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# A new approach to monitoring spatial distribution and dynamics of wetlands and associated flows of Australian Great Artesian Basin springs using QuickBird satellite imagery

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SUMMARY

This study develops an expedient digital mapping technique using Very High Resolution satellite imagery to monitor the temporal response of permanent wetland vegetation to changes in spring flow rates from the Australian Great Artesian Basin at Dalhousie Springs Complex, South Australia. Three epochs of QuickBird satellite multispectral imagery acquired between 2006 and 2010 were analysed using the Normalised Difference Vegetation Index (NDVI). A regression of 2009 NDVI values against vegetation cover from field botanical survey plots provided a relationship of increasing NDVI with increased vegetation cover ($R^2 = 0.86$; $p < 0.001$). On the basis of this relationship a vegetation threshold was determined (NDVI $\geqslant 0.35$), which discriminated perennial and ephemeral wetland vegetation from surrounding dryland vegetation in the imagery. The extent of wetlands for the entire Dalhousie Springs Complex mapped from the imagery increased from 607 ha in December 2006 to 913 ha in May 2009 and 1285 ha in May 2010. Comparison of the three NDVI images showed considerable localised change in wetland vegetation greenness, distribution and extent in response to fires, alien vegetation removal, rainfall and fluctuations in spring flow. A strong direct relationship ($R^2 = 0.99$; $p < 0.001$) was exhibited between spring flow rate and the area of associated wetland vegetation for eight individual springs. This relationship strongly infers that wetland area is an indicator of spring flow and can be used for monitoring purposes. This method has the potential to determine the sensitivity of spring wetland vegetation extent and distribution to associated changes in spring flow rates due to land management and aquifer extractions. Furthermore, this approach is timely and provides reliable and repeatable monitoring, particularly needed given the projected increased demand for groundwater extractions from the GAB for mining operations.



## 1. Introduction

The Australian Great Artesian Basin (GAB) is one of the largest artesian basins in the world, containing an estimated 64,900,000 GL of water within a confined aquifer. The GAB underlies approximately 1.76 million km$^2$ (22%) of the Australian continent, encompassing a number of states and territories (Queensland, New South Wales, South Australia and the Northern Territory) (Gotch et al., 2006). The GAB supports a unique and diverse range of wetland ecosystems termed GAB springs, formerly known as mound springs, which contain a number of rare and relic endemic flora and fauna (Fensham and Fairfax, 2003; Framenau et al., 2006; Gotch et al., 2008; Ponder, 2004). The GAB springs are of great national and international importance for their ecological, scientific and economic values, and are culturally significant to indigenous Australians (Ah Chee, 2002). They also provide a vital source of water in the arid inland heart of Australia (Badman et al., 1996; Boyd, 1990; Mudd, 2000). The GAB springs are considered threatened ecosystems and a number of their endangered plant and animal species are protected by Australian national environmental protection and conservation legislation. In recent decades the ecological sustainability of the springs has become uncertain as demands on the GAB for this precious water resource increase. The eco-hydrogeological impacts of existing water extractions for mining and pastoral activities, along with their land use impacts are unknown. This situation is further compounded by the likelihood of future increasing demand for extractions, particularly from proposed mining and petroleum activities.

Despite the importance of the GAB springs, few have been documented in terms of water flows or wetland vegetation extent and composition: accurate, repeatable and cost-effective methods for inventory and monitoring are required for these remote and spatially dispersed ecosystems. Previous mapping and monitoring of wetland vegetation associated with selected mound springs in

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South Australia has relied on visual interpretation and classification of aerial photography, combined with considerable field work (BHP Billiton, 2009). Williams and Holmes, (1978) developed a method of estimating discharge from springs at the Dalhousie Springs Complex (DSC) using aerial photography, current meter and bucket and stop-watch measurements. However, these approaches are time consuming and site specific, and also particularly limiting for discriminating wetland from dryland vegetation. The advancement in remote sensing technologies means that mapping and monitoring using satellite imagery is now achievable and cost effective. A remote sensing approach has the potential to provide an expedient, reliable and repeatable method which can cover the broad spatial extent needed to capture these disparate groundwater dependent ecosystems in the arid landscape.

The study presented in this paper forms part of a larger research program, Allocating Water and Maintaining Springs in the Great Artesian Basin, that is developing new tools for monitoring GAB spring sensitivity to water allocations and land use in South Australia and the Northern Territory. The remote sensing component of this program is developing a suite of new advanced remote sensing methods for mapping and monitoring the wetland vegetation supported by the groundwater-fed GAB springs, to identify potential impacts of aquifer water extractions (White and Lewis, 2009, 2010a,b,c). The current paper provides a pivotal contribution to this wider program by linking GAB surface flows with their groundwater-dependent wetland ecosystems using advanced remote sensing techniques.

In this paper, we develop an expedient method for determining the response of GAB spring perennial wetland vegetation to changes in spring flow rates using Very High Resolution (VHR) digital satellite imagery. Particular objectives are to delineate the extent and distribution of perennial wetland associated with the springs, to discriminate this from ephemeral wetland and surrounding dryland vegetation, to quantify changes in the wetlands over time and to relate the extent of wetland vegetation to spring flow rates. This approach will provide a reliable and repeatable methodology to assess the temporal dynamics of mound spring wetland vegetation associated with changes in spring flow rates, which can be used for groundwater allocation plan management decisions and associated policies.

### 1.1. Study area

The Dalhousie Springs Complex (DSC) is located at latitude −26.45° and longitude of 135.51°, 50 km south of the Northern Territory (NT) border and 50 km west of the western edge of the Simpson Desert in South Australia (SA) (Fig. 1). The DSC traverses a region of approximately 19,000 ha, with average climate conditions at Oodnadatta airport SA (latitude: −27.56; longitude: 135.45, 100 km south of DSC, the closest Australian Bureau of Meteorology automatic weather station providing synoptic climatological data; Fig. 1) of mean annual rainfall 179.4 mm, maximum mean annual relative humidity of 44%, and maximum annual average temperatures ranging between a minimum of 19.6 °C in July and maximum of 37.8 °C in January. The DSC is selected for this study because of its ecological and conservation importance within South Australia, Australia and internationally, and because it includes the most extensive and diverse spring-fed wetlands in the GAB. The GAB spring wetlands are listed collectively as threatened ecological communities, and many of their endangered plant and animal species protected under the Australian Environmental Protection and Biodiversity Conservation Act 1999 (Department of Sustainability, Environment, Water, Population and Communities, 2011). DSC is included in the Australian Government Register of the National Estate and the National Heritage List and is also protected by its inclusion in the Witjira National Park in 1985. Within the DSC there are 30 endemic, relict or rare species of significance listed (Gotch, 2005). The springs at Dalhousie are a permanent historical source of water and are therefore important features in the landscape for indigenous Australians, in particular to the traditional Irrwanyere owners. Their long-term use is evidenced from many *Altyerre* (Lower Southern Arrernte word for traditional lore and customs) and extensive archaeological deposits (Ah Chee, 2002; Gotch et al., 2006; Department for Environment and Heritage, 2009). The DSC and surrounding region are also currently under threat from proposed extensive GAB aquifer water extraction associated with mining activities in the surrounding NT and SA regions.

The hydrogeology of the DSC consists of several main aquifers within several distinct geological units of Jurassic and Cretaceous age. The aquifer ranges in thickness from approximately 250 m in SA up to 1000 m in the NT (Love et al., 2000; Matthews, 1997), overlain by regional aquitard shales with maximum thickness of 400 m (Habermehl, 1980; Herczeg and Love, 2007). At DSC the confined Algebuckina Sandstone aquifer (depths of 50–200 m) is brought near the surface by the mid-Cainozoic Dalhousie anticline and the artesian flow is focused along a series of faults that breach the anticline's eroded crest (Clarke et al., 2007; Krieg, 1985, 1989; Williams and Holmes, 1978). The 148 springs at DSC (Gotch unpublished data) are supported by the natural outflow of the GAB at an estimated 54 ML/day along these north–northeast trending faults (Gotch et al., 2006; Williams and Holmes, 1978). In the geological time frame, the springs are dynamic, with abundant evidence of cyclic waxing, waning and extinction, but previous work has also documented considerable short term fluctuation in flow (Harris, 1992; BHP Billiton, 2009; Ponder et al., 1989).

The region around the springs at Dalhousie is dominated by extensive stone-covered clay plains, known as gibber, which support sparse low herb vegetation dominated by chenopodiaceous species, typically with a more open than vegetated surface (Boyd, 1990; Purdie, 1984). Smaller areas of limestone pavement also support sparse herbaceous vegetation, saline flats have restricted halophytic vegetation and some ephemeral rain-fed creeks and floodplains support a richer flora of perennial shrubs, trees (*Acacia* spp. and *Eucalyptus* spp.) and a range of herbs (Boyd, 1990).

The surface geomorphological formation of the DSC GAB springs comprises travertine mounds and terraces, soft sand/silt mounds, seeps and soaks (Fatchen and Fatchen, 1993; Gotch et al., 2006). Individual springs are defined as surface outlets where artesian water discharges and consist of several components: the vent, the mound and the tail. The vent is an area where water issues from the ground; it can vary in form from an active spring with pool of open water, either circular or elongate in shape, to a damp soak. GAB spring mounds are defined as a wet region immediately surrounding the vent (Clarke et al., 2007; Fatchen and Fatchen, 1993; Gotch et al., 2006). Many of the GAB spring mounds at DSC have formed from the precipitation of dissolved solids present in the groundwater along with both the deposition of particles derived from the aquifers, and the trapping of aeolian sand and silt in the vegetation that often grows on the mounds (Gotch et al., 2006; Krieg, 1989). Mounds at DSC are low features attaining heights of 6 m and widths of 180 m and consist of autochthonous materials (largely carbonates, sulphates, and oxides–hydroxides of iron and manganese) precipitated by the spring waters and allochthonous materials (sand, mostly quartz with minor feldspar, and clay with some carbonate) (Clarke et al., 2007). The tail results from the outflow of spring water away from the vent, which can take the form of a single channel, braided multiple interconnecting channels, or a uniform flow radiating out from the vent (Clarke et al., 2007; Fatchen and Fatchen, 1993; Gotch et al., 2006).

Biologically, the GAB springs represent unusually specialised aquatic habitats, their discontinuity being analogous to islands and the isolation just as great for species with limited dispersal