini et al., 2018).

Five papers in this volume enrich our understanding of the patchy distribution patterns, special habitat requirements and conservation status of invertebrates and fish found nowhere else but GAB springs (Choy, 2020; Clifford et al., 2020; Kerezsy, 2020a,b; Rossini, 2020). The patterns of endemism they describe are especially interesting and of central relevance to setting conservation priorities for springs of the basin (Fensham & Price, 2004; Fensham et al., 2011).

Over the past century, development of the water resources and landscapes of the GAB has seen many changes and growing threats to springs and their endemic biota, as well as to the relationships that Aboriginal Peoples maintain with springs. Threats identified in the Recovery Plan include: aquifer drawdown; excavation of springs; stock and feral animal disturbance; alien (introduced exotic) species of plants and animals; tourist visitation; and development of impoundments (Fensham et al., 2010). Papers in this compendium address some of the more prominent threats and lay a foundation for reviews of progress towards threat abatement, effective management strategies and more effective conservation mechanisms. Flook et al. (2020) demonstrate how detailed hydrogeological conceptualisation and an understanding of the spring wetland water balance underpin monitoring strategies to enhance the detection of impacts of groundwater drawdown on spring wetlands.

The discovery in the 1880s that settlers could dig wells and drill bores to exploit the artesian water that fed springs was pivotal for the early pastoral industry. By 1915 more than 1500 artesian bores had been drilled into the GAB to provide flowing artesian water, and a vast system of open artificial channels, known as bore drains, was constructed to distribute flowing water to individual and grouped properties, often over significant distances (Brake et al., 2020). The benefits for travellers, settlements and the growing pastoral industry were enormous, but within 40 years grave concerns were emerging about declining bore pressure, huge water losses via evaporation and seepage (up to 80–95% wastage, Mudd, 2000; Noble et al., 1998) and adverse effects on springs. Brake (2020) describes this history and the implementation of the Great Artesian Basin Sustainability Initiative (GABSI) and progenitor programs, centred on artesian pressure recovery, sustaining GAB spring flows, and assisting landholders in the rehabilitation of bores and water delivery infrastructure.

The ecological consequences of aquifer drawdown on GAB springs and their resident biota have been severe in many spring complexes, undoubtedly resulting in loss of endemic species in some areas of the basin (Fairfax & Fensham, 2002; Fensham et al., 2010). Furthermore, hydrological and habitat changes associated with groundwater drawdown can greatly increase the vulnerability of springs and their biota to other threatening processes (Nevill et al., 2010).

Direct human modifications (excavation, impoundment) and patterns of surrounding land use have threatened the persistence and ecological health of numerous springs (Kennard et al., 2016; Rossini et al., 2018). As sources of water and food for livestock and feral grazers, many springs and their biota have been severely disturbed, especially during dry periods (Kodric-Brown & Brown, 2007). The establishment of alien aquatic species (plants, fish and amphibians) places further pressure on springs affected by drawdown and loss of aquatic habitat. Climate variability and future projections of a warmer and drier regime imply impacts on both recharge of the GAB and demands on the resource (Fu et al., 2020).

Alien aquatic species present particularly challenging management problems (Kerezsy, 2020a). The alien eastern gambusia (Gambusia holbrooki), a small live-bearing fish first introduced to Australia for control of larval mosquitoes, now threatens the persistence of the critically endangered red-finned blue-eye (Scaturiginichthys vermeilipinnis) in several springs at Edgbaston Reserve in the Aramac district of central western Queensland (Kerezsy & Fensham, 2013). Another alien pest, the cane toad (Rhinella marina) also threatens the conservation
of desert spring ecosystems by consuming endemic aquatic invertebrates (Clifford, et al., 2020). The occurrence of both pest species in springs at Edgbaston (Byarri), a precious cultural and conservation reserve (Ponder et al., 2010), is particularly worrying.

Disturbance and total grazing pressure from stock, feral species and native animals can seriously damage spring habitats and vegetation. De-stocking, and fencing around GAB springs to exclude stock and feral animals, are well-established management approaches, with early efforts dating back decades. The paper by Peck (2020) evaluates the management effectiveness of exclusion fences around springs in Currawinya National Park (south-western Queensland) using qualitative and quantitative condition assessment tools. Threat mitigation like fencing does not always result in a predictable or ecologically positive outcome. Total exclusion of all grazing through fencing can result in over-proliferation of native species such as the common reed (*Phragmites australis*) and *Fimbristylis* spp. Lewis & Packer (2020) present a remarkable 35 years of observational data on the response of *P. australis* and other wetland vegetation in GAB springs following stock exclusion.

Although discussions of spring management and conservation actions in this Special Issue focus heavily on the role of policy and basin-scale initiatives, several contributions remind us of the powerful role of citizens in understanding threats and protecting springs. Harris (2020) describes five decades of ‘watching mound springs’ through professional activities and engagement with many key scientists and Aboriginal custodians of South Australia’s mound springs. He recalls the interest and controversy surrounding the Olympic Dam Mine project developed to mine world-ranking quantities of copper, uranium, silver, gold and rare earth elements. Later in life he formed the community group Friends of Mound Springs (FOMS). As Founding President, Harris has generated a huge following of friends devoted to protecting springs and saving threatened species.

Edgbaston (Byarri) and its conservation programs are shining examples of how the FOMS legacy is growing and expanding. The professional conservation experiments of not-for-profit conservation group Bush Heritage Australia have been supported by volunteers brought together to work with a shared passion to save endangered species and conserve the spring wetlands on which they depend (Kerezsy, 2020a,b; Kerezsy & Fensham, 2013).

Despite the unique hydrogeological character of GAB springs, their many endemic species and the severity of the threats they continue to face, these groundwater-dependent ecosystems have only recently attracted formal conservation attention. The “community of native species dependent on natural discharge of groundwater from the Great Artesian Basin” was listed as endangered and protected under Australia’s main environmental legislation in 2001, under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act, 1999), and the 2013 EPBC Act amendment (the “Water Trigger”) establishes water resources as a “matter of national environmental significance” (MNES) in relation to coal seam gas and large coal mining developments.

Pointon & Rossini (2020) review the relative strength, complexities and limitations within this system of legal protections as it applies to the conservation of GAB spring species and the particular features of their biological communities. They do so in broad terms relevant to the whole GAB, and in a case study of the Doongmabulla Springs (Central Queensland), which are not GAB springs, in relation to development of a major coal mine in their vicinity.

The twin themes of conservation and management bring this Special Issue to a close with papers offering principles, practical procedures and governance models to ensure the future of GAB springs and their endemic biological systems. Lewis & Harris (2020) propose a GAB springs conservation program and governance framework for South Australia. While not directly transferable to other jurisdictions, this program sets out important framing elements based around robust data systems, identification of priorities for conservation, Indigenous engagement, incentives for landholders, initial protection works, ongoing maintenance of protective measures, and an underpinning regulatory framework.

The final paper by Jensen et al. (2020) describes the GAB Springs Adaptive Management Plan (Brake
et al., 2020), designed to secure Lynn Brake’s vision—shared by so many others—to achieve long-term and well-funded care and protection of springs. The multi-agency and multi-jurisdictional project was managed by Natural Resources SA Arid Lands, and funded by the (then) Australian Government Department of Agriculture, and by South Australian, New South Wales, Queensland and Northern Territory jurisdictions. The GAB Adaptive Management Plan and Template presents evidence-based methodologies to assess and manage risks to spring groups across the GAB while minimising disruption to current users of basin water resources.

As always with Special Issues, many important gaps in knowledge and ideas for further research have emerged in the papers themselves and from the critiques and commentaries of reviewers. To conclude this volume we offer a synthesis of knowledge gaps and future directions for research, management and conservation of GAB springs (Rossini et al., 2020). We hope this collection of papers and our synthesis will encourage deeper appreciation of the cultural, historical, ecological and economic significance of GAB springs (and springs with other groundwater dependencies throughout Australia), by offering new insights and enlightened strategies to protect and manage them. We anticipate that papers in this volume will stimulate new research, novel insights across all forms of expertise, and greater commitment to the wise use and protection of these miraculous oases of life and cultural history in Australia’s Great Artesian Basin.

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Renee Rossini is an early-career ecologist who focuses on the ecology of invertebrates, particularly species endemic to GAB springs, where she completed her PhD in 2018 on how the environmental requirements of endemic molluscs create and maintain their narrow patterns of distribution. She now works across Griffith University, The University of Queensland and the private not-for-profit Queensland Trust for Nature, engaging in spring ecology and conservation through policy, ecological and evolutionary research, and education partnerships.

Craig Walton is a senior policy officer in the Queensland Department of Natural Resources, Mines and Energy. His role is focused on water policy in the Great Artesian Basin; and with a background in plant ecology, Craig is pleased to be overseeing policies and programs targeted at making the basin in Queensland watertight, because of the important ecological and social outcomes that will result from this work.

Steven Flook is Director of Management Strategies and Implementation, Office of Groundwater Impact Assessment, DNRME, Queensland. He is a passionate water resource professional with experience in water planning, cumulative impact assessment, groundwater-dependent ecosystems, science communication, design and implementation of research programs and inter-jurisdictional policy development. His experience relates predominately to investigations in the Great Artesian Basin and the Condamine Alluvium for the Queensland Government.