Lake Eyre Basin Springs Assessment

Great Artesian Basin spring wetland area mapping and flow estimation

DEWNR Technical report 2015/54

Government of South Australia
Department of Environment, Water and Natural Resources

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Prepared for

The Department of Environment, Water and Natural Resources

By

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Summary

The remotely sensed methods outlined and implemented in this report achieved the main aims: (i) to identify and map the extent of the vegetated areas around spring vents to generate date stamped wetland polygons for spring groups and complexes of interest to LEBSA; and (ii) calculate the wetland area and flow rates for these spring groups and complexes using ancillary data from the Lewis et al. (2013) study. Outputs of wetland areas are reported along with a guide to their interpretation and an example figure to illustrate their range of variability in extent and spatial distribution. Wetland areas and estimated flow rates for whole spring groups are provided. Flow rates are provided as a range, based on the regression relationships developed by White et al. (2015) between wetland extent and flow rate, which encapsulate the range of natural variability in the wetlands in response to rainfall events, climatic conditions and historic land management. The wetland extent polygons have also been provided as a digital record for comparison with any future monitoring programs.

Estimated ranges of spring flow rates are reported, providing a baseline ‘envelope’ against which any future changes in spring flow rates can be monitored and objectively compared. The data provided in this report synthesizes existing and new remotely sensed outputs for mapping and monitoring GAB spring wetland extents and flow rates along its western margin in South Australia. The methods implemented in this report are designed for monitoring and could be used to document any future changes in spring wetland extents and associated flow rates due to mining operations in the region.

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1 Introduction

This report is part of a series of studies forming part of the Lake Eyre Basin Springs Assessment (LEBSA) project. The LEBSA project is one of three water knowledge projects undertaken by the South Australian Department of Water, Environment and Natural Resources (DEWNR) to inform the Bioregional Assessment Programme in the Lake Eyre Basin (LEB). The three projects are:

- Lake Eyre Basin Rivers Monitoring (LEBRM)
- Arckaringa Basin and Pedirka Basin Groundwater Assessment
- Lake Eyre Basin Springs Assessment (LEBSA)

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with potential water-related impacts of coal seam gas (CSG) and large coal mining (LCM) developments. The coal-bearing Arckaringa, Pedirka, Cooper and Galilee basins (Figure 1) have been identified as regions where CSG and LCM developments are likely to occur or increase in the future. Bioregional assessments are being prepared in the LEB for the four coal regions to strengthen the science underpinning future decisions about CSG and LCM activities and their impacts on groundwater quality, surface water resources and aquatic ecosystems.

The objective of the LEBSA project was to address knowledge gaps relating to the potential impacts of mining developments on groundwater resources and assets across the LEB. In particular, the project aimed to characterise and attribute aspects of springs and other GDEs that are critical for the maintenance of those assets (e.g. ecological, hydrogeological, hydrochemical), in a way that is consistent across South Australia and Queensland.

For the LEBSA project the South Australian Department of Environment, Water and Natural Resources (DEWNR) requested further extension and application of the methods developed by researchers at the University of Adelaide (Lewis et al., 2013) for quantifying Great Artesian Basin (GAB) spring wetland extents and associated estimates of groundwater flows. These methods have been peer reviewed and published in the scientific literature (White and Lewis 2011; White et al., 2015), and are a robust and repeatable means for spatially computing spring wetland extent from remotely sensed satellite and airborne imagery. Regression relationships established between wetland extents and spring flow rates provide a reliable remote indicator of spring flow for groups of springs distributed over broad landscapes.

These outputs will provide a valuable baseline assessment for the Bioregional Assessment Programme. The methods are designed for monitoring and can be used to document any future changes in spring wetland extents and associated flow rates due to mining operations in the region.

Thus, the aims of this study were to:

- identify and map the extent of vegetated areas around spring vents to generate date-stamped wetland polygons for the named spring groups; and
- calculate the wetland area and flow rates for spring groups using existing satellite and airborne imagery and spatial spring vent DGPS data (obtained during the *Allocating Water and Maintaining Springs in the Great Artesian Basin*, National Water Commission project; Lewis et al., 2013), for all sites included in the study.

Wetland areas and estimated flow rates for whole spring groups are provided. Flow rates are provided as a range, based on the regression relationships developed by White et al. (2015) between wetland extent and flow rate, which encapsulate the range of natural variability in the wetlands in response to rainfall events, climatic conditions and historic land management.

2 Methods

2.1 Study area

The study area (Figure 1) covers an extensive part of northern South Australia. This arid region is punctuated with contrasting spring wetlands supported by artesian water outflow from aquifers on the western margin of the Great Artesian Basin (GAB). A number of spring groups and complexes have been identified for the LEBSA that require baseline and continued monitoring in light of proposed mining operations in the region. The groups and complexes of interest are: Freeling South Spring Group, Billa Kalina Spring Group, Hawker Spring Group, Levi spring Group, Fred Spring Group, and all groups in the Hermit Hill Complex, Beresford Hill Complex, Strangways, and Coward Complex (Figure 1).

Figure 1 provides the location and spatial extent of the spring groups covered by the satellite and airborne hyperspectral imagery within the study area. Images were acquired in 2009 and 2011 for the *Allocating Water and Maintaining Springs in the Great Artesian Basin*, National Water Commission project (Lewis et al., 2013). The analyses reported here are based on the 2009 imagery, as this is considered the most reliable basis for this baseline study; the six preceding years were very dry, allowing us to infer that wetland extents and flows were almost entirely a result of GAB groundwater outflow. Lewis et al. (2013) and White et al. (2015) observed that antecedent rainfall could substantially increase wetland vegetation extents (evident in the 2011 image captures – refer to White et al., 2015), due to increased availability of surface water leading to responsive growth, particularly of bore drain sedge (*Cyperus laevigatus*) along spring tails.

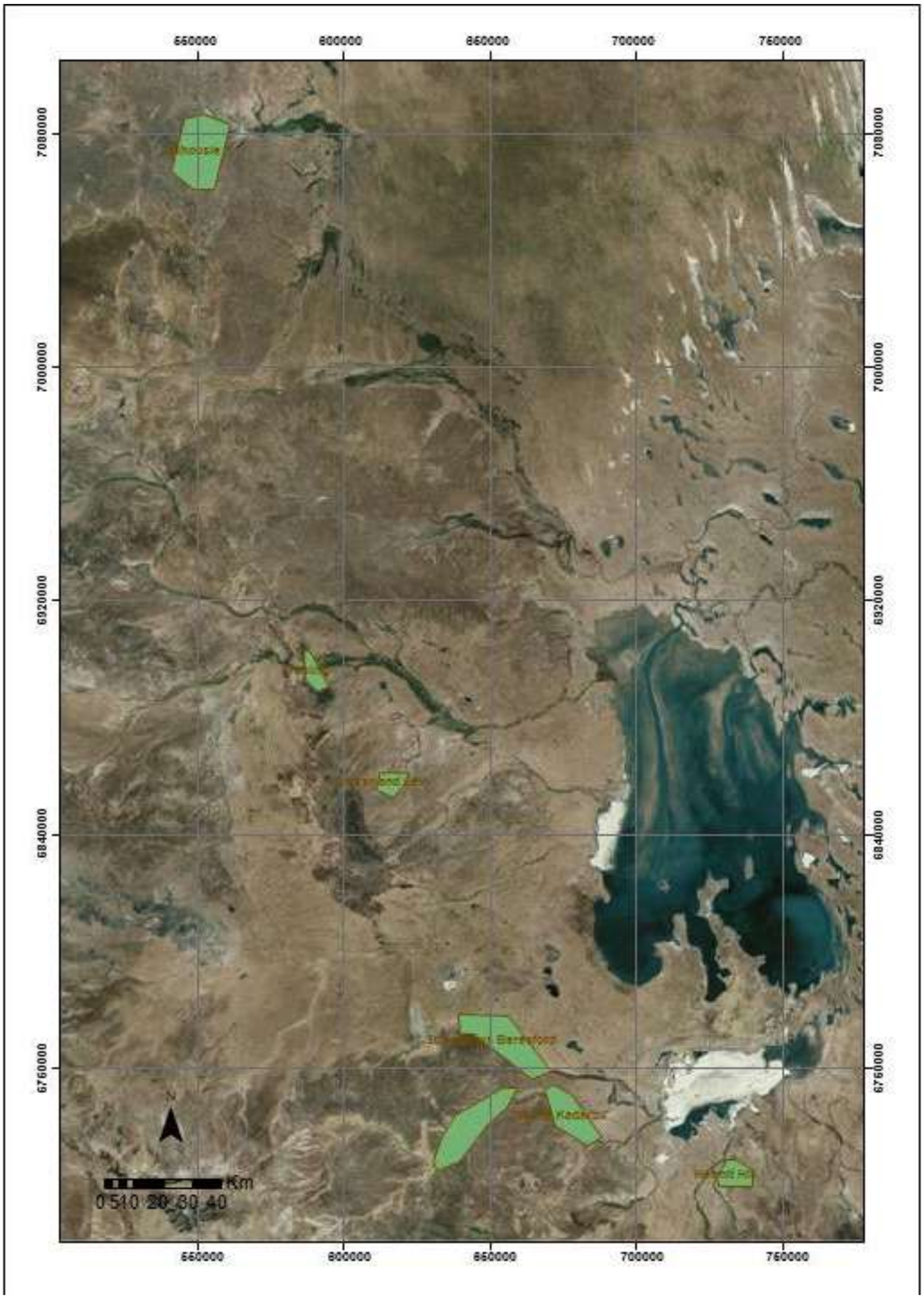

Figure 1. Study area extent and location of South Australian Great Artesian Basin springs captured with satellite and airborne imagery (modified from Lewis et al., 2013).

2.2 High resolution satellite image data and pre-processing

The mapping of wetland area and estimation of spring flows for Dalhousie Spring Complex (DSC) used QuickBird high resolution multispectral satellite imagery acquired in May 2009 (Table 1). The images were provided partially orthorectified (coarse terrain corrections and projected to a constant base elevation) and partially radiometrically corrected (DigitalGlobe, 2013). Further geo-registration was performed to improve positional accuracy for aligning the imagery with field survey plots (White et al., 2015). Further radiometric correction was conducted to convert the images to apparent surface reflectance. The satellite scene tiles were subsequently colour balanced and mosaicked to give full seamless coverage (White et al., 2015).

Digital colour (red, green and blue) aerial photography at 0.3 m GSD was acquired in March 2009. The high resolution photography was used to assist with interpretation of the wetland extent mapping from the satellite image analysis.

Table 1. QuickBird satellite imagery captured for selected sites and waveband specifications (modified from White et al., 2015).

Site	Date captured	GSD*	Waveband configuration	Band centres used for NDVI** calculations
DSC	6 May 2009	2.62 m	479.5 nm – blue; 546.5 nm – green; 654.0 nm – red; 814.5 nm – near-infrared	654.0 nm – red 814.5 nm – near-infrared

*GSD refers to Ground Sample Distance (equivalent to pixel size at nadir – directly overhead).
** NDVI refers to Normalized Difference Vegetation Index – a measure of vegetation greenness.

2.3 Airborne hyperspectral image data and pre-processing

The remaining spring groups and complexes of interest to LEBSA were covered by HyMap hyperspectral airborne imagery for the *Allocating Water and Maintaining Springs in the Great Artesian Basin*, National Water Commission project; Lewis et al., 2013 (Table 2). The airborne hyperspectral imagery was provided by HyVista Corporation with image pre-processing completed, which included atmospheric correction with the HyCorr model, geometric correction and colour balancing swaths to form seamless mosaics of each study area (Lewis et al., 2013, Appendix A2.3.1, pp.132). Full specifications of the hyperspectral imagery are provided in Table 2. The 3 m image pixels of this imagery provided sufficiently fine spatial resolution to delineate individual spring wetlands, while covering a wide range of spring sizes at the group and complex scale.

This remote sensing study for LEBSA used HyMap imagery flown on 15th – 25th March 2009 (refer to Lewis et al., 2013 report pp. 10), following very dry antecedent conditions. Thus, the extents of wetlands derived from the 2009 hyperspectral imagery have a high probability of being influenced only by groundwater flows.

Table 2. Airborne hyperspectral imagery captured for selected sites and waveband specifications (modified from Lewis et al., 2013, Appendix 2, p. 135).

<table>
<tr><th>Site

(spring group)</th><th>Date captured</th><th>GSD *</th><th>Waveband configuration</th><th>Band centres used for NDVI** calculations</th></tr>
<tr><td>Freeling South</td><td rowspan="9">15 - 25 March 2009</td><td rowspan="9">3 m</td><td rowspan="9">126 near contiguous narrow (~15 nm) wavebands; wavelength range 450 - 2,500 nm</td><td rowspan="9">665.7 nm - red

847.8 nm - near-Infrared</td></tr>
<tr><td>All groups within Hermit Hill Complex</td></tr>
<tr><td>Billa Kalina</td></tr>
<tr><td>Hawker</td></tr>
<tr><td>Levi</td></tr>
<tr><td>Fred</td></tr>
<tr><td>Strangways</td></tr>
<tr><td>All groups within Beresford Hill Complex</td></tr>
<tr><td>All groups within Coward Complex</td></tr>
</table>

*GSD refers to Ground Sample Distance (equivalent to pixel size at nadir – directly overhead).

** NDVI refers to Normalized Difference Vegetation Index – a measure of vegetation greenness.

Note that no imagery was captured over Gosse Springs, therefore wetland extent calculations could not be produced for this study.

2.4 On-ground calibration data collection

Vegetation cover and composition were recorded between March and April 2009, within ground survey plots of 9 × 9m, designed to allow for geolocation errors and geometric accuracy of the imagery, as well as the scale of vegetation stands and variation. Within the plots, percentage cover of plant species and overall fractions of photosynthetic vegetation, dry vegetation, water and soil were recorded using the methods described by Lewis et al. (2013) and White and Lewis (2011). Differential GPS locations were recorded at the corners of the survey plots to enable their later identification on the imagery (White et al., 2015). These data were used to derive regression relationships between image NDVI values and on-ground estimates of vegetation cover. These relationships were used in mapping and estimating wetland extent (Section 2.5).

Spring flow data were selected either from ongoing monitoring records or new *in-situ* measurements that were made in the Lewis et al. (2013) and White et al. (2015) studies. The *in-situ* flow measurements coincided with the vegetation surveys. The timing of the discharge measurements corresponded as closely as feasible with the image acquisitions.

2.5 Wetland extent calculations

Calculation of wetland area extents involved the sequence of analyses shown in Figure 2.

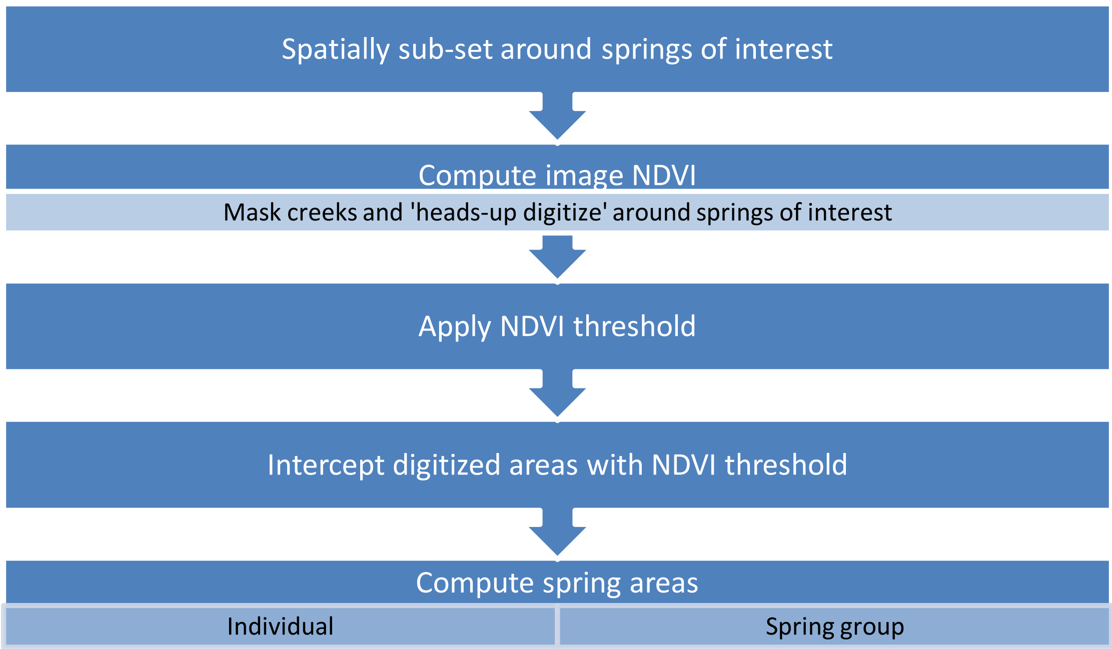

Figure 2. Schematic of image analysis sequence for calculating wetland extents.

The Normalized Difference Vegetation Index (NDVI – a measure of vegetation greenness) was applied to both the HyMap hyperspectral airborne imagery and the QuickBird satellite imagery. Tables 1 and 2 summarize the image wavebands used for the NDVI calculations for all imagery employed (for full derivation of the equations refer to White and Lewis, 2011; Lewis et al., 2013, pp. 133). The NDVI image outputs were calibrated using the on-ground survey data comprising vegetation cover and composition (Lewis et al., 2013; White and Lewis, 2011; White et al., 2015). Regression relationships were developed between image NDVI values and corresponding on-ground percentage vegetation cover for each plot surveyed for three sites in the Lewis et al., 2013 and White et al., 2015 studies (Dalhousie Springs Complex, Freeling Spring South Group, and Hermit Hill Spring Group). For DSC overall vegetation cover (photosynthetic and dry vegetation) was used to develop the regression relationship (White and Lewis, 2011). This approach was refined for Freeling South Spring Group and Hermit Hill Spring Group where the photosynthetic vegetation fraction of cover was used for the analyses. From these relationships NDVI thresholds were determined for each site to separate wetland vegetation from surrounding dryland vegetation (White et al., 2015). The threshold of importance for the current reporting for DSC, 0.35, was derived from White and Lewis (2011).

NDVI was also calculated for the HyMap hyperspectral airborne imagery as part of the Lewis et al. (2013) study for the following sites: Freeling South Springs Group, and all spring groups in the Hermit Hill Complex (Beatrice, Bopeechee, Bopeechee Mound, Bopeechee North, Dead Boy, Finniss Well, Hermit Hill, North West, Old Finniss, Old Woman, Sulphuric, West Finniss). For the current reporting these analyses were extended to the following sites: Billa Kalina, Hawker, Levi, Fred, Strangways, all spring groups within the Coward Spring Complex, and all spring groups within the Beresford Hill Spring Complex. The airborne hyperspectral image NDVI thresholds were a consistent value of 0.17, derived from Lewis et al. (2013). This threshold value was appropriate for delineating spring wetland vegetation from surrounding dryland vegetation at all sites.

The methodology developed by White and Lewis (2011) for DSC was applied with some site-specific modifications (refer to Appendix 1 for details) to all other spring groups presented in the current report. The method involved the following steps:

(i) the extent of spring groups was broadly delineated by heads-up digitising on the NDVI threshold imagery;

(ii) where spring groups were more difficult to delineate, their associated wetlands were distinguished using a suite of ancillary data, including spring vent DGPS coordinates and codes (Gotch, 2010; Lewis et al., 2013), and expert knowledge of the sites;

(iii) polygons produced from the digitising were intersected with the NDVI threshold image to produce precise delineations of wetland extent for the spring groups of interest; and

(iv) spring group wetland areas were calculated in hectares.

2.6 Estimating flow rates

White et al. (2015) developed strong positive linear regression relationships between spring wetland area and discharge at the individual spring level for all three sites they investigated (DSC $R^2 = 0.99$; FSG $R^2 = 0.95$; HHSG $R^2 = 0.92$; $p < 0.001$ in all cases; refer to White et al., (2015) for details. Differences in the relationships between the sites captured variability primarily due to differences in antecedent conditions (rainfall driven), site specific geomorphological and hydrogeological settings and lags between on-ground calibration data and image capture (for Hermit Hill Spring Group) as reported by Lewis et al. (2013) and White et al. (2015). The regression relationships developed by White et al. (2015) were used for the LEBSA spring flow estimates:

DSC: $y = 1.21x + 0$

Hermit Hill Spring Group: $y = 0.68x + 0$

Freeling South Spring Group: $y = 2.58x + 0$

where y is wetland area and x is spring flow.

However, analysis of covariance (ANCOVAR) indicated that the slopes of the three regression lines for the three sites are not significantly different. A very strong positive linear regression relationship was also apparent between spring wetland area and discharge for all sites combined ($R^2 = 0.99$ $p<0.001$) (White et al., 2015).

For the purposes of this report a range of estimated spring flow rates is provided to capture the variations mentioned above: these values are based on the White et al. (2015) regression relationships outlined above. The shallower slope for Hermit Hill Spring Group is most likely due to a lag of eight weeks between the collection of on-ground calibration data and image capture. The spring wetland vegetation over the eight week period senesced, resulting in lower NDVI values recorded in the captured imagery relative to on-ground vegetation cover. Therefore, the higher flow rates resulting from calculations using this lower slope in the regression equation are likely to be an over-estimate of actual flow values. To address this likely over-estimation we have provided the full range of possible flow values in Table 4, the value in parentheses represents the estimated flow rate from the DSC slope of 1.21. We provide our interpretation of the most probable flow rate range for each LEBSA site investigated in section 3.2.

2.7 Methodological considerations

The methods presented in this report are reliable, robust and repeatable and have been peer-reviewed and published in the scientific literature. There are a number of decisions we have made concerning the methods for deriving the spring wetland extents and their associated flow measurements, which are explained below to assist with interpretation of the results presented in Section 3.

- Spring wetland extents have been calculated at the spring group scale where spring inter-connectivity is extensive and delineation of individual springs would therefore be impractical.
- The range of spring flow rates captured in the White et al. (2015) study demonstrates the range of natural variability of the springs in response to rainfall and climatic conditions. The estimated spring flow rates have been presented as ranges and the most likely location within the range provided in the interpretation of these results. The envelope defined by this range could be considered a baseline natural flow regime, within which the springs are currently performing.
- There are differences in the NDVI thresholds applied to spring group and complex sites, where different remotely sensed imagery was used to calculate NDVI. These differing values are largely the result of image band widths. All imagery was calibrated to at-surface reflectance enabling comparison between sites, dates and image types. Consequently wetland mapping and area estimations are comparable between image types.

3 Results

This section provides the results of the image analyses to determine wetland extents, derived from delineating spring wetlands from NDVI thresholds applied to the high resolution satellite imagery (DSC) and hyperspectral imagery (all other sites). Spring flow rate estimates are derived from the wetland area to flow regression equations outlined in section 2.6.

3.1 Wetland extents

The wetland extents calculated for all LEBSA spring sites of interest are summarized in Table 3. The spring wetland extents differ considerably between groups and within complexes. DSC has the largest overall wetland extent at 913 ha, followed by the Hermit Hill Springs Complex 39 ha, Coward springs Complex 15.72 ha, and Beresford

Hill Springs Complex 2.11 ha. Spring group wetland extents vary most widely at the Hermit Hill Springs Complex, ranging between 12.93 and 0.12 ha, for Hermit Hill Springs Group and Bopeechee Mound Springs Group, respectively. Overall, the most extensive wetland area associated with a single spring group is Hawker at 14.86 ha, the least extensive is Secret (BSS) at 0.001 ha.

For Strangways and Billa Kalina Spring Groups further ancillary data is required to provide more accurate and robust calculations of wetland extent, i.e., DGPS measurements of vent activity (extinct, active, damp) to locate all springs with associated wetland vegetation within these groups. Remotely sensed imagery is not available for Gosse Springs, so no calculations of wetland extent could be conducted for this site.

An example of mapped outputs illustrating the wetland extents and their spatial variability and inter-connectivity within two spring complexes is provided in Figure 3.

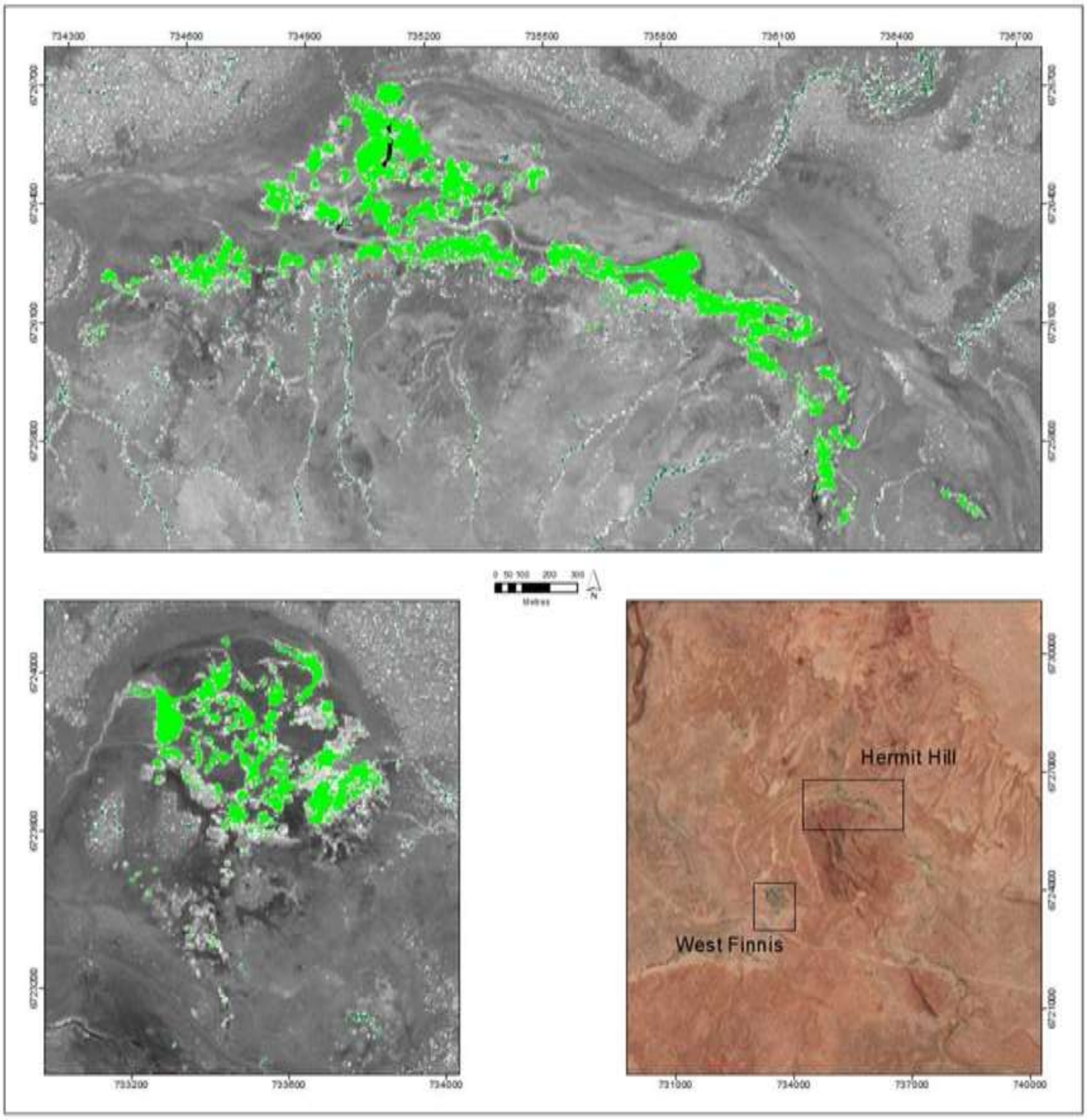

Figure 3. Mapped spatial distribution of spring wetland extents at Hermit Hill Springs Complex.

3.2 Flow estimates

The estimates of spring flow rates follow a similar pattern to the wetland extents at the spring group and complex scales (Table 4). Generally, the flow rates most closely correspond with the DSC regression relationship with a slope of 1.21, which is noted in parentheses. However, given variations in substrate and vegetation community composition between sites, applying a lower range of flow values (for the Freeling South Spring Group regression slope of 2.58) is generally advisable. In the context that the wetland areas were calculated from 2009 imagery, the derived flow rate values are likely to be the lower estimates of flow for springs investigated in this study, and are most likely to be solely groundwater-fed.

Table 3. Spring group wetland extents in hectares.

Site(spring group)	Wetland area (ha)
Dalhousie Springs Complex (DSC)	913
Freeling South Springs Group	9.4
All groups within Hermit Hill Complex:	
Beatrice (HBS)	0.19
Bopeechee (HBO)	3.83
Bopeechee Mound (HBM)	0.12
Bopeechee North (HBN)	0.23
Dead Boy (HDB)	0.13
Finniss Well (HFL)	0.23
Hermit Hill (HHS)	12.93
North West (HNW)	2.46
Old Finniss (HOF)	6.20
Old Woman (HOW)	1.57
Sulphuric (HSS)	1.31
West Finniss (HWF)	5.74
Pigeon Hill (HPH)	Extinct – No vegetation
Pigeon Hill North (HPN)	Extinct – No vegetation
Whole Complex	39.00
Billa Kalina (KBK)	4.11*
Hawker (NHS)	14.86
Levi (NLS)	1.76
Fred (LFE)	1.97
Strangways (CSS)	Additional ancillary data required*
All groups within Beresford Hill Complex:	
Beresford (BBH)	0.40
Warburton (BWS)	1.70
Secret (BSS)	0.001
Whole Complex	2.11
All groups within Coward Complex:	
Blanche Cup (CBC)	9.26
Buttercup (CBU)	0.28
Mt Hamilton Ruin (CMH)	0.25
Horse West (CHW)	0.25
Hose East (CHE)	0.16
Jersey (CJE)	1.33
Elizabeth North (CEN)	1.41
Elizabeth (CEL)	0.66
Kewson Hill (CKH)	0.41
Coward (CCS)	1.71
Whole Complex	15.72

* Requires further analysis

Table 4. Spring group flow estimate ranges in litres per second (best estimate flow rate in parentheses).

Site (spring group)	Flow range (L/sec)
Dalhousie Springs Complex	353.89 – 1,342.65 (754.54)
Freeling South Springs Group	3.64 – 13.82 (7.77)
All groups within Hermit Hill Complex:	
Bopeechee Mound (HBM)	0.05 – 0.20 (0.11)
Bopeechee North (HBN)	0.16 – 0.61 (0.34)
Bopeechee (HBO)	2.59 – 9.84 (5.53)
Beatrice (HBS)	0.10 – 0.36 (0.21)
Dead Boy (HDB)	0.05 – 0.20 (0.11)
Finniss Well (HFL)	0.13 – 0.48 (0.27)
Hermit Hill (HHS)	5.21 – 19.75 (11.10)
North West (HNW)	0.95 – 3.61 (2.03)
Old Finniss (HOF)	2.43- 9.20 (5.17)
Old Woman (HOW)	0.64 – 2.42 (1.36)
Pigeon Hill (HPH)	Extinct -No vegetation
Pigeon Hill North (HPN)	Extinct - No vegetation
Sulphuric (HSS)	0.57 – 2.15 (1.21)
West Finniss (HWF)	2.25 – 8.53 (4.80)
Whole Complex	15.12 – 57.36 (32.24)
Billa Kalina (KBK)	1.59 – 6.04 (3.39) Requires further analysis
Hawker (NHS)	5.76 – 21.86 (12.28)
Levi (NLS)	0.68 - 2.59 (1.45)
Fred (LFE)	0.76 – 2.89 (1.63)
Strangways (CSS)	Additional ancillary data required
All groups within Beresford Hill Complex:	
Beresford (BBH)	0.16 – 0.59 (0.33)
Warburton (BWS)	0.66 – 2.51 (1.41)
Secret (BSS)	0.0004 – 0.002 (0.0009)
Whole Complex	0.82 – 3.10 (1.74)
All groups within Coward Complex:	
Blanche Cup (CBC)	3.59 – 13.61 (7.65)
Buttercup (CBU)	0.11 – 0.41 (0.23)
Mt Hamilton Ruin (CMH)	0.10 – 0.36 (0.20)
Horse West (CHW)	0.10 – 0.37 (0.21)
Horse East (CHE)	0.06 – 0.24 (0.13)
Jersey (CJE)	0.51 – 1.95 (1.10)
Elizabeth North (CEN)	0.55 – 2.10 (1.17)
Elizabeth (CEL)	0.26 – 0.98 (0.55)
Kewson Hill (CKH)	0.16 – 0.61 (0.34)
Coward (CCS)	0.66 – 2.52 (1.41)
Whole Complex	6.09 – 23.12 (13.00)

4. Conclusions and Recommendations

For springs in the LEBSA region the outputs of wetland extent and estimated flow rates from remotely sensed imagery presented in this report provide an excellent baseline for assessing potential future changes in flow rates in response to climatic conditions and mining operations. Any changes to wetland extent and flow rates can be assessed in an objective and reliable way, enabling future monitoring to be conducted easily, efficiently and objectively, using the methods outlined in this report. This section provides guidelines on interpretation of the image outputs for wetland extent and estimated spring flows as well as recommendations for using these data for future studies and improvements for future work.

The outputs provided in this report have been produced by remote sensing scientists along with input from spring experts. We recommend the following guidelines for interpreting these outputs.

- The wetland extents are specific to the time of image data capture in 2009 and should be interpreted in the context that they are at the lower end of the range of wetland extents. The main rationale is that the 2009 images were captured after a prolonged dry period of six years, and the wetland extents represent groundwater fed-wetlands, without surface rainfall influences.
- Where one very large spring dominates a spring group wetland extent it can have a major influence on the wetland extent of the whole spring group or complex. It is therefore important to consider any impacts to springs which are particularly extensive within a group or complex, in which case any changes in wetland extent should be closely monitored.
- The range of flow rate estimates should be interpreted as a guide to flows at the springs mapped. We recommend using the lower range values up to the Dalhousie regression slope values (1.21) in parentheses. The higher values are likely to be an over-estimate based on the Hermit Hill regression equation, which has a shallower slope. This is largely due to drying of the wetland vegetation prior to image capture and the eight week lag between on-ground calibration data collection and image capture.
- These estimates of wetland area and spring flows represent one epoch in time. The springs are dynamic naturally-occurring features in the arid landscape. Future rainfall, climatic and land use impacts will all influence the wetland extent and flow values.

Wetland extent and flow rate estimates have not been provided for the following spring groups, either because they were not outlined in the project definition or there is insufficient data for the analyses: Billa Kalina, Strangways, Gosse, Welcome, McEwins, Francis Swamp, Freeling Springs North. The methods employed in this study are ideal for monitoring any future changes in spring wetland extents and associated flow rates due to mining operations or other land use impacts and aquifer pressure changes in the region. The baseline data generated in this study could be used with future comparable information for monitoring of the springs in the western margin of the GAB.

We recommend that the methods presented in this report, which have been peer-reviewed and published in the scientific literature, are implemented to monitor future changes in spring wetland extents and flow rates in the LEBSA region. The following specific recommendations are provided for end users to make the best use of these data for alignment with other projects within the LEB and for future reporting and monitoring.

- Adoption of remote sensing wetland area mapping in future will enable time series of comparable data to be built up, allowing objective assessment of changes in the spatial distribution and extent of spring wetlands. Methods developed by White and Lewis (2011) for detecting and quantifying changes in wetland extents at DSC using high resolution satellite imagery are suitable for wider implementation for springs within the western margin of the GAB using existing hyperspectral airborne imagery captured in 2011 (Lewis et al., 2013). This approach would enable differences in wetland extents to be quantified and changes in their spatial distribution to be mapped with confidence.
- If future monitoring identifies spring flows that fall outside the ranges estimated here, then at the very least further investigation should be undertaken to determine the cause of the change in spring flow.In addition, the methods used in this study could also be applied to other water flows, seepage or leakage from bores and pipes that draw on GAB artesian water, where such flows support wetland vegetation. For example, the extensive wetland supported by uncontrolled artesian flows from Big Blyth Bore to the east of Freeling Springs was mapped in April 2011 using high resolution satellite imagery and the methods presented in this report (White et al. 2013, p 57). Since then Big Blyth Bore has been capped. A repeat image-based study could confirm reduction in the wetlands associated with the bore, and allow assessment of any change at Freeling Springs as a result of increased local aquifer pressure.
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5. References

Gotch, T.B., 2010. Great Artesian Basin Springs of South Australia: Spatial Distribution and Elevation Map. South Australia Arid Lands Natural Resources Management Board, Adelaide, Australia (last Updated June 2010).

Lewis, M.M., White, D.C. & Gotch, T.B. (Eds.) 2013, Allocating Water and Maintaining Springs in the Great Artesian Basin, Volume IV: Spatial Survey and Remote Sensing of Artesian Springs of the Western Great Artesian Basin, National Water Commission, Canberra. ISBN: 978-1-922136-09-1.

White, D.C. and Lewis, M.M., 2011, A new approach to monitoring spatial distribution and dynamics of wetlands and associated flows of Australian Great Artesian Basin springs using QuickBird satellite imagery. *J. Hydrol*. 408, 140-152, http://dx.doi.org/10.1016/j.hydrol.2011.07.032.

White, D.C., Gotch, T.B., Alaak, Y., Clark, M., Ryan, J. and Lewis, M.M. 2013. Characterising spring groups. In Lewis, M.M., White, D.C. & Gotch, T.G. (Eds.). Allocating Water and Maintaining Springs of the Western Great Artesian Basin. Volume IV. Spatial Survey and Remote Sensing of Artesian Springs of the Western Great Artesian Basin. National Water Commission, Canberra. ISBN: 978-1-922136-09-1.

White, D.C., Lewis, M.M., Green, G. and Gotch, T.B. 2015, A generalizable NDVI-based wetland delineation indicator for remote monitoring of groundwater flows in the Australian Great Artesian Basin. *Ecol. Indic., Special Issue: Spatial Indicators*, In Press. Open Access, http://dx.doi.org/10.1016/j.ecolind.2015.01.032.

Williams, A.F. and Holmes, J.W. 1978, A novel method of estimating the discharge of water from mound springs of the Great Artesian Basin, Central Australia. *J. Hydrol.* 38, 263-272, http://dx.doi.org/10.1016/0022-1694(78)90073-2.

Appendix 1. Site specific methodological notes for wetland extent calculations

Site: Hawker
The 'individual' method was used at Hawker. 99/105 springs had associated wetland vegetation. In three instances pairs of springs (NHS001/NHS002, NHS080/NHS081, NHS090/NHS091) were combined because they could not be individually delineated; their wetlands were too intermingled.
Site: Levi
Levi consists of 13 springs. However, many of them are located near creek beds. If a grouping method had been applied much of that creek vegetation would have been included. Therefore, the spring wetlands were individually identified to reduce the amount of surrounding vegetation. The wetland identified for one spring (NLS011) may have been a slight over-estimate: the mapped vegetation may include dryland vegetation proximal to the vent. The master copy of DGPS locations was used at Levi rather than creating a spreadsheet with only the Levi vents.
Site: Fred
Both the 'grouping' and 'individual' methods were applied at Fred and both resulted in very similar wetland areas (equal to 2 decimal places). The wetlands were very easy to define and there was no surrounding dry land vegetation present. Only 8 springs but they're very close with intertwined wetlands. Therefore individual spring wetland extents may not be correct. However, the total wetland area for the site should be accurate. The individual regions of interest created for the Levi springs can be used/intersected with different thresholds. Took care to include the entire spring environment/extent, even if no vegetation was present (vegetation may appear there if threshold is lowered).
Site: Hermit Hill
Separate spring groups were identified for Hermit Hill rather than individual springs. So the method was considered as a 'grouping' technique since multiple springs were identified at a time. There are too many individual springs in close proximity to apply the individual method. Deleted the Venebles spring (HVS) from the Hermit Hill Complex. Extinct so doesn't need to be mapped.

Site: Beresford Hill
Beresford Hill was done in addition to other sites (although wasn't included in project brief). It was located within the Strangways imagery and consisted of only a few springs. Three separate spring groups were identified for Beresford Hill rather than individual springs. So the method was considered as a 'grouping' technique since multiple springs were identified at a time. All of the vegetation near the springs was considered wetland so a grouping method could be applied accurately to this site. An 'individual' method was not necessary as accurate results were already achieved with the grouping method.
Site: Billa Kalina
The 'individual' method was applied at Billa Kalina because there was considerable dryland vegetation present in between springs which would have been included if springs were grouped. Identified all springs in individual regions of interest (in case different thresholds were applied) but only those with vegetation were intersected and further processed. There were a few springs where it was difficult to distinguish between wetland and surrounding dryland vegetation. These springs are noted on the spreadsheet. Some springs were merged because their tails were intermingled. Only active vents have been included in the wetland extent calculation. DGPS data is still required for a number of springs at this site, so the wetland extents and estimated flows are likely lower than for the whole group. It is too difficult at this stage to delineate all of the springs without the additional DGPS points for the vents remaining to be mapped.
Site: Strangways
Require more details on vent records, to determine which springs are active. This additional data is still required as the current data is inconsistent. There was considerable dryland and creek vegetation surrounding/ proximal to the spring vents. Even with the true colour imagery displayed, it was very difficult to decide whether it was spring related or not. The overall results for Strangways were not considered accurate due to the difficulty of this site. Further knowledge of the site and ground data might be required to identify the distribution of wetland and dryland vegetation

Site: Coward
Wabma Kadarbu imagery was split into two subsets: north and south. File size was too large to process as a whole so was split into two regions. South encompasses the CBC, CBU, CMH, CHW, CHE groups. North encompasses the CJE, CEN, CEL, CKH, CCS groups. Ckh002 is included with Horse East (CHE). Flows and wetland extent were determined separately for these two areas and then added together. Separate spring groups were identified for Wabma Kadarbu rather than individual springs. So the method was considered as a 'grouping' technique since multiple springs were identified at a time. Not every spring was encompassed by the regions of interest when the grouping technique was applied, however all those with vegetation/wetland were. At the CEN group in Wabma Kadarbu north it was difficult to differentiate between wetland and surrounding dryland vegetation. A large section of vegetation was excluded near CKH051 because it doesn't appear to be wetland but it may be. Vegetation near CKH046 was considered wetland but may not be.

Government of South Australia

Department of Environment, Water and Natural Resources