6

Evaluation of remote sensing approaches

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6. Evaluation of remote sensing approaches

6.1. Evaluation

This chapter provides an evaluation of the types of remote sensing data and approaches that were employed in this study to further understanding of the springs along the western margin of the Great Artesian Basin (GAB). During the study, careful consideration was given to the most appropriate choice of sensors and image analyses for detecting GAB Springs and their various surface expressions in space and time. Table 6.1 summarises the study components, remote sensing instruments and image analyses used for each application, as well as providing a rationale for selection of sensors and an evaluation of the effectiveness of the approaches adopted.

This evaluation is best considered in relation to the nature of the spring environments including their spatial extent, temporal variability and surface expressions. The study covered a wide range of spatial scales of relevance to the GAB Springs, from spring complexes down to spring groups and individual springs. It spanned time scales ranging from seasons and years to the past decade through new acquisitions and use of archival imagery. A range of ecological units were targeted, from total plant growth in the landscape and precise measurements of wetland area, to community and species discrimination. In addition, spring surface characteristics were differentiated and documented, including vegetation, soil moisture and evaporite crusts related to diffuse groundwater discharge.

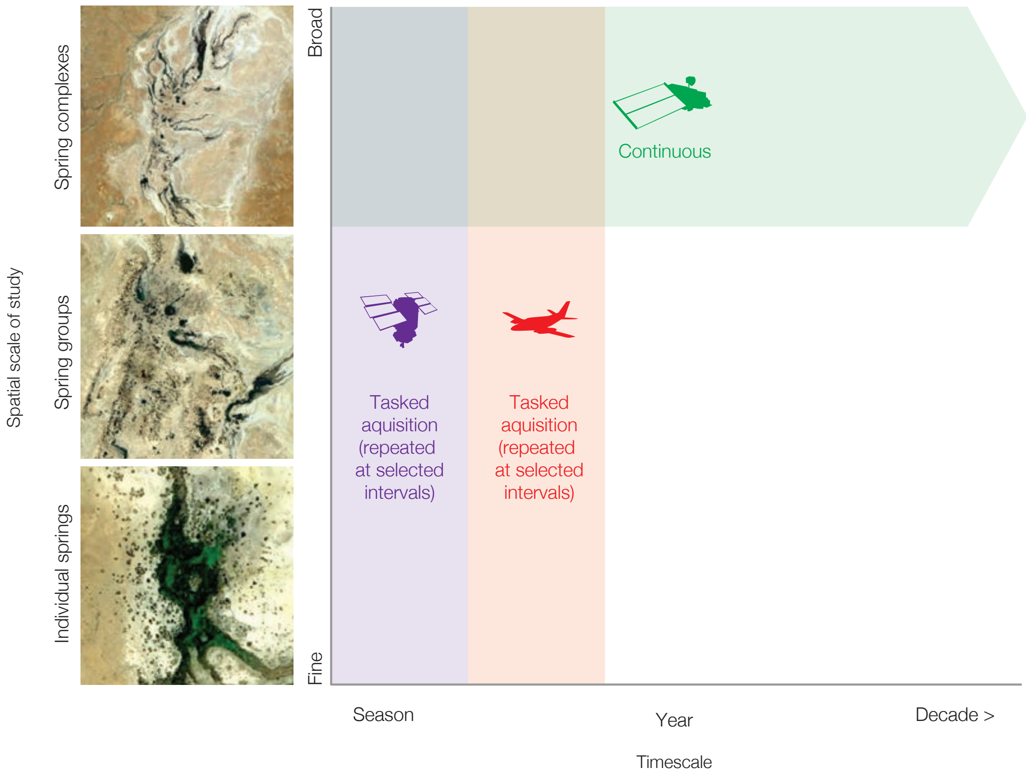
6.2. Imagery

Figure 6.1 illustrates the spatial and temporal domains of the spring environments, in relation to the spatial and temporal resolutions of the sensors employed in this study. The selection of imagery for specific GAB spring mapping and monitoring purposes was influenced by the spatial coverage and repeat frequency of the imagery, as outlined in Table A2.1, Appendix 2.

MODIS imagery, with its moderate spatial resolution, broad spatial coverage and high temporal frequency (16-day composites were used in this study) and long archive of continuous measurements (since 2000), was ideally suited to monitoring change at the spring complex scale. MODIS imagery was used to determine long-term trends in wetland extent for spring complexes and demonstrate the influence of climatic conditions. It was also capable of determining interseasonal variability and phenology in several dominant spring vegetation communities. MODIS normalised difference vegetation index (NDVI) was suitable for tracking trends at the largest of the spring complexes, but its spatial resolution limits its utility for smaller or more geographically dispersed spring complexes. This high temporal frequency information was also useful for informing optimal times for capturing higher resolution airborne and satellite imagery for more detailed characterisation of the springs.

Photograph on facing page: Megan M Lewis

Figure 6.1: Spatial and temporal scales of studies of springs in the western margin of the GAB, in relation to spatial and temporal resolutions of sensors used in this report



Legend

- WorldView-2 and QuickBird very high resolution satellites
- HyMap airborne hyperspectral
- MODIS 16 day composites

QuickBird and WorldView-2 satellite images combine very high spatial resolution with extensive spatial coverage, both required for precise delineation of wetlands at the spring complex, spring group and individual spring scales. Springs of differing spatial extent, from tens to hundreds of hectares, as well as entire spring complexes were well documented with this imagery. These images provided precise delineation of perennial and ephemeral wetland from surrounding dryland vegetation associated with the springs, and were used to quantify detailed changes in the wetlands over time in response to rainfall, spring flow and ecological processes.

The opportunity to task images at selected times allowed for coincident field data collection and validation activities, and study of change over time, as was undertaken at the Big Blyth Bore and Freeling Springs. The high spatial accuracy of the imagery and well-documented radiometric characteristics made it very suitable for objective documentation of wetland change over time, as demonstrated by the Dalhousie Springs 2006–2010 study. Although these very high resolution sensors are a relatively new technology, with limited historical archives, they can provide useful baseline records for future detection of spring changes over time.

With high spatial resolution, airborne hyperspectral imagery is especially suited to detailed detection and mapping of a wide range of spring surface characteristics. The imagery was used to target specific study areas (e.g. Eagle image swaths over Dalhousie) or provide comprehensive coverage over large areas (e.g. HyMap image mosaics of spring complexes), providing information at both spring group and spring complex scales.

The levels of ecological differentiation and focus in this volume range from assessments of average total vegetation greenness across the landscape to differentiation of wetlands

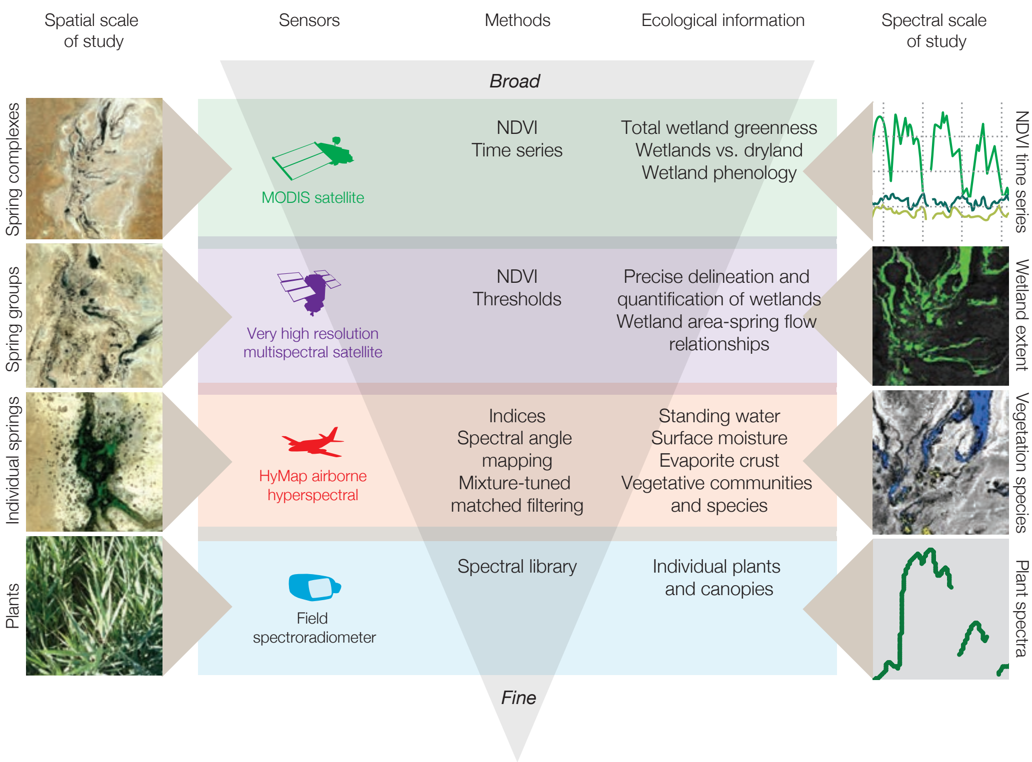


Figure 6.2: Levels of ecological differentiation of the springs in the western GAB, in relation to remote sensing data and approaches used in this report

from arid vegetation and understanding of wetland function, to more precise delineation and quantification of wetlands (Figure 6.2). At the broadest landscape and spring complex scales, MODIS NDVI time-series provided information about total wetland greenness and penology, while very high resolution multispectral satellite imagery was ideally suited to the precise delineation and quantification of wetlands. At the most specific level, a range of surface expressions that characterise the western Great Artesian Basin springs were identified and their spatial distribution mapped at fine spatial resolution. The high spectral and spatial resolution of airborne hyperspectral imagery was necessary to reveal this degree of landscape composition. At the level of individual plants and communities, field spectrometer measurements provided reflectance signatures that helped clarify similarities and differences that could be detected.

6.1.2. Analysis

A range of analytical approaches were applied to these rich sources of remote sensing data to extract new information about the spring ecosystems and their function. The NDVI, applied to MODIS, multispectral satellite and airborne hyperspectral imagery was highly suitable for defining and characterising the spring-fed wetlands as 'oases' in the arid landscape. The index was strongly related to percentage cover of vegetation measured on the ground, with higher values over defined thresholds effectively differentiating perennial and ephemeral wetlands, and wetlands from the surrounding dryland vegetation communities. Other narrow-band spectral indices and hyperspectral mapping methods proved effective for differentiating areas of high soil moisture and salt crusts indicative of diffuse evaporative groundwater discharge.

Several of the characteristic wetland species have reflectance signatures, as measured with the field spectroradiometer, which are sufficiently different to make discrimination by hyperspectral methods possible. This knowledge paved the way for differentiation and mapping of several dominant wetland plant species on the basis of their distinctive spectral signatures, and was best performed at the spring group scale, requiring close comparison with field botanical records and high resolution digital aerial photography. Spectral angle mapping was an

Table 6.1: Rationale for selection and evaluation of effectiveness of remote sensing instruments and analyses

Study purpose	Features mapped	Sensors	Rationale for selection
Characterising spring groups	• Distribution and composition of vegetation types • Wetland extent • Near surface soil moisture • Diffuse discharge	HyMap	• High spectral resolution for discrimination of surfaces, species and minerals • High spatial resolution for scale of springs • Targeted temporal acquisition
	• Vegetation height • Vegetation classification	LiDAR	• Evaluation of elevation and height data to augment spectral discrimination
		Eagle	• Evaluation and comparison with HyMap
Temporal dynamics of wetland vegetation	• Seasonal variability of vegetation types • Spring complex greenness • Long-term trends	MODIS 16-day composites	• High temporal resolution • Long continuous archive • Free
Changes in wetland distributions	• Precise delineation of extent and distribution of wetlands, perennial versus ephemeral wetlands and dryland vegetation	QuickBird, WorldView-2	• Very high spatial resolution and broad spatial extent appropriate for springs, groups and complexes • Targeted repeat acquisitions • Multispectral resolution appropriate for vegetation discrimination
Changes in spring environments	• Changes between March 2009 and April 2011 • Vegetation types • Soil Moisture • Diffuse discharge	HyMap	• Spectral resolution necessary for species, surface moisture and mineral discrimination • High spatial resolution • Targeted repeat acquisitions
Associating wetland extent and spring flows	• Relationships between wetland area and flow	QuickBird, WorldView-2	• Very high spatial resolution for individual spring definition • Targeted repeat acquisitions • Multispectral resolution appropriate for vegetation discrimination

effective approach to discriminating surface characteristics such as diffuse discharge zones and evaporite minerals across the broader areas of spring groups and complexes.

Although only exploratory work was conducted, airborne LiDAR has shown potential for characterising vegetation canopy heights and forms, with scope for improving wetland community classification in conjunction with multispectral or hyperspectral imagery.

	Analyses	Performance: advantages and limitations
	• Narrow band ratios • Spectrally-segmented principal components analysis • Spectral angle mapping • Mixture-tuned matched filtering	• Successful detailed discrimination of wetland extent at spring group scale • Identification of key wavelengths for discriminating spring vegetation • Detailed mapping of dominant spring vegetation communities and types • Successful delineation of substrate properties (diffuse discharge, near surface moisture, evaporite minerals) • Formal validation of mapped products to be undertaken
	• Decision tree using NDVI and height	• Accurate measurements of vegetation structure and height • Decision tree combing LiDAR height with image classification demonstrates great potential for vegetation mapping
	• Recommendations for future work in Section 6.1	• To be evaluated in future studies
	• NDVI, hypertemporal analysis • Climatic influences	• Detection of seasonal fluctuations in several key spring vegetation types • Delineation of spring wetland vegetation at spring complex scale • Successfully determined long-term trends in wetland extent and climatic influences • Strong relationship between rainfall events and wetland extent response
	• NDVI and thresholds • Relationships to vegetation % ground cover	• Successful discrimination of wetland extent at complex, group and individual spring scales • Strong relationship between vegetation % ground cover and image NDVI • Red-edge analysis identified perennial versus ephemeral wetland differences • Objective and detailed record of changes
	• Narrow band ratios • Spectral angle mapping • Mixture-tuned matched filtering	• Capability to detect changes in key wetland species at spring group scale • Detection of change in surface substrate features and soil moisture due to rainfall • Potential for further quantitative change analysis with refined image calibration
	• NDVI and thresholds • Regressions between wetland area and flow	• Strong relationships established between wetland area and flow rate: small and large springs • Repeat acquisitions identify range of variation in relationship

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Conclusions and recommendations

7. Conclusions and recommendations

7.1. Spring survey

7.1.1. Summary of findings and outcomes

Spring vents mapped to survey standard
This study provided the first comprehensive survey of the location and status of springs in the western margin of the Great Artesian Basin (GAB) in South Australia. A total of 4516 spring vents within almost all the spring groups have been mapped to survey standard, providing essential baseline data for the Allocating Water and Maintaining Springs in the Great Artesian Basin project (AWMSGAB Project) and for future research, management and monitoring. The survey provides an important resource for managers, scientists and industry. Many of the conditions of water licences and exploration agreements are dependent on the accurate positioning of GAB springs, as are numerous scientific studies.

The spring elevation survey has been compiled with the updated potentiometric head data for the GAB (Volume II: Groundwater Recharge, Hydrodynamics and Hydrochemistry of the Western Great Artesian Basin (Love *et al.* 2013a)), giving excess head measurements for springs in the western GAB. These data are invaluable for assessing the risk to springs from drawdown arising from water allocations and have been used to develop a risk assessment framework (Volume VI: Risk Assessment Process for Evaluating Water Use Impacts on Great Artesian Basin Springs (Green *et al.* 2013)).

New network of permanent survey marks
A network of permanent survey marks (PSMs) has been established across the western margin of the GAB for future spatial survey works. This network was derived from zero-order horizontal and third-order vertical survey benchmarks provided by the Surveyor General of South Australia. Thus, it provides the best available reference positions for any future survey work to be undertaken in and around GAB springs in South Australia. Future survey work will be able to use this control network, enabling changes over time in elevation and flow to be assessed confidently. This control network will give a consistent base station point for registration of ground control points for future airborne and satellite imagery. Because the elevation survey and PSM network is spatially referenced to the survey benchmarks of the South Australian Office of the Surveyor General, any other Surveyor General's PSMs can be used to reference spring surveys across South Australia, provided they are of sufficient quality.

Standardised spring nomenclature
A standardised classification and nomenclature system has been developed and implemented for springs, spring groups, complexes and supergroups. If adopted by future studies, this system will give consistency and allow comparability of results over time. Numerous previous studies have used different *ad hoc* naming conventions, making it very difficult for researchers and mangers to interrelate the their findings. It has also caused some confusion

Photograph on facing page: Megan M Lewis in spring names, for example between two Welcome Spring groups KWS and WWS (located at Anna Creek and Callana Stations respectively) and between Margaret Springs (FMS) and Billa Kalina Springs (KBK) which are located adjacent to Margaret Creek.

Confusion has also arisen through the interchangeable use of the terms 'spring group' and 'spring complex'. While this report does not claim to have developed these concepts, it has properly and clearly explained the differences between these units, and shown how they should be applied.

Reconciliation of historic water data with updated spring locations

There are many records of flow from springs, dating back to the 19th century; where possible these have been reconciled with the newly surveyed, accurate spatial locations. This allows future studies to have confidence that the springs under investigation are in fact the same vents recorded in the past and increases the ability to properly examine changes over time. This information is stored in SA Geodata.

2012 Baseline spring status

A comprehensive and accurate baseline record of spring status for future monitoring and evaluation has been established. Springs which are flowing or extinct have been recorded as of February 2012 providing an objective basis for comparison with future records and increasing certainty about the time of any future spring extinctions in this part of the GAB. This is a valuable tool for monitoring and compliance.

Spring attributes

In addition to the high-precision survey of spring vent locations, the study has generated a large set of baseline data for more than 1000 spring vents, including vegetation composition, grazing pressure and stock impacts. These new records expand and complement existing information about the ecological composition and status of the springs. The data are available on request from the South Australian Arid Lands Natural Resources Management Board (SAALNRMB).

7.1.2. Recommendations

Standard classification and nomenclature

All future studies should adopt the spring hierarchy nomenclature established and documented during the AWMSGAB Project. This will enable more efficient data management and allow more robust and credible monitoring and evaluation of springs in the future.

Central database for GAB springs

A central database containing spatial, hydrological and biological data for GAB springs should be developed and maintained. At present, valuable data are stored across three databases and this can result in data being lost or not updated with new information.

Complete western margin GAB survey

A survey should be completed of the remaining spring groups that were inaccessible during the AWMSGAB Project due to unseasonal rain events. These include some springs in the Billa Kalina Group and remaining groups in the Peake Creek and Lake Cadibarrawirracanna complexes. The springs on Lake Eyre, Lake Eyre South and Lake Frome need to be surveyed when conditions are drier.

Photo: Erika Lawley

7.2 Remote sensing

7.2.1. Summary of findings and outcomes

New spatially-explicit spring characterisation
The study has provided new spatially-explicit characterisation of several priority spring complexes and groups in the western GAB in South Australia. For the Dalhousie, Francis Swamp and Hermit Hill complexes and Freeling Spring Group, this report presents the first thorough documentation and baseline mapping of the geomorphic context and surface expression of the springs, their associated wetlands and environments. This has included high-resolution definition of the spatial extent and distribution of wetland vegetation, selected dominant vegetation species, and surrounding zones of high surface moisture (wetted areas) and diffuse evaporative discharge. Although some of these spring groups have been described in the past, none have been mapped or their spatial characteristics documented and quantified to this extent.

The descriptions and maps of the four focal spring complexes illustrate the uniqueness and extreme diversity of the western margin GAB springs in terms of size, land system and geomorphic setting, wetland development, plant species composition and dominance and extent of diffuse evaporative discharge.

This new understanding of the spring environments provides valuable information for future ecological studies and assessments of conservation status. At the Dalhousie Spring Complex, for example, the image-based mapping has been used to define an ecological focal zone for the Australian Government High Ecological Value Aquatic Ecosystems (HEVAE) in the Lake Eyre Basin (LEB). This is defined as 'the core elements, either singly or as an aggregation of aquatic ecosystems, which contain the key ecological values and functions, plus the surrounding area that directly supports and/or connects them' (Hale & Brooks 2011). At Freeling Spring Group, delineation of surface water and stream flow paths has allowed ecologists to make more accurate predictions of native fish populations and their risk of invasion by Mosquito Fish, while at Francis Swamp Spring Complex the integration of precision spring survey with remotely-sensed surface temperature and evaporite mineral deposits has provided new insights into spring function and evolution.

An objective baseline of spring character and condition for comparison with future assessments has also been established. For example, the quantification of wetland area to flow relationship for Freeling and Freeling North Springs established conditions in 2011, while the nearby Big Blyth Bore was still freely flowing. The bore, which had flowed for 93 years with an estimated loss of 1000 ML per annum of artesian water, was capped in late October 2011. A repeat of the image-based assessment of wetland area and flows at Freeling Springs is planned to monitor their response to local recovery of aquifer pressure. This information will help refine models of aquifer function and response, as well as improving understanding of spring wetland ecology and recovery, both of which will assist the development of GAB management strategies.

Wetland dynamics

This report provides valuable new insights into the variability of the springs in space and time. Different wetland communities have characteristic seasonal phenological patterns of greening and drying and these are quite distinct from those of dryland and intermittent watercourse vegetation.

Changes in wetland area for Dalhousie and Hermit Hill complexes have been documented over the past 11-year period with fortnightly time-steps. This is the first characterisation of the detailed temporal dynamics of vegetation of these wetland communities. Both spring complexes show a six-monthly lagged response to preceding regional rainfalls, with clear trends over the past decade. Wetland area at Dalhousie Spring Complex was greatest between 2000 and 2003, followed by a strong decline to 2009, then increases in 2010 and 2011, although the extent of wetland area has not completely returned to earlier levels. At the Hermit Hill Complex, wetland development was relatively constant from 2002 to 2009, also increasing markedly in 2010 and 2011 in response to high rainfalls.

Detailed spatial changes in wetland vegetation, wetted area and diffuse discharge have been mapped at high resolution, quantified and described for several spring complexes and groups for selected dates in recent years. These show considerable mobility in the location and extent of spring tails over periods of two to four years, in response to season, antecedent rainfall, fire and management practices. Comparisons of wetted area and diffuse discharge reveal site-specific increases in diffuse discharge, which vary depending upon the geomorphic setting of

Photo: Victoria Marshall

individual spring groups. Wetted area shows a more general trend of increasing extent, largely due to high rainfalls between the 2009 and 2011 image captures.

This information will help identify the appropriate season for monitoring spring vegetation, whether by remote sensing or field records. For consistency, comparisons of wetland area and development should be made in comparable seasons, when the wetlands are at similar phenological stages.

The significant influences of rainfall, ecological processes and management on wetland area should be acknowledged when assessing trends in wetland status and condition. The long-term trends documented for Dalhousie and Hermit Hill illustrate the range of natural variation in spring-fed wetlands. Consequently, the concept of a baseline against which impacts might be measured is not a simple one. Rather than a fixed benchmark against which change might be measured, the 'baseline' is a range of variation observed under recent conditions and could be used to establish limits of acceptable change. Under natural conditions, wetland area for the large complexes closely follows trends in antecedent rainfall; changes in response to groundwater extractions and decreases in artesian pressure would be signalled by deviations from this relationship and could serve as an early warning system of adverse impacts on the wetlands.

Area of wetland vegetation as a surrogate for spring flow

A strong linear relationship between wetland area and spring flow has been demonstrated for selected springs at Dalhousie and Mt Denison complexes, with field and remote sensing studies underway to further test the relationship for the Hermit Hill Complex. This relationship was proposed by earlier studies and has been widely assumed but not objectively tested. Wetland vegetation at individual spring scales was highly correlated with the volume of spring flow. Consequently, wetland area can be used a surrogate for spring flow volume, which provides a newly proven, objective and cost-effective means for monitoring spring response to aquifer changes. The relationship holds for quite different scales of springs, although the precise regression relationship varies with spring setting and preceding rainfalls.

Remote sensing tools and methodologies

In addition to this new knowledge about the springs, a wide range of forms of remote sensing and spatial information data have been evaluated and applied for spring characterisation, assessment and monitoring.

Testing over a range of spring contexts and scales enables recommendations about the appropriateness and utility of various remote sensing and spatial technologies for these purposes.

Image-based vegetation indices such as the Normalised Difference Vegetation Index (NDVI) are related to percentage cover of vegetation in these ecosystems and can be used to differentiate wetland vegetation from surrounding dryland communities. Several important surface characteristics of springs and surrounding environments, such as areas of standing water, wetted areas and diffuse discharge, can be discriminated very effectively and mapped using airborne and satellite imagery. Some of the characteristic species of the wetlands have reflectance signatures that are sufficiently different to make hyperspectral discrimination possible. Airborne hyperspectral imagery has sufficient spectral resolution and appropriate spatial resolution to discriminate key dominant vegetation species and communities of the springs. Hyperspectral imagery also has potential to be used more widely for characterising spring environments, for example, to map the distribution and abundance of evaporite minerals which define zones of diffuse discharge.

Very high resolution satellite imagery is highly suitable and cost-effective for accurately monitoring changes in the extent of wetland vegetation over time. The cost-effectiveness of this approach is reflected in the techniques which have now been developed and are easy to reapply to newly captured imagery. Moreover, the relationship between image NDVI values and ground vegetation cover have been established at select sites, thus additional field work will only be required at these sites if a notable change in conditions occurs in the future. The spatial resolution and image coverage of multispectral satellite imagery such as QuickBird and WorldView-2 was appropriate for precise delineation of wetland extent and distribution at a range of scales, from very small flows to whole spring groups and complexes.

Long-term sequences of MODIS imagery are suitable for characterising intra- and inter-annual variations in wetland vegetation response for the larger complexes of Dalhousie and Hermit Hill. In addition, this can be used to understand natural spring variability over time, providing context for targeted image captures for more detailed mapping and monitoring. Other spring complexes and groups in the western GAB are too small to be monitored with this data and method.

Protocols for spring field studies

The AWMSGAB Project has developed, extensively tested and applied methodologies for field sampling, quantification and characterisation of wetland vegetation. The consistency and standardisation of these approaches within the study has allowed comparative studies within and between sites across a diversity of spring contexts. The field methodologies have served multiple purposes, generating data for calibration relationships between in-situ vegetation cover and image indices, as well as providing reference sites for image-based mapping and validation, all essential for reliable and repeatable mapping. Together with the image mapping, over 150 GPS-located field plots provide an important record of current wetland composition and status. The field methods also provide protocols that are recommended for future studies and monitoring of GAB wetlands.

7.2.2. Recommendations

Extend spring characterisation in the western margin of the GAB

This volume has presented methods and findings for four focal spring complexes. Imagery and

Photo: Adam Kilpatrick

field data were acquired during the AWMSGAB Project for several other major spring complexes and groups in the western margin of the GAB. This should be analysed and interpreted to provide a more comprehensive picture of the springs. The additional spring complexes and groups, Beresford, Warburton, Billa Kalina, Hawker, Levi, Strangways and those within Wabma Kadarbu Conservation Park, each have unique features and add to the diversity of spring types, scales and expressions presented in this volume.

Extend satellite image monitoring of wetland vegetation

The utility of applying NDVI thresholds to radiometrically calibrated very high resolution multispectral satellite imagery has been demonstrated at the Dalhousie Springs Complex (Section 4.4). This approach has considerable potential to be used more widely in the western margin of the GAB, where there is substantial investment in ongoing spring vegetation monitoring and where several spring groups and complexes are at risk from aquifer drawdown. This approach would provide a more cost-effective and reliable record of wetland change than current methods using aerial photography and visual interpretation of wetlands.

Extend spring characterisation and monitoring in the greater GAB

The methods developed in this study for documenting and monitoring spring environments have wider applicability across the GAB. They are particularly transferrable to spring complexes in arid environments, where very green wetland vegetation can be discriminated from halophytic, arid and riparian communities. Springs in more heavily-vegetated higher rainfall zones, however, may be identified and delineated by high-resolution multispectral imagery when the perennially-green wetlands contrast with seasonally-dry pastures and grasslands. This approach was used to identify the wetlands fed by Big Blyth Bore and delineate them from the intermixed riparian communities of intermittent streams. The differentiation of wetland species and communities and detection of evaporite minerals using hyperspectral imagery and analyses illustrates the potential of this form of remote sensing. These approaches have much wider applicability in the GAB.

The analysis of MODIS NDVI time-series also demonstrates that perennial wetland complexes may be identified and located by their temporal greenness signatures, which contrast with surrounding landscapes. Location of groundwater-dependent wetlands by this means could be followed by seasonally-targeted acquisitions of high-resolution imagery to more precisely define wetland extent.

Preliminary investigations have been made in conjunction with the Queensland Water Commission to evaluate the transferability of the methods presented in this volume to a wider range of springs in the eastern parts of the GAB.

Monitoring at a spring group and complex scale

The studies of detailed change in wetlands (Dalhousie Spring Complex 2006 to 2010, Hermit Hill and West Finniss spring groups 2009 to 2011) demonstrate the dynamic nature of spring flows and vegetation species composition at fine scales. The extent and distribution of flows from individual spring vents can change markedly over relatively short periods, while the distribution and abundance of species may change within spring tails. By contrast, monitoring wetlands, wetted and diffuse discharge areas for whole spring groups and complexes gives a more complete picture of the ecosystems sustained by groundwater and can be achieved efficiently using satellite or airborne imagery. It is recommended that assessments and monitoring of potential impacts be conducted at the spring group and complex scale.

Continued monitoring

The decade-long MODIS studies of Dalhousie and Hermit Hill complexes have provided new insights into the temporal variability of spring wetland vegetation at the scale of whole spring complexes. They have also pointed to the importance of rainfall, as well as the more constant supply of artesian spring water, in influencing wetland area and development. Monitoring these large complexes with MODIS NDVI 16-day composite imagery should be continued. The longer this record, the greater the potential understanding of the influence of longer-term climatic influences on the springs, with increased ability to detect departures from natural patterns of variation as possible impacts of aquifer drawdown.

Repeat studies

Several of the assessments in this study were designed as baselines against which to monitor future changes at specific springs. For example, repeat imaging is planned for Freeling South and Freeling North spring groups to assess wetland area and condition after the capping of Big Blyth Bore in October 2011, providing comparison with the analyses presented in this report.

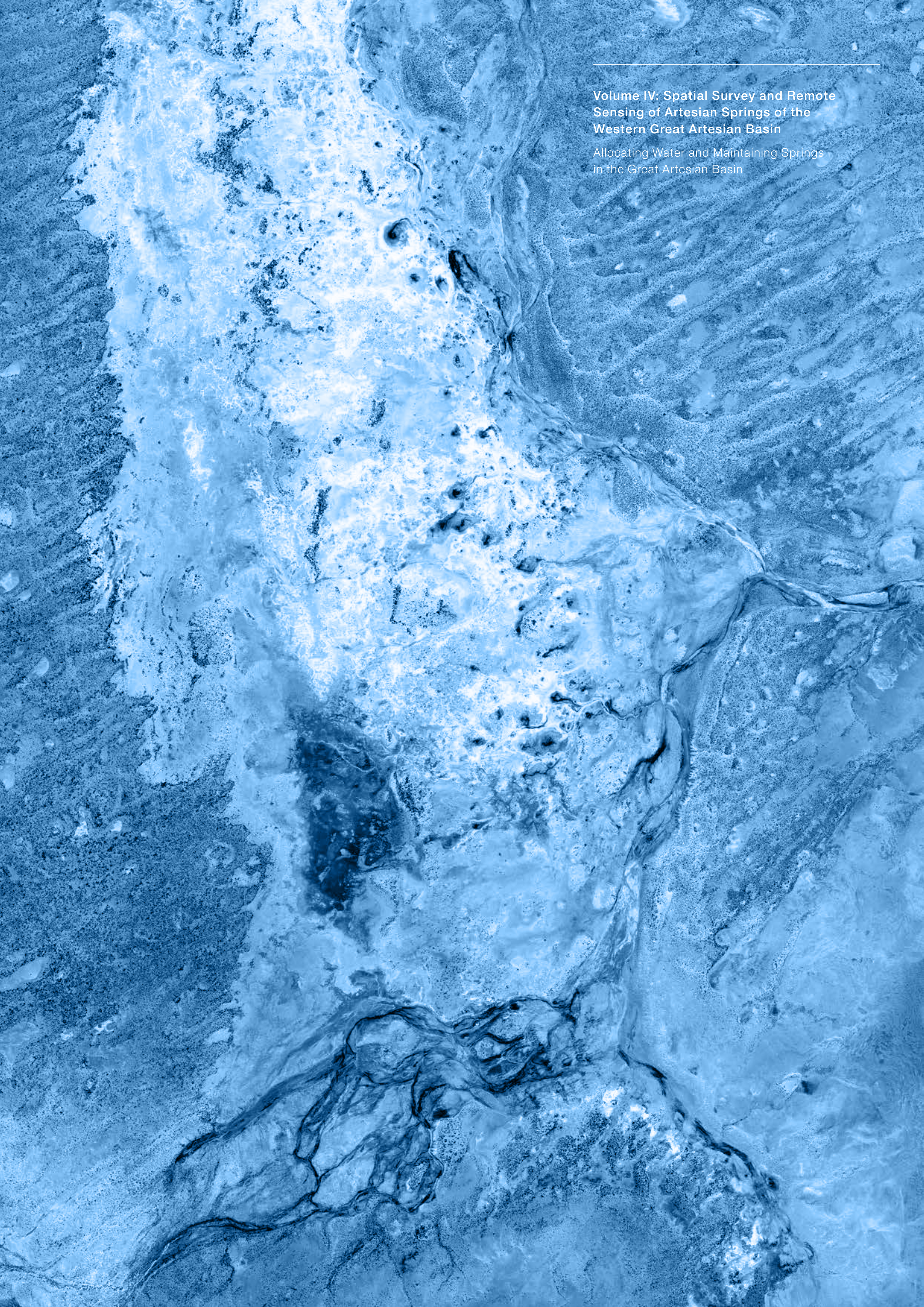
Remote sensing applications for mapping and monitoring western GAB springs

A range of satellite and airborne imagery was used in this study for mapping and monitoring the characteristics of the western margin GAB springs. Table 7.1 provides a synthesis of the types of imagery best suited to particular mapping and monitoring purposes. The moderate-resolution MODIS NDVI imagery with high-frequency (16-day), long archive (2000–continuing) is ideally suited to determining seasonal and longer term changes in spring wetland vegetation at the larger spring complexes. Very high resolution

Table 7.1 Recommended applications and collection frequency for sensor image products developed in this study

Sensor / imagery	Optimal applications	Recommended frequency
MODIS satellite (NDVI product, 250 m resolution)	• Seasonal variability of dominant spring wetland vegetation types • Longer-term changes in spring wetland vegetation area	• NDVI composites available every 16 days; ongoing
Very High Resolution WorldView-2 satellite (multispectral, 1.8 m resolution)	• Detailed mapping and quantification of the extent of spring wetland vegetation • Relate wetland vegetation extent with spring flow rates • Potential to map and monitor spring wetland vegetation condition	• Annual – March, coinciding with maximum greenness of wetlands • Bi-annual – March; October • Response to events and/or major change
Hyperspectral airborne sensor (visible-shortwave infrared, ≤3 m resolution)	• Detailed mapping of composition and extent of dominant spring wetland vegetation species • Mapping of spring associated surface features – standing water, wetted areas, and evaporite crust • Change over time in spring surface features and dominant wetland vegetation species • Potential to map and monitor spring wetland vegetation condition	• Initial baseline prior to any known change event • Every three years – March • Response to events and/or major change
Digital colour aerial photography (blue, green, red, near Infrared, 20–30 cm resolution)	• Validation of mapped image products	• Coincident with other airborne or high-resolution satellite image acquisition • Initial baseline prior to any known change event • Every three years – March • Response to events and/or major change

WorldView-2 satellite imagery provides the fine detail necessary to map and quantify wetland vegetation extent to relate to spring flow rates, and can be used to develop surrogate measures for spring flow. Hyperspectral imagery such as HyMap contains fine detail with many spectral wavebands, ideally suited to discriminating dominant spring vegetation types and associated surface features. The four band (visible and near-infrared) colour digital aerial photography with very fine spatial resolution is a staple image product for validating mapped outputs, particularly important for capturing remote sites. Table 7.1 summarises the recommended frequency with which this imagery should be captured. Biannual image capture of the WorldView-2 satellite imagery is recommended to provide an estimate of the range of variation in the wetland area – flow relationship for different sites and spring complexes. The March capture for WorldView-2 satellite imagery and hyperspectral airborne imagery is recommended, based on the optimal timing indicated by the MODIS seasonal greening results.



Volume IV: Spatial Survey and Remote Sensing of Artesian Springs of the Western Great Artesian Basin

Allocating Water and Maintaining Springs in the Great Artesian Basin

Appendix 1

A1.1. GAB spring spatial hierarchy and RTK DGPS survey

Table A1.1: GAB spring hierarchical classification and total number of spring vents surveyed

Supergroup	Complex	Spring group name	Spring group code	Number of vents	Surveyed
Dalhousie	Dalhousie	Kingfisher	DAA	12	Yes
Dalhousie	Dalhousie	Bananas	DBA	4	Yes
Dalhousie	Dalhousie	Main Pool	DCA	15	Yes
Dalhousie	Dalhousie	Witcherrie	DCB	10	Yes
Dalhousie	Dalhousie	Ilpikwa	DCC	10	Yes
Dalhousie	Dalhousie	Loveheart	DCD	13	Yes
Dalhousie	Dalhousie	Errawanyera	DDA	4	Yes
Dalhousie	Dalhousie	Dalhousie Proper	DDB	16	Yes
Dalhousie	Dalhousie	Dinner	DEA	17	Yes
Dalhousie	Dalhousie	Cadni Dreaming	DFA	9	Yes
Dalhousie	Dalhousie	Donkey Flat	DGA	9	Yes
Dalhousie	Dalhousie	Frog Dreaming	DGB	22	Yes
Dalhousie	Dalhousie	Mt Jessie	DHA	4	Yes
Lake Eyre	Mt Margaret	Edith	AES	6	Yes
Lake Eyre	Mt Margaret	Tarlton	ATS	9	Yes
Lake Eyre	Beresford Hill	Beresford	BBH	1	Yes
Lake Eyre	Beresford Hill	Secret	BSS	4	Yes
Lake Eyre	Beresford Hill	Lethbridge	BUB	1	No
Lake Eyre	Beresford Hill	Warburton	BWS	13	Yes
Lake Eyre	Coward	Anna	CAS	2	Yes
Lake Eyre	Coward	Blanche Cup	CBC	20	Yes
Lake Eyre	Coward	Buttercup	CBU	1	Yes
Lake Eyre	Coward	Coward	CCS	14	Yes
Lake Eyre	Coward	Elizabeth	CEL	76	Yes
Lake Eyre	Coward	Elizabeth North	CEN	179	Yes
Lake Eyre	Coward	Horse East	CHE	6	Yes
Lake Eyre	Coward	Horse West	CHW	2	Yes
Lake Eyre	Coward	Jersey	CJE	9	Yes

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Table A1.1: GAB spring hierarchical classification and total number of spring vents surveyed					
Supergroup	Complex	Spring group name	Spring group code	Number of vents	Surveyed
Lake Eyre	Coward	Kewson Hill	CKH	51	Yes
Lake Eyre	Coward	Mt Hamilton Ruin	CMH	1	Yes
Lake Eyre	Strangways	Strangways	CSS	433	Yes
Lake Eyre	Mt Denison	Breakneck	EBN	1	No
Lake Eyre	Mt Denison	Blind	EBS	1	No
Lake Eyre	Mt Denison	Coppertop	ECS	1	No
Lake Eyre	Mt Denison	Freeling North	EFN	23	Yes
Lake Eyre	Mt Denison	Freeling	EFS	100	Yes
Lake Eyre	Mt Denison	Murra murrana	EMM	2	No
Lake Eyre	Mt Denison	Mud	EMS	1	No
Lake Eyre	Mt Denison	Sandy Creek	ESC	2	No
Lake Eyre	Mt Denison	Tidnamurkuna	EUC	1	No
Lake Eyre	Francis Swamp	Emily	FES	3	Yes
Lake Eyre	Francis Swamp	Francis Swamp	FFS	884	Yes
Lake Eyre	Francis Swamp	Margaret	FMS	9	Yes
Lake Eyre	Francis Swamp	Lake William	FWS	3	Yes
Lake Eyre	Lake Eyre	Elliott Price	GEP	1	No
Lake Eyre	Lake Eyre	Unnamed 3	GNA	1	No
Lake Eyre	Lake Eyre	Unnamed 4	GNB	1	No
Lake Eyre	Lake Eyre	Unnamed 5	GNC	1	No
Lake Eyre	Lake Eyre	Unnamed 6	GND	1	No
Lake Eyre	Lake Eyre	Unnamed 1	GNE	1	No
Lake Eyre	Lake Eyre	Unnamed 2	GNF	1	No
Lake Eyre	Hermit Hill	Bopeechee Mound	HBM	39	Yes
Lake Eyre	Hermit Hill	Bopeechee North	HBN	39	Yes
Lake Eyre	Hermit Hill	Bopeechee	HBO	62	Yes
Lake Eyre	Hermit Hill	Beatrice	HBS	15	Yes
Lake Eyre	Hermit Hill	Dead Boy	HDB	11	Yes
Lake Eyre	Hermit Hill	Finniss Well	HFL	1	Yes
Lake Eyre	Hermit Hill	Hermit Hill	HHS	429	Yes
Lake Eyre	Hermit Hill	North West	HNW	56	Yes
Lake Eyre	Hermit Hill	Old Finniss	HOF	266	Yes
Lake Eyre	Hermit Hill	Old Woman	HOW	45	Yes
Lake Eyre	Hermit Hill	Pigeon Hill	HPH	1	Yes
Lake Eyre	Hermit Hill	Pigeon Hill North	HPN	1	Yes
Lake Eyre	Hermit Hill	Sulphuric	HSS	56	Yes
Lake Eyre	Hermit Hill	Venebles	HVS	1	Yes

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Table A1.1: GAB spring hierarchical classification and total number of spring vents surveyed

Supergroup	Complex	Spring group name	Spring group code	Number of vents	Surveyed
Lake Eyre	Hermit Hill	West Finniss	HWF	122	Yes
Lake Eyre	Billa Kalina	Billa Kalina	KBK	268	Partial
Lake Eyre	Billa Kalina	McEwins	KME	10	Yes
Lake Eyre	Billa Kalina	Welcome	KWS	2	Yes
Lake Eyre	Lake Eyre South	Centre Island	LCI	1	No
Lake Eyre	Lake Eyre South	Lake Eyre South	LES	2	Yes
Lake Eyre	Lake Eyre South	Fred	LFE	8	Yes
Lake Eyre	Lake Eyre South	Gosse	LGS	6	Yes
Lake Eyre	Lake Eyre South	Jacobs	LJS	2	Yes
Lake Eyre	Lake Eyre South	Long Island	LLI	2	No
Lake Eyre	Lake Eyre South	McLachlan	LMS	11	Yes
Lake Eyre	Lake Eyre South	Priscilla	LPS	2	Yes
Lake Eyre	Lake Eyre South	Smith	LSS	16	Yes
Lake Eyre	Lake Eyre South	Walkarinna	LWS	16	Yes
Lake Eyre	Maree	Boorloo	MBO	1	No
Lake Eyre	Maree	Bitter	MBS	7	Yes
Lake Eyre	Maree	Four Mile	MFM	1	No
Lake Eyre	Maree	Goolong	MGS	1	No
Lake Eyre	Maree	Hergott	MHS	1	Yes
Lake Eyre	Maree	Lignum	MLS	1	No
Lake Eyre	Maree	Mundowdna	MMS	1	No
Lake Eyre	Maree	One Tree	MOT	1	No
Lake Eyre	Maree	Two Mile	MTM	1	No
Lake Eyre	Maree	Wirringina	MWS	2	No
Lake Eyre	Neales River	Big Perry	NBP	9	Yes
Lake Eyre	Neales River	Brinkley	NBS	11	Yes
Lake Eyre	Neales River	Fanny	NFS	8	Yes
Lake Eyre	Neales River	Hawker	NHS	104	Yes
Lake Eyre	Neales River	Loudon	NLO	1	No
Lake Eyre	Neales River	Little Perry	NLP	1	No
Lake Eyre	Neales River	Levi	NLS	13	Yes
Lake Eyre	Neales River	Milne	NMI	9	Yes
Lake Eyre	Neales River	Outside	NOS	9	Yes
Lake Eyre	Peake Creek	Primrose	NPS	3	Yes
Lake Eyre	Neales River	Spring Hill	NSH	5	Yes
Lake Eyre	Neales River	Fountain	NTF	2	Yes
Lake Eyre	Neales River	Twelve Mile	NTM	5	Yes

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Table A1.1: GAB spring hierarchical classification and total number of spring vents surveyed

Supergroup	Complex	Spring group name	Spring group code	Number of vents	Surveyed
Lake Eyre	Neales River	Vaughn	NTV	1	Yes
Lake Eyre	Peake Creek	Little Piabullina	PBB	1	No
Lake Eyre	Peake Creek	Balyaweelbanyana	PBI	1	No
Lake Eyre	Peake Creek	Birribiana	PBI	2	Yes
Lake Eyre	Peake Creek	Cootanoorina	PCN	7	Yes
Lake Eyre	Peake Creek	Coorandatana	PCR	1	No
Lake Eyre	Peake Creek	Cardajalburrana	PCS	3	Yes
Lake Eyre	Peake Creek	Cootabarcoollia	PCT	1	No
Lake Eyre	Peake Creek	Edadurrana	PES	11	Yes
Lake Eyre	Peake Creek	Goorgyana	PGS	1	No
Lake Eyre	Peake Creek	Keckwick	PKS	3	No
Lake Eyre	Peake Creek	One Mile Bore	POM	1	Yes
Lake Eyre	Peake Creek	Old Nilpina	POS	10	No
Lake Eyre	Peake Creek	Saline	PSS	2	No
Lake Eyre	Peake Creek	South Well	PSW	2	Yes
Lake Eyre	Peake Creek	Unnamed	PUA	1	No
Lake Eyre	Peake Creek	Unnamed	PUB	1	No
Lake Eyre	Peake Creek	Warrangarrana	PWA	1	Yes
Lake Eyre	Peake Creek	Oodloodlana	PWD	1	No
Lake Eyre	Peake Creek	Weedina	PWE	6	Yes
Lake Eyre	Peake Creek	Weedina North	PWN	1	No
Lake Eyre	Peake Creek	Oortookoolana	PWO	1	No
Lake Eyre	Peake Creek	Wintro Warduna	PWW	1	No
Lake Eyre	Toodina	Toodina	TTS	1	Yes
Lake Eyre	Mt Dutton	Allandale	UAS	9	Yes
Lake Eyre	Mt Dutton	Big Cadna-owie	UBC	9	Yes
Lake Eyre	Mt Dutton	Little Cadna-owie	ULC	9	Yes
Lake Eyre	Mt Dutton	Ockenden Old	UOP	1	No
Lake Eyre	Mt Dutton	Ockenden Proper	UOS	1	Yes
Lake Eyre	Mt Dutton	Wandillinna	UWS	9	Yes
Lake Eyre	Wangianna	Davenport	WDS	75	Yes
Lake Eyre	Wangianna	Theepa	WTS	1	No
Lake Eyre	Wangianna	Wangianna	WWA	8	Yes
Lake Eyre	Wangianna	Welcome	WWS	34	Yes
Lake Eyre	Lake Cadibarrawirracana	Castine	XCS	1	No
Lake Eyre	Lake Cadibarrawirracana	Eurilyna	XES	2	No

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Table A1.1: GAB spring hierarchical classification and total number of spring vents surveyed

Supergroup	Complex	Spring group name	Spring group code	Number of vents	Surveyed
Lake Eyre	Lake Cadibarrawirracana	Giddi-Giddinna	XGG	1	No
Lake Eyre	Lake Cadibarrawirracana	Lake Cadi	XLC	3	No
Lake Eyre	Lake Cadibarrawirracana	Oolgelima	XOS	2	No
Lake Eyre	Lake Cadibarrawirracana	Oolgelima West	XOW	2	No
Lake Eyre	Lake Cadibarrawirracana	Giddiphantom North	XPN	4	No
Lake Eyre	Lake Cadibarrawirracana	Giddiphantom South	XPS	4	No
Lake Eyre	Lake Cadibarrawirracana	Wirracanna	XWC	1	No
Lake Eyre	Lake Cadibarrawirracana	Widigiedona	XWS	1	No
Lake Frome	Petermorra	Chimney Hill	OCH	1	Yes
Lake Frome	Petermorra	Catt	OCT	2	Yes
Lake Frome	Petermorra	Petermorra	OPC	44	Yes
Lake Frome	Petermorra	Public House	OPH	152	Yes
Lake Frome	Reedy	Reedy	ORE	383	Yes
Lake Frome	Reedy	Rocky	ORO	1	Yes
Lake Frome	Petermorra	Twelve	OTS	72	Yes
Lake Frome	Lake Blanche	Lake Blanche	QLB	2	Yes
Lake Frome	Lake Blanche	Sunday	QSU	8	Yes
Lake Frome	Reedy	St Marys Pool	STM	1	Yes
Lake Frome	Lake Frome	Unnamed 1	YUA	1	No
Lake Frome	Lake Frome	Unnamed 2	YUB	1	No
Lake Frome	Lake Frome	Unnamed 3	YUC	1	No
Lake Frome	Lake Frome	Unnamed 4	YUD	1	No
Lake Frome	Lake Frome	Unnamed 5	YUE	1	No
Lake Frome	Lake Frome	Unnamed 6	YUF	1	No
Lake Frome	Lake Frome	Unnamed 7	YUG	1	No
Lake Frome	Lake Frome	Unnamed 8	YUH	1	No
Lake Frome	Lake Frome	Yarol Mound	YUI	1	No
Lake Frome	Lake Callabonna	Mulligan	ZMS	1	No
Lake Frome	Lake Callabonna	Unnamed 1	ZUA	1	No
Lake Frome	Lake Callabonna	Unnamed 2	ZUB	1	No
Lake Frome	Lake Callabonna	Wooltachi Soak	ZUG	1	No

A1.2. Survey control points

Table A1.2 shows all the control points used during the survey. 'Survey benchmarks' are Surveyor General's Office points, 'control points' are those points created during the survey.

'Loop-closure points' are of control quality but are not specifically associated to any spring group, however they can be used as control points for georegistering imagery or other survey work conducted in the area.

Table A1.2: Control network of permanent survey marks

Point ID	Mark type	Solution type	Description	Easting	Northing	Elevation	Latitude (local)	Longitude (local)
BM1730	Permanent survey mark	Survey benchmark	Survey benchmark	669867.028	6752818.25	26.22	-29.342	136.750
BM3125	Permanent survey mark	Survey benchmark	Survey benchmark	614198.042	6802365.65	95.718	-28.901	136.171
BM_PS1	Permanent survey mark	Static	Control point	724446.565	6723610.845	4.212	-29.597	137.318
PSM_BKS001	Permanent survey mark	Static	Control point	644589.305	6740140.238	47.2	-29.460	136.491
PSM_BWS	Permanent survey mark	Static	Control point	662342.595	6760479.147	27.541	-29.274	136.671
PSM_FSS001	Permanent survey mark	Static	Control point	624895.935	6781319.567	69.564	-29.090	136.283
PSM_NTM001	Permanent survey mark	Static	Control point	623236.464	6868389.611	45.006	-28.305	136.257
PSM_PFS001	Permanent survey mark	Static	Control point	588959.094	6893951.115	76.93	-28.077	135.905
PSM_PHS001	Permanent survey mark	Static	Control point	613078.781	6856345.968	117.788	-28.414	136.154
PSM_STR001	Permanent survey mark	Static	Control point	650720.428	6772935.477	63.993	-29.163	136.550
PSM_WK001	Permanent survey mark	Static	Control point	681990.723	6738884.903	6.73	-29.466	136.877
PSM_NILPINA001	Permanent survey mark	AUSPOS	Control point	572951.64	6855398.373	116.506	-28.426	135.745
PSM_POS001	Permanent survey mark	AUSPOS	Control point	568309.484	6879235.973	82.76	-28.211	135.696
PSM_UBC	Steel rod	AUSPOS	Control point	565904.277	6918658.192	90.174	-27.855	135.669

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Table A1.2: Control network of permanent survey marks

Point ID	Mark type	Solution type	Description	Easting	Northing	Elevation	Latitude (local)	Longitude (local)
PSM-DALHOUSIE	Permanent survey mark	AUSPOS	Control point	550517.383	7077135.178	112.646	-26.425	135.507
PSM_Callana001	Steel rod	Observed control point	Control point	758720.907	6716696.745	87.03	-29.653	137.673
PSM_Dalhousie002	Steel rod	Observed control point	Control point	549367.686	7066711.974	124.065	-26.519	135.495
PSM_Gosse	Steel rod	Observed control point	Control point	727067.882	6738344.887	-2.782	-29.464	137.341
PSM_NILPINA002	Steel rod	Observed control point	Control point	553456.143	6858402.007	103.133	-28.400	135.546
PSM_PCN001	Steel rod	Observed control point	Control point	554206.35	6882146.461	79.065	-28.185	135.552
PSM_WMC501	Steel rod	Observed control point	Control point	739255.224	6725635.247	29.27	-29.576	137.470
PSM_WMC502	Steel rod	Observed control point	Control point	750813.992	6716345.395	46.585	-29.658	137.591
PSM-LakeEyreSth	Permanent survey mark	Observed control point	Control point	705126.954	6738002.568	7.972	-29.471	137.115
601	Steel rod	Observed control point	Shoot forward / loop closure	660302.528	6757416.23	38.896	-29.302	136.651
602	Steel rod	Observed control point	Shoot forward / loop closure	635300.734	6795703.207	80.584	-28.960	136.389
603	Steel rod	Observed control point	Shoot forward / loop closure	624895.218	6781318.12	70.673	-29.090	136.283
604	Steel rod	Observed control point	Shoot forward / loop closure	634024.647	6764224.135	88.073	-29.244	136.379

Appendix 2

A2.1. Study design

This report developed a study design based on near-simultaneous image acquisitions and field observations comprising botanical survey records, field spectroradiometry, differential GPS (DGPS) measurements and associated ancillary data. In general, airborne and satellite imagery was tasked for March to May to record the wetlands during phases of maximum greenness, and field campaigns were conducted in March 2009, March/April 2010 and April/May 2011 to coincide as closely as possible with image acquisitions.

A comprehensive, robust and repeatable field data collection methodology was developed and extensively tested, to ensure standardisation at all sites reported (Dalhousie, Hermit Hill, Freeling and Francis Swamp springs). The methodology was also developed to provide a protocol for reliable and repeatable future monitoring of mound spring vegetation.

A key element of the field survey design is simultaneous spectral and ecological characterisation of sites that are representative of the dominant spring vegetation species and communities. The design also accommodates for differences in composition and diversity within and between springs and spring groups. The survey design is flexible, providing data for:

- development of a field spectral library
- testing of relationships between vegetation cover and spectral response
- reference sites and spectra for mapping dominant wetland vegetation types
- development of empirical relationships between field and image variables
- validation and accuracy assessment of image-based mapping.

This appendix details the field data collection methods, technical specifications of the imagery acquired and methods used in image analysis throughout this report.

A2.2. Field data collection methods

A2.2.1. Vegetation sampling

Extensive vegetation sampling surveys were conducted on repeated dates at all sites reported, the majority of which coincided with airborne and/or space-borne image capture.

The size of vegetation sample plots was designed to accommodate the scale of spring vegetation communities in relation to the field of view of the field spectroradiometer and the spatial resolution of the airborne hyperspectral sensors (HyMap, Eagle) and the space-borne multispectral sensors (QuickBird, WorldView-2).

Vegetation cover and species composition were recorded at sample sites chosen to be representative of dominant communities and variation within wetlands. Sample sites were 9 x 9 m or 6 x 6 m where vegetation stands were less extensive, with coordinates of plot corners recorded by a single hand-held GPS receiver or DGPS where feasible (Figure A2.1).

Within each plot, records were made of overall vegetation cover, species composition, including their respective cover class and phenology and, where necessary, sketch maps of the site. Vegetation cover classes were based on the Braun-Blanquet relevé method (ASTM 2008), modified for wetland delineation as recommended by Tiner (1999). Vegetation cover classes ranged from 1 (sparse; cover range <5%) to 5 (very dense; cover range 75–100%). A completed sample vegetation survey data sheet is provided for reference in Figure A2.2. Pengra *et al.* (2007) adopted a similar approach for classifying wetland vegetation cover for mapping invasive *Phragmites australis* in coastal wetlands of Green Bay, Wisconsin, USA, using Hyperion hyperspectral satellite imagery.

The vegetation sampling records were slightly modified for the 2011 field campaign to accommodate the wetter antecedent conditions leading to greening up of surrounding dryland vegetation in the vicinity of the Great Artesian Basin (GAB) spring environs. Additional records included average vegetation height and overall cover of each plot subdivided into four broad categories: photosynthetic vegetation, dry vegetation, water and soil (dry or wet) (Figure A2.3).

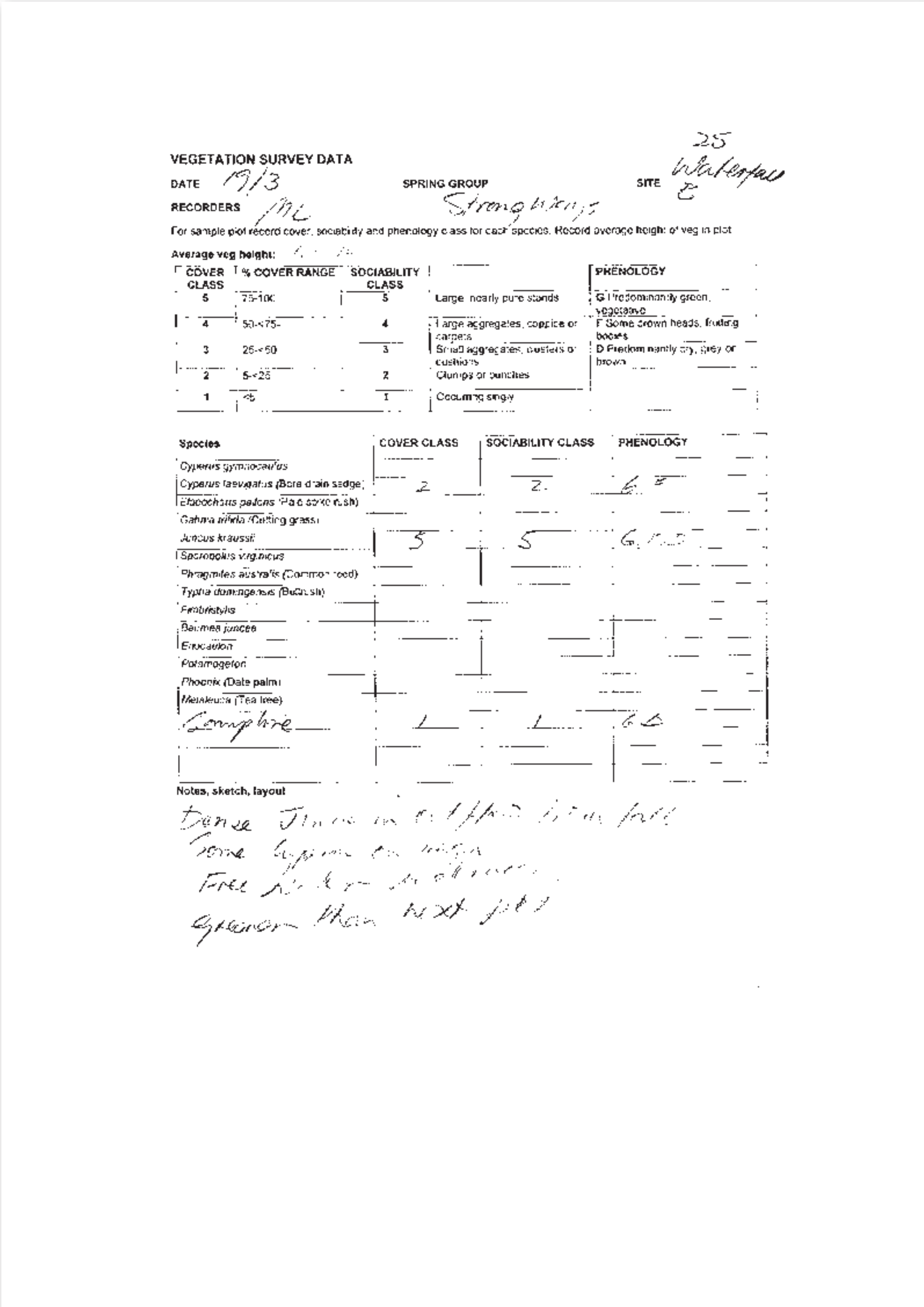
Voucher herbarium specimens of wetland plant species recorded in the sample plots were collected, and their identification verified by South Australian State Herbarium staff and botanically qualified members of the research team.

Digital photographs were taken at all sample sites to provide objective records to supplement plot data and spectral measurements. The photographs included general overviews of each sample plot and at least ten vertical photographs taken from a height of 1.5 m as well as the instantaneous field of view for spectroradiometer measurements. In addition, photographs were taken of sky and solar illumination conditions to assist interpretation of spectral measurements.

Photo: Adam Kilpatrick

Figure A2.1: Field sampling plots of 9 x 9 m

Figure A2.2: Example of completed 2009 vegetation survey data sheet



VEGETATION SURVEY DATA

DATE 19/3 SPRING GROUP Strongbarks SITE Waterfall E 25

RECORDERS ML

For sample plot record cover, sociability and phenology class for each species. Record average height of veg in plot

Average veg height:

COVER CLASS	% COVER RANGE	SOCIABILITY CLASS		PHENOLOGY
5	75-100	5	Large, nearly pure stands	G Predominantly green, vegetative
4	50-<75	4	Large aggregates, coppice or carpets	F Some brown heads, fruiting bodies
3	25-<50	3	Small aggregates, clusters or cushions	D Predominantly dry, grey or brown
2	5-<25	2	Clumps or bunches	
1	<5	1	Occurring singly	

Species	COVER CLASS	SOCIABILITY CLASS	PHENOLOGY
Cyperus gymnocaulos			
Cyperus laevigatus (Bore drain sedge)	2	2	G F
Eleocharis pallens (Pale spike rush)			
Gahnia trifida (Cutting grass)			
Juncus kraussii	5	5	G, F, D
Sporobolus virginicus			
Phragmites australis (Common reed)			
Typha domingensis (Bulrush)			
Fimbristylis			
Baumea juncea			
Eriocaulon			
Potamogeton			
Phoenix (Date palm)			
Melaleuca (Tea tree)			
Samphire	1	1	G D

Notes, sketch, layout

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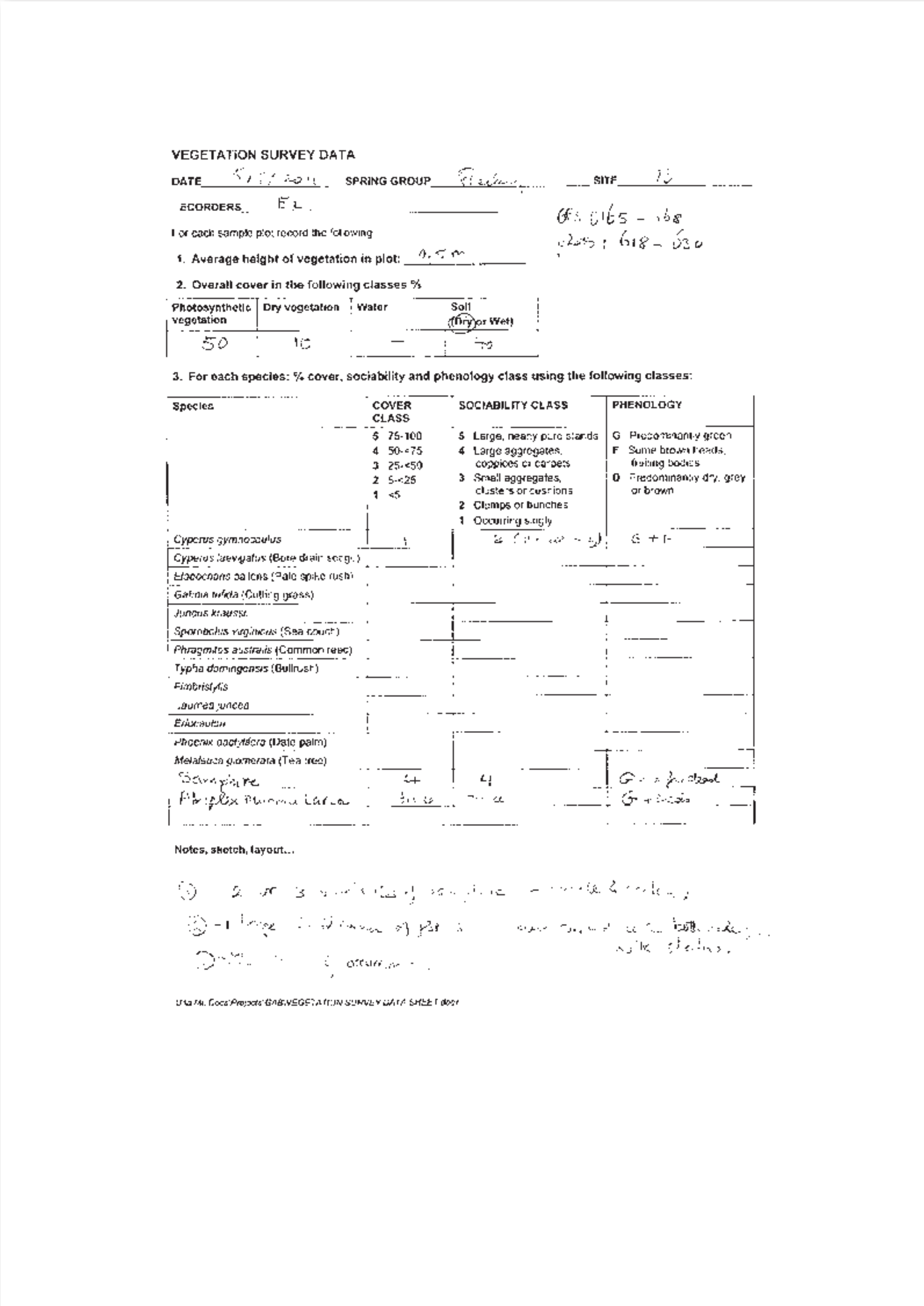

VEGETATION SURVEY DATA

DATE ______ SPRING GROUP ______ SITE ______

RECORDERS ______

For each sample plot record the following

1. Average height of vegetation in plot: ______

2. Overall cover in the following classes %

Photosynthetic vegetation	Dry vegetation	Water	Soil (Dry or Wet)
50	10	–	40

3. For each species: % cover, sociability and phenology class using the following classes:

Species	COVER CLASS	SOCIABILITY CLASS	PHENOLOGY
	5 75-100 4 50-<75 3 25-<50 2 5-<25 1 <5	5 Large, nearly pure stands 4 Large aggregates, coppices or carpets 3 Small aggregates, clusters or cushions 2 Clumps or bunches 1 Occurring singly	G Predominantly green F Some brown heads, fruiting bodies D Predominantly dry, grey or brown
Cyperus gymnocaulus			
Cyperus laevigatus (Bore drain sedge)			
Eleocharis pallens (Pale spike rush)			
Gahnia trifida (Cutting grass)			
Juncus kraussii			
Sporobolus virginicus (Sea couch)			
Phragmites australis (Common reed)			
Typha domingensis (Bullrush)			
Fimbristylis			
Baumea juncea			
Eriocaulon			
Phoenix dactylifera (Date palm)			
Melaleuca glomerata (Tea tree)			
Samphire	4	4	
Atriplex			

Notes, sketch, layout...

Figure A2.3: Example of completed 2011 vegetation survey data sheet

A2.2.2. Spectral measurements

Field spectral measurements were recorded in the vegetation sample plots at selected spring sites, adapting the method used by Schmid *et al.* (2004) for spectral sampling of wetland vegetation. In addition to vegetation signatures in plots, spectra were also collected of soil and substrates associated with the spring environments. An Analytical Spectral Devices (ASDs) full-range FieldSpec® 3 spectroradiometer, with a spectral range of 350–2500 nm, comparable to the HyMap imagery (Table A2.1) was used for this work. This instrument is well suited to field canopy scale studies with uncontrolled illumination and field conditions (Milton *et al.* 2007).

At least three spectra were recorded of representative surface features (e.g. vegetation, substrate), giving at least 30 spectra at each of the sample sites. This technique ensured that at least one good quality spectrum, with no artefacts, was acquired of representative surface features within each sample site, whilst remaining within the time constraints of the field campaign window of opportunity. Spectra were collected using a boom attachment held at approximately 1.5 m in height to give a suitable distance from the target to avoid shadowing from the instrument operator and to enable a suitable top of canopy field of view to be recorded, approximately 21 cm^2 (Figure A2.4).

A2.3. Imagery and analyses

A2.3.1. Sensors and imagery

New and archival imagery from a number of satellite and airborne sensors, at a range of spatial, spectral and temporal resolutions, was acquired and analysed in this study. These sensors and their specifications are summarised in Table A2.1. An evaluation of the sensors used in this study and the image analysis methods adopted is provided in Chapter 6.

A2.3.2. Image pre-processing

A series of widely used pre-processing steps were applied to the airborne and satellite images to prepare them for feature extraction and comparison with field measurements. This pre-processing enables comparisons to be made with confidence between sites at different locations and the same site at different times. The primary generic steps were atmospheric correction (conversion to apparent surface reflectance), mosaicking and colour-balancing of image tiles or swaths to form a seamless image covering an entire spring complex and correction to improve positional accuracy (this was achieved using the Australian Geographic Reference Image mosaic imagery, with an absolute positional accuracy of 2.5 m across track and 3.5 m along track).

Multispectral satellite imagery

The QuickBird and WorldView-2 very high resolution multispectral satellite imagery was provided partially orthorectified (coarse terrain corrections and projected to a constant base elevation) and partially radiometrically corrected (Digital Globe 2009). Positional errors were less than 10 m, although further image-to-image co-registration was performed as part of subsequent change analysis. Further radiometric correction, to convert the images to apparent surface reflectance, was conducted using a modified MODTRAN (MODerate spectral resolution atmospheric TRANSmittance) algorithm, FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes), in the Atmospheric Correction Module of ENVI 4.7 remote sensing software (Digital Globe 2009; Cook *et al.* 2009). The QuickBird and WorldView-2 scene tiles for each of the image epochs were subsequently colour balanced and mosaicked to give full seamless coverage of the Dalhousie Springs Complex study areas. ENVI V.4.7 software (Exelis Visual Information Solutions, Boulder, CO) was used for this and subsequent image analysis.

MODIS

Moderate Resolution Imaging Spectroradiometer (MODIS) MYD13Q1 Normalised Difference Vegetation Index (NDVI) 16-day composite images, produced by the NASA Group (Huete *et al.* 2002) were downloaded from the NASA Warehouse Inventory Search Tool (WIST) website. MODIS data from the Aqua satellite covered the period 4 July 2002 to 6 September 2011 and from the Terra satellite for the period from 18 February 2000 to 19 December 2003. Two composite dates were missing from the data: 4 July and 5 August 2007. Comparison of NDVI values for the Dalhousie Springs Complex from an overlapping period (July 2002 to December 2003) showed that they were compatible and hence data from the two sensors were combined to form a time-series for the Dalhousie Springs Complex study site from 2000–2011.

Photo: Megan M Lewis

Photo: Megan M Lewis

Figure A2.4: Field spectral collection using the FieldSpec® Pro full range spectroradiometer

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Table A2.1: Sensor and technical specifications for imagery acquired during the AWMSGAB Project					
Sensor	Wavebands	Wavelength range	Band width	Spatial resolution	Swath width
HyMap 2009 (sensor II)	126	450–2,500 nm	~15 nm	~3 m	1.5 km
HyMap 2011 (sensor I)	124	450–2,500 nm	~15 nm	~3 m	1.5 km
AISA Eagle	122	400–970 nm	3.3 nm (res.)	~1 m	350 m
			4.6 nm (sampling)		
Digital aerial photography	3 (Mamiya)	Visible	n/a	30 cm	n/a
	4 (UltraCAM)	Visible/near-infrared		30 cm	
LiDAR	n/a	n/a	n/a	Average pulse density 6.1 m^{-2}	1.2 km
QuickBird	4	430–918 nm	57–101 nm	2.62 m (GSD multi.)	18.0 km
WorldView-2	8	400–1,040 nm	31–94 nm	1.85 m (GSD multi.)	16.4 km
ASTER	14	520–11,650 nm	60–350 nm	15–90 m	60 km
MODIS	36	620–14,385 nm	50–300 nm	250–1,000 m	2330 km (cross track); 10 km (along track)

ASTER

Apparent surface temperature was derived from the ASTER thermal infrared bands using the emissivity normalisation technique, which calculates temperature for every pixel and band in the data using a fixed emissivity value. Temperature is calculated from radiant energy recorded by ASTER. Measurements of surface radiance are affected by atmospheric variation. The atmosphere can absorb radiance and emit its own radiance, both toward the surface and into space.

Surface temperature is calculated in multiple stages through ENVI image analysis software. The Thermal Atmospheric Correction tool is a pre-processing treatment for known irregularities in acquisitions. The Emissivity Normalisation tool calculates surface emissivity for each thermal IR band and a single surface temperature. This tool combines the use of multiple techniques and algorithms. The calculated surface temperatures are produced in degrees Kelvin, which are converted to degrees Celsius where necessary. The calculations are approximations as there are five measurements but six unknowns. An assumed emissivity value of 0.96 was used. In practical applications the absolute accuracy for thermal IR bands in the temperature range being investigated is ±1 degree.

HyMap airborne imagery

Pre-processing of the HyMap hyperspectral imagery was conducted by HyVista Corporation and included radiometric correction with the HyCorr atmospheric correction model (a modified version of the Atmospheric Removal (ATREM) algorithm; Gao *et al.* 1993) and EFFORT polishing, with geometric correction and colour balancing of swaths to form seamless mosaics for each study area.

Eagle airborne imagery

The imagery was georegistered using an in-flight global positioning system and inertial navigation system data and converted to apparent surface reflectance using the simultaneous solar irradiance measurements made by the sensor. SPECIM CaliGeo software was used for these pre-processing steps.

LiDAR

Pre-processing of the LiDAR data was performed using the manufacturer's proprietary software. Discrete multi-return points were extracted from the full waveform data and output in American Society for Photogrammetry and Remote Sensing (ASPRS) LASer File Format Exchange 1.1 (LAS). Derived accuracy was 10 cm in the vertical plane and 30 cm in the horizontal plane with an average pulse density of 6.1 m^{-2}.

Integrity of the LiDAR data was checked using the Point File Information tool in ArcGIS 10; the resultant attribute table was examined for valid vegetation classification fields, X, Y, Z coordinates and point spacing statistics. Initial visualisation employed BCAL software (Boise Center Aerospace Laboratory 2011) to gauge surface elevation and intensity values, which were compared with DGPS field records. Fusion software (McGaughey 2010) was employed to generate a working image from the complete coverage of LiDAR intensity data, from which focal study areas were extracted.

A2.3.3. Waveband indices: definitions and applications

A number of waveband indices, also termed band ratios, were used in this study for mapping various aspects of the GAB springs vegetation and surrounding surface features. Waveband indices are commonly employed in remote sensing environmental applications. The indices are quotients between measurements of reflectance, radiance or sensor raw digital numbers in different portions of the electromagnetic spectrum, selected to emphasise spectral contrasts in surface materials of interest. In addition, they have the ability to reduce background effects, such as shadow and differences in solar illumination (Campbell 2002; Mather 2004; Perry & Lautenschlager 1984).

For this study both multispectral broadband and hyperspectral narrowband indices were applied to imagery which had been corrected for ground surface reflectance. The indices used and the purpose of the analyses is explained in the following sub-sections.

Multispectral indices and analyses

The NDVI (Rouse *et al.* 1974; Tucker 1979), a widely used vegetation index which provides a measure of vegetation greenness, was applied to both the QuickBird and WorldView-2 very high resolution multispectral satellite imagery. The NDVI exploits the strong contrast between red and infrared reflectance (R) and takes the form:

$$NDVI = \frac{R_{Infrared} - R_{Red}}{R_{Infrared} + R_{Red}}$$

Because of the differing band configurations and widths of the multispectral sensors, different red and infrared bands were used in the NDVI analyses (Table A2.2).

Derivative analysis of the WorldView-2 imagery was used to highlight more subtle differences in vegetation greenness and growth within wetlands at the Dalhousie Springs Complex. The first derivative lagrangian red-edge position (REP) algorithm developed by Dawson and Curran (1998) was used (refer to Dawson and Curran 1998 for further details). The WorldView-2 wavebands used for computing the Lagrangian REP were 724 nm for the maximum first derivative and 659 nm and 833 nm for the wavebands either side of the maximum first derivative.

Table A2.2: Multispectral sensors, waveband indices and applications within the AWMSGAB Project			
Sensor	Index	Bands (centres)	GAB springs applications
QuickBird	NDVI	654.0 nm, 814.5 nm	Delineating wetland extent
			Short-term changes in distribution of wetlands over time
WorldView-2	NDVI	659 nm, 950 nm	Delineating wetland extent
WorldView-2	Red-edge position	659 nm, 724 nm, 833 nm	More subtle differences in vegetation greenness
MODIS	NDVI	Band 1, Band 2	Delineating wetland extent
			Seasonal variability of wetland vegetation
			Long-term dynamics of wetland vegetation area

A2.3.4. Hyperspectral indices and approaches

Normalised Difference Vegetation Index
The NDVI based on the narrow wavebands of HyMap hyperspectral imagery was employed to establish the extent of perennial and ephemeral wetland vegetation at the spring group scale. The wavelengths used for the NDVI calculation for the HyMap I and II sensors are listed in Table A2.3. These wavelengths were also identified by Andrew and Austin (2008) for mapping invasive plants in wetlands using HyMap imagery.

Normalised Difference Soil Moisture Index
The Normalised Difference Soil Moisture Index (NDSMI) developed by Haubrock *et al.* (2008) was employed to establish the wetted area associated with the springs, incorporating moist ephemeral and perennial vegetation as well as associated saturated and moist substrate. The NDSMI takes the form:

$$NDSMI = \frac{R_{1800} - R_{2119}}{R_{1800} + R_{2119}}$$

The index is based on the strong absorption around 1900 nm and the clay diagnostic absorption feature at 2200 nm, which is drastically reduced when soils are moist; this effect provides a means of measuring soil moisture. Because of the differing band configurations of the two HyMap sensors, different wavebands were used in the NDSMI analyses (Table A2.3).

Modified Normalised Difference Water Index
The extent of standing water at Freeling Springs was delineated using the Modified Normalised Difference Water Index (MNDWI), developed by Xu (2006). The MNDWI is based on the contrast between visible and shortwave infrared absorption associated with surface water features, while the normalisation aids in minimising contributing noise effects (e.g. soil, topography and sensor calibration (Lei *et al.* 2009)) as is the case for NDVI algorithm. The MNDWI has been applied successfully in previous remote sensing studies to map the dynamics of surface water features (Lei *et al.* 2009), with recommendations for adjustment of index thresholds for different situations, which is the approach adopted in this study.

Table A2.3: Hyperspectral sensors, narrow waveband indices and applications within the AWMSGAB Project			
Sensor	Index	Bands (centres)	GAB springs applications
HyMap II 2009	NDVI	665.7 nm, 847.8 nm	Delineating wetland extent
			Short-term changes in spring environments
	NDSMI	1,803.4 nm, 2,120.1 nm	Characterising spring wetted area
HyMap I 2011	NDVI	667.9 nm, 834.9 nm	Delineating wetland extent
			Short-term changes in spring environments
	NDSMI	1,795.2 nm, 2,124.9 nm	Characterising spring wetted area
	MNDWI	546.0 nm, 1,647.4 nm	Delineating spring-fed standing water

MNDWI applied to HyMap II imagery takes the form:

$$MNDWI = \frac{R_{543.7} - R_{1657.2}}{R_{543.7} + R_{1657.2}}$$

with bands modified for HyMap 1 (Table A2.3).

MNDWI thresholds developed by Lei *et al.* (2009) were used as a guide to determine those optimal for delineating spring-fed standing water at Freeling Springs. Ancillary data were also used to aid this process, including spring vent DGPS data, GPS locations of spring vegetation and water extents, interpretation of HyMap imagery and ground knowledge.

Spectrally Segmented Principal Components Analysis

Prior to conducting the more advanced hyperspectral approaches, a Spectrally Segmented Principal Component Analysis (SSPCA) was used with the HyMap imagery to determine the spectral variation within the wetland vegetation (White & Lewis 2010b). An NDVI mask was used to ensure that the SSPCA focused on spectral variation within types of wetland vegetation, rather than separation of plants from other land cover types, such as substrate and diffuse discharge zones; NDVI values ≥ 0.2 adequately defined the wetlands. A similar approach was adopted by Andrew and Ustin (2008) who constrained an area of the Cosumnes River Reserve to encompass vegetation within NDVI ranges to spectrally separate Perennial Pepperweed (*Lepidium latifolium*) from other sparse vegetation.

SSPCA was subsequently applied to spectrally segmented portions of the HyMap imagery with wavelength regions VIS-NIR 450–1350 nm, SWIR1 1400–1800 nm, and SWIR2 1950–2480 nm. SSPCA helped establish the spectral separability of spring wetland vegetation communities and identified the key wavelengths conveying the most variation within the spectra.

Identification of image reference spectra

Two other hyperspectral approaches, Spectral Angle Mapper (SAM) and Mixture Tuned Matched Filtering (MTMF), were subsequently applied to the 2009 and 2011 HyMap imagery to map dominant spring vegetation communities and surrounding substrate. Prior to conducting the SAM and MTMF analysis, two initial processing steps were conducted: Minimum Noise Fraction (MNF) and Pixel Purity Index (PPI). The MNF analysis enables noisy waveband removal, reducing the number of wavebands to those containing the most spectral information. The selected information-rich MNF components were used to perform the PPI analysis, which identified the most spectrally-pure image pixels in the HyMap imagery. The PPI output was then interpreted to identify the purest pixels and regions of interest which corresponded to the dominant spring vegetation communities. Ancillary data was used to assist with this process including colour digital aerial photography, locations of the vegetation sample plots, DGPS locations of spring vents and displays of the HyMap imagery.

Mixture Tuned Matched Filtering

Mixture Tuned Matched Filtering (MTMF) analysis was then performed on areas encompassing selected spring groups. The reference spectra from the Pixel Purity Index (PPI) analysis, representing the dominant vegetation types, were compared with the HyMap Minimum Noise Fraction (MNF) image. The analysis produces two output images: a Matched Filtering (MF) score which estimates relative degree of match to the reference spectrum, and an infeasibility score which indicates the degree of mixing between the reference spectrum and the composite background. These two outputs were displayed as a two-dimensional scatter plot to identify the best matches to a target spring vegetation type: pixels with high MF scores and low infeasibility scores. These 'best match' pixels correspond to image regions with greatest similarity to the reference signature for the chosen vegetation type.

Spectral Angle Mapping

SAM analysis was also performed on larger regions of HyMap MNF imagery, using the same spring vegetation reference spectra identified from the PPI analysis, as well as zones of diffuse discharge. SAM compares the angle between the reference spectrum vector and each pixel spectrum vector in n-dimensional space, with smaller angles representing closer matches to the reference spectrum. Pixels further away than the specified maximum angle threshold are not classified. Determining the most appropriate spectral angle thresholds to discriminate spring vegetation communities and surfaces was an iterative process, aided by visual comparison with the original HyMap imagery and digital colour aerial photography.

The resulting distributions of spring vegetation types and associated zones of diffuse discharge mapped with MTMF and SAM analyses were verified through comparison with digital colour aerial photography, field samples and observations and ground photography.

A2.3.5. Calibration of NDVI to plant cover

Several components of the study required an objective basis for discriminating wetland vegetation from arid vegetation communities in NDVI images. To determine the relationship between QuickBird and WorldView-2, image NDVI values and percentage vegetation cover regression analyses were performed of mean NDVI pixel values against vegetation cover in corresponding 9 x 9 m field sample plots. Such relationships were established for imagery and vegetation samples at Dalhousie (March 2009) and Freeling (May 2011). From these relationships, NDVI thresholds were determined which separated wetland vegetation from dryland sites.

Delineation of wetland extent at Big Blyth Bore was determined by applying the same relationship established between vegetation cover and NDVI at Freeling Springs. In addition, a mask of bore-related wetland vegetation was digitised from interpretation of the wetland extent in dry conditions from 2006 Landsat Thematic Mapper imagery. This technique enabled a clear delineation of bore wetland vegetation from photosynthetic ephemeral creek vegetation for the April 2011 WorldView-2 image. The mask was subsequently overlayed and an intersect operation applied to derive the area of wetland vegetation extent for Big Blyth Bore.

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Glossary and shortened forms

AACWMB: Arid Areas Catchment Water Management Board

Actual evapotranspiration: The amount of water that actually evaporates and transpires from a surface.

Adaptive management: A management approach often used in natural resource management where there is little information and/or a lot of complexity and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions, and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Adiabatic: Relating to or describing a process or condition in which heat does not enter or leave a system.

Advection: The transport of dissolved constituents (i.e., solutes), particulate/colloidal matter, and/or heat by flowing groundwater.

Aeolian: Pertaining to material deposited by wind.

AFDW: Ash-free dry weight

AHD: Australian Height Datum

AISA Eagle: Airborne hyperspectral (visible–near-infrared) image sensor operated by Specim Spectral Imaging Ltd.

Alluvium: sediments deposited by or in conjunction with running water in rivers, streams, or sheetwash and in alluvial fans.

Ambient: The background level of an environmental parameter (e.g. a measure of water quality such as salinity).

AMS: Accelerator mass spectrometry

AMS ^{14}C: Accelerator Mass Spectrometry (AMS) Carbon^{14}

ANAE: Australian National Aquatic Ecosystem

Analytical model: A type of mathematical model that is composed of a closed-form solution (i.e. the solution can be expressed as a mathematical analytic function).

Andesite: An extrusive igneous, volcanic rock, of intermediate composition, with aphanitic to porphyritic texture.

Anemochory: Dispersal of seeds, fruits or other plant parts by wind.

Anisotropy: The directional variation of a property at a point.

Anoxic: Related to or defined by a severe deficiency in oxygen.

Anticline: A fold formed in strata that is arch-shaped (convex up) in which the strata slope downward from the axis.

Anthropogenic: Caused by humans, in the context of human degradation of the environment.

Aquatic ecosystem: The stream channel, lake or estuary bed, water, and/or biotic communities, and the habitat features that occur therein.

Aquatic habitat: Environments characterised by the presence of standing or flowing water.

Aquiclude: A geologic material, stratum, or formation that contains water (i.e. has porosity) but does not transmit it (i.e. has zero or negligible permeability).

Aquifer: An underground layer of rock or sediment that holds water and allows water to percolate through.

Aquifer, confined: Aquifer in which the upper surface is impervious (see 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer.

Aquifer system: Intercalated permeable and poorly permeable materials that comprise two or more permeable units separated by aquitards that impede vertical groundwater movement but do not affect the regional hydraulic continuity of the system.

Aquitard: A bed of low permeability adjacent to an aquifer; may serve as a storage unit for groundwater.

Aquifer, unconfined: Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure.

ARA: Airborne Research Australia

ARC: Australian Research Council

Arenite: A sedimentary rock that consists of sand-sized particles (0.06–2 millimetres [0.0024–0.08 inch] in diameter).

Arid: A climatic region that receives little or no rain. In South Australia, arid lands are usually considered to be areas with an average annual rainfall of less than 250 mm and support pastoral activities instead of broadacre cropping.

Aridification: Drying of an environment from wet to arid.

Arid lands: In South Australia, arid lands are usually considered to be areas with an average annual rainfall of less than 250 mm and support pastoral activities instead of broadacre cropping.

Artesian: An aquifer in which the water surface is bounded by an impervious rock formation; the water surface is at greater than atmospheric pressure, and hence rises in any well which penetrates the overlying confining aquifer.

ASD: Analytical Spectral Device

ASS: Acid sulfate soils

ASTER: Advanced Spaceborne Thermal Emission and Reflectance Radiometer

Asthenosphere: A portion of the upper mantle that is directly below the lithosphere, in which there is relatively low resistance to plastic flow and convection is thought to occur. This weak zone allows the plates of the lithosphere to slide across the top of the asthenosphere.

ATREM: Atmospheric removal algorithm

Auger: Rotary drilling equipment, used in soils or poorly-consolidated materials, that removes cuttings from a borehole by mechanical means without the use of drilling fluids. Augers operate on the inclined plane or screw principle.

AUSPOS: Online tool for post-processing GPS data.

AVH: Australia's Virtual Herbarium

AWMSGAB Project: Allocating Water and Maintaining Springs in the Great Artesian Basin project

Basinal: Pertaining to a basin.

Bicubic: Of or pertaining to the interpolation in two dimensions using cubic splines or other polynomials.

Biodiversity: (1) The number and variety of organisms found within a specified geographic region; (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems.

Biological diversity: See 'biodiversity'.

Biological integrity: Functionally defined as the condition of the aquatic community that inhabits unimpaired water bodies of a specified habitat as measured by community structure and function.

Bioregion: Geographical region based on IBRA classification.

Bioturbated: The displacement and mixing of sediment particles and solutes by fauna or flora.

BoM: Bureau of Meteorology

Bore: See 'well'.

BP: Before present

Buoyancy: The resultant vertical force exerted on a body by the static fluid in which it is floating or submerged.

Caprock: A harder, more resistant rock type overlying a weaker or less resistant rock type

Carbonaceous: Consisting of or containing carbon or its compounds.

Clastics: An accumulation of transported weathering debris.

cm: Centimetre

CMB: Chloride mass balance

CO1: Cytochrome Oxidase subunit 1

Compaction: The processes by which sediment is densified (reduction of porosity or increase in bulk density caused by an increase in the compressive or total stress). In soil mechanics this term is limited to processes involving the expulsion of air from the voids.

Complexes: Clusters of spring groups that share similar geomorphological settings and broad similarities in water chemistry.

Conceptual model: A descriptive form of model in which concepts and the relationships between them are used to describe an overarching idea or theory.

Cone of depression: A curved water table or potentiometric surface that forms around a pumping well.

Confining layer: A rock unit impervious to water, which forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'.

Conformably: Of or relating to, sedimentary strata that are parallel to each other without interruption.

Connate: Pertaining to fluids (usually water) that were trapped in the pores of sedimentary rocks as they were deposited.

Consequence: The outcome of an event affecting objectives.

Control Point Network: A set of reference points of known geospatial coordinates from which a spatial survey is based.

Critical habitat: Those areas designated as critical for the survival and recovery of threatened or endangered species.

Cross-formational flow: Vertical groundwater flow from one hydrostratigraphic unit to another.

CSIRO: Commonwealth Scientific and Research Organisation

Cyanobacteria: A form of large photosynthetic bacteria. Cyanobacteria can produce thick and extensive mats. Commonly known as "blue-green algae", but can also be yellow-green, brown, or even reddish-purple.

Darcian flow condition: A condition of groundwater flow in which flow occurs in a non-turbulent way and complies with the predictable conditions assumed in the application of Darcy's Law of groundwater flow though saturated porous media.

Darcy's Law: The discharge of water (Q) through a unit area of porous medium is directly proportional to the hydraulic gradient (i) normal to that area (A). The constant of proportionality is the hydraulic conductivity (K). $Q = KiA$

DEH: Department for Environment and Heritage (Government of South Australia)

Deltaic: Pertaining to or like a delta.

DEM: Digital Elevation Model

DENR: Department of Environment and Natural Resources (Government of South Australia)

Density: The mass of a substance divided by its volume.

Denudation: The long-term sum of processes that cause the wearing away of the earth's surface, leading to a reduction in elevation and relief of landforms and landscapes.

Depocentre: The deepest point of a sedimentary basin, normally at a basin's centre. Point where thickest accumulation of sediment collects.

Desorption: A process by which solutes, ions, and colloids are released from or through a surface into a liquid of gaseous phase. The opposite of sorption.

DFR: Driving Force Ratio

DFW: Department for Water (Government of South Australia)

DGPS: Digital GPS

Diagenetic: The sum of physical and chemical processes that affect a sediment following deposition.

Diaspore: A plant dispersal unit consisting of a seed or spore plus any additional tissues that assist dispersal.

Diffuse discharge: The discharge of groundwater by molecular movement from zones of high head to zones of low head.

Diffuse recharge: The recharge of groundwater into a groundwater system by molecular movement.

Discharge: (1) The volume of water that passes a given location within a given period of time. Usually discussed with respect to springs, streams or groundwater systems; (2) The water leaving a groundwater system.

Disconformably: Pertaining to a type of unconformity in which the rock layers are parallel.

Diversity: The distribution and abundance of different kinds of plant and animal species and communities in a specified area.

Divide: A topographic high (or ridge) separating surface watersheds (catchments). A groundwater divide is elevated area, line, or ridge of the potentiometric surface separating different groundwater flow systems.

DMITRE: Department of Manufacturing, Innovation, Trade, Resources and Energy (Government of South Australia)

DO: Dissolved oxygen

Domal: Dome-like

Down-warping: A segment of the crust of the Earth that bends downward.

Down-welling: The downward movement of fluid.

DSC: Dalhousie Spring Complex

DSEWPaC: Department of Sustainability, Energy, Water, Population and Communities (Government of South Australia)

DSM: Digital Surface Model

Duricrust: A thin hard layer on or near the surface of soil.

DW: Dry weight

EC: Electrical conductivity; 1 EC unit = 1 micro-Siemen per centimetre (µS/cm) measured at 25°C; commonly used as a measure of water salinity as it is quicker and easier than measurement by TDS.

Ecological processes: All biological, physical or chemical processes that maintain an ecosystem.

Ecological resilience: The capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks (Walker *et al.* 2004).

Ecological values: The habitats, natural ecological processes and biodiversity of ecosystems.

Ecology: The study of the relationships between living organisms and their environment.

Ecosystem: Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment.

Efflorescence: The crystallisation of a salt from a hydrated or solvated state via the loss of water to the atmosphere on exposure to air.

EFFORT polishing: Empirical Flat Field Optimal Reflectance Transformation; applies a mild adjustment to apparent reflectance data so that spectra appear more like real materials on the ground surface.

EFZ: Ecological focal zones

Elevation head: Head due to the energy that is the result of gravity (the elevation of the water relative to some datum).

Endangered species: Any species in danger of extinction throughout all or a significant portion of its range.

Endemic: A plant or animal restricted to a certain locality or region.

Endogenic: Formed or occurring beneath the surface of the earth.

Endozoochory: Seed dispersal via ingestion by a vertebrate animal.

ENSO: El Nino / Southern Oscillation

ENVI: Software for processing and analysing geospatial imagery.

Environmental water head: The sum of the elevation head and the pressure head calculated using the average density of the water over the whole water column, not just the screened interval. This is used for calculating the vertical hydraulic gradient.

EPBC Act: Environment Protection and Biodiversity Conservation Act 1999

Epeiric sea: A shallow sea that extends over part of a continental landmass.

Ephemeral: (1) Pertaining to a watercourse or body flows or contains water only in direct response to precipitation, and thus discontinues its flow or becomes dry during dry seasons; (2) plants with more than one life cycle, which are often short in duration.

Ephemeral river recharge: A term used to describe indirect recharge resulting from episodic flow events in arid zone rivers.

Ephemeral streams or wetlands: Those streams or wetlands that usually contain water only on an occasional basis after rainfall events; many arid zone streams and wetlands are ephemeral.

Epigenic: Pertaining to a geological change in the mineral content of rock that occurs after the rock has formed.

Epizoochory: Seed dispersal where seeds are transported on the outside of vertebrate animals.

Epoch: Defined periods of time.

ERI: Electrical resistivity imaging

ERR: Ephemeral river recharge

ESU: Evolutionary significant unit

Evapotranspiration: The total loss of water as a result of transpiration from plants and evaporation from land and surface water bodies.

Excess head: The level to which water will rise above ground surface in an artesian well, measured in metres (m).

Facies: A unit or body of rock with definable and specific characteristics that can be used in classification.

FLAASH: Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes. An atmospheric correction algorithm.

Floristic: Of or relating to flowers or flora.

Flow: The rate of water that discharges from a source expressed as a volume per unit time.

Flow line/flow path: The path a molecule of water takes in its movement through a porous medium.

Flow net: A map showing both equipotentials and streamlines of an aquifer or geological system.

Flow regime: The character of the timing and amount of flow in a stream.

Fluvial: Of or relating to inhabiting a river or stream. Produced by the action of a river or stream.

Fluvio-deltaic: Of or relating to streams rivers or deltas.

Fm: Formation

FNPWA: Far North Wells Prescribed Area

Fresh water: Water with salinity < 1000 mg/L; drinkable or potable water is implied.

Fresh-water head: The sum of the elevation head and the pressure head calculated using the density of the fresh water (~1000 kg m^{-3}). This is used for calculating the horizontal hydraulic gradient.

FR FieldSpec® 3: Full range (400–2500 nm) FieldSpec Pro portable field spectroradiometer by Analytical Spectral Devices.

Ga: Billion years

GA: Geoscience Australia

GAB: Great Artesian Basin

GDA94: Geocentric Datum of Australia 1994

GDE: Groundwater-dependent ecosystem/s

Geological features: Include geological monuments, landscape amenity and the substrate of land systems and ecosystems.

Geomorphic: Of or resembling the Earth or its shape or surface configuration.

Geomorphology: Study of landforms and the processes that make them.

Geo-registered: To geographically reference a remotely sensed image or spatial data to an Earth model.

GIS: Geographic information system

GL: Gigalitres

Glacio-fluvial: Of or relating to a glacial rivers or streams.

Glaciogene: Formed by glacial activity.

Glacio-lacustrine: Of or related to glacial lakes.

Glauconated: To be altered into the mineral glauconite. Glauconite is a greenish clay mineral of the illite group, found chiefly in marine sands. Chemical formula is (K,Na)(Fe^{3+},Al,Mg)$_2$(Si,Al)$_4$$O_{10}$$(OH)_2$.

GMI: Gidgealap-Merrimelia-Innaminka

GMWL: Global Meteoric Water Line

GNIP: Global Network of Isotopes in Precipitation

GNSS: Global Navigation Satellite System

gph: Gallons per hour

Graben: An elongated block of the earth's crust lying between two faults and displaced downward relative to the blocks on either side.

Granitoid: A granite or granitic rock.

Groundwater: Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground.

Groups: Clusters of spring vents that share similar water chemistry and source their water from the same fault or structure.

GSD: Ground sample distance

Gypcrete: A gypsum indurated or cemented duricrust.

Gypsiferous: Containing appreciable amounts of the mineral gypsum ($CaSO_4 \bullet 2H_2O$).

ha: Hectare

Habitat: The natural place or type of site in which an animal, plant, or community of plants and animals lives.

Halophytic: Adapted to living in salty soil, particularly plants.

Head: Fluid mechanical energy per unit weight of fluid, which correlates to the elevation that water will rise to in a well.

Headward: In the region or direction of the head.

Heterogeneity: The condition in which the property of a parameter or a system varies with space.

HEVAE: High Ecological Value Aquatic Ecosystem

Hummocky: Lumpy terrain or land which has an irregular shape.

Hydraulic conductivity (K): A measure of the ease of flow through aquifer material: high K indicates low resistance or high flow conditions, usually measured in metres per day.

Hydrochemistry: Science that deals with the chemical characteristics of water.

Hydrochory: Seed dispersal by water.

Hydrogeology: The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also 'hydrology'.

Hydrology: The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'.

Hydrostatic pressure: The pressure exerted by liquid at equilibrium due to the force of gravity.

Hydrostratigraphy: Refers to stratigraphic classification with respect to the hydrogeological properties of strata.

HyMap: An airborne hyperspectral image sensor operated by HyVista Corporation.

Hyperspectral: Imagery or ground data derived from subdividing the electromagnetic spectrum into numerous (more than 10) very narrow bandwidths.

IAEA: International Atomic Energy Agency

IBRA: Interim Biogeographic Regionalisation for Australia

Indigenous species: A species that occurs naturally in a region.

Interbedding: Where layers or rock (or beds) of a particular lithology lie between or alternate with beds of a different lithology.

Intercalation: The reversible inclusion of a molecule (or group) between two other molecules (or groups).

Intrabasinal: Pertaining to the interior of a basin

Intracratonic: Pertaining to the interior of a craton

Intraplate: Pertaining to the interior of a tectonic plate

Isopach Map: A map illustrating variation of thickness within a tabular unit or stratum. Each line, or isopach represents where a particular stratum has the same thickness.

Isopotentials: A vector or region in space where every point in it is at the same potential.

Isotropy: The condition in which the properties of a system or a parameter do not vary with direction.

ka: Kilo annum (1000 years)

Kaolinitic: Where the composition has a significant proportion of the mineral kaolin ($Al_2Si_2O_5(OH)_4$).

kL: Kilolitre

km: Kilometre

km^2: Square kilometres

Lacustral: Of, or pertaining to, a lake.

Lacustrine: Of, or pertaining to, a lake.

Lag time: The time between the middle of the precipitation event in a watershed (or catchment) and the arrival of the flood peak at a given location.

LAS: LASer file format exchange

LEB: Lake Eyre Basin

Level of risk: Magnitude of a risk, or combination of risks, expressed in terms of the combination of consequences and likelihood.

LGM: Last Glacial Maximum

LiDAR: Light Detection and Ranging

Limnological: The study of life and phenomena of freshwater.

Lithosphere: The rigid, outermost shell of the Earth. The lithosphere sits on top of the asthenosphere and is that portion of the Earth that interacts with the hydrosphere, biosphere and atmosphere.

Lithostratigraphic: Refers to the stratigraphy with respect to the strata's rock properties.

LMWL: Local Meteoric Water Lines

Loop closure: A check to assess the cumulative error generated from moving sites with multiple base stations.

L/s: Litres per second

Lunette: A sand or sediment dune formed by wind activity that typically takes the shape of a crescent.

m: Metre

Ma: Million years

Macro-invertebrates: Aquatic invertebrates visible to the naked eye including insects, crustaceans, molluscs and worms that inhabit a river channel, pond, lake, wetland or ocean.

mAHD: Metres Australian Height Datum**.** Defines elevation in metres (m) according to the Australian Height Datum (AHD).

Mantle-derived: To be derived from the earth's mantle.

mBNS: Metres below natural surface

MBR: Mountain block recharge

m/day: Metres per day

Meteoric water: Water that is or has recently been a part of the atmospheric portion of the hydrologic cycle.

MF: Matched Filtering

MFR: Mountain front recharge

mg/L: Milligrams per litre

Micaceous: Where the composition has a significant proportion of mica minerals. Mica can be one of any group of chemically and physically related aluminum silicate minerals.

Mining (hydrogeology): This implies extraction of water from a groundwater system which is not currently receiving recharge.

MIS: Marine isotopic stage

mL: Millilitres

ML: Megalitres

mm: Millimetre

m/Ma: Metres per million years

mm/yr: Millimetres per year

MNDWI: Modified Normalised Difference Water Index

MNF: Minimum Noise Fraction

Model: A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions; examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change.

MODIS: Moderate Resolution Imaging Spectroradiometer

MODTRAN: Moderate Spectral Resolution Atmospheric Transmittance

Monocline: A geologic structure in which all layers are inclined in the same direction.

Mountain block recharge: A term used to describe subsurface inflows from a consolidated mountain block.

Mountain Front recharge: A term used to describe infiltration (or seepage) from streams (either perennial or ephemeral), at a mountain front.

Mountain system recharge: A term to used to describe the contribution of groundwater recharge derived from mountains to adjacent aquifers.

mS/cm: milliSiemens per centimetre

MSL: Mound spring line

MSR: Mountain system recharge

mt: Mitochondrial

MTMF: Mixture Tuned Matched Filtering

Multispectral: Images with multiple wavelengths, usually between four to 15, representing broad bandwidths of the electromagnetic spectrum.

m/yr: Metres per year

NASA: National Aeronautics and Space Administration (United States of America)

Natural resources: Soil, water resources, geological features and landscapes, native vegetation, native animals and other native organisms, ecosystems.

NCSSA: Nature Conservation Society of South Australia

NDSMI: Normalised Difference Soil Moisture Index

NDVI: Normalised Difference Vegetation Index

Neotectonic: Tectonic activity considered to be current or recent in geologic time.

nm: Nanometres

NRM: Natural resource management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively.

NSW: New South Wales

NT: Northern Territory

Numerical model: A form of mathematical model that uses some sort of numerical time-stepping procedure to obtain a modeled behavior over time.

NWI: National Water Initiative

Observation well: A narrow well or piezometer whose sole function is to permit water level measurements.

Orogen: A section of the earth's crust that is subject to the formation of mountains.

Orogenic: In reference to a process in which a section of the earth's crust is folded and deformed to form a mountain range.

Orographic: Of, or relating to mountains, particularly their form and position.

Orthophotography: A digital photograph that has been registered to a Digital Elevation Model that allows for accurate measurement of features directly from the photograph.

OSL: Optically stimulated luminescence

pa: Per annum

Palaeochannel: Refers to the channel of a river or stream, or the sediments contained within a riverbed or streambed that is no longer active.

Palaeoclimate: Climate conditions or events that occurred in the past and is no longer active.

Palaeo-ecology: The study of fossil animals and plants in order to deduce their ecology and the environmental conditions in which they lived.

Palaeohydrological: Hydrological changes or events that occurred in the past and is no longer active.

Palaeorecharge: Groundwater recharge event or condition that occurred in the past and is no longer active.

Palaeo-wind: Wind conditions that occurred in the past and are no longer active.

Paludal: Of or pertaining to marshes, swamps or fens.

Palynology: The study of pollen grains and other spores, particularly those found at archaeological sites or in geological deposits

Paralic: Pertaining to deposits laid down on the landward side of a coast.

PCA: Principal Components Analysis

Pericratonic: Of, or pertaining to the boundary of continental crust and oceanic crust.

Periglacial: Of, or referring to a place at the edges of glacial areas. Can also be used to refer to any place where geomorphic processes related to freezing of water occur.

Permeability: The state or quality of a material that causes it to allow liquids or gases to pass through it.

Petroglyphs: Rock engravings created by removing part of a rock surface by incising, picking, carving, and abrading.

pH: Standard measurement of acidity/alkalinity

Phenological: Plant growth cycle

Phreatic zone: Water in the zone beneath the water table where the fluid pressure is equal to or greater than atmospheric pressure.

Phreatophytic vegetation: Vegetation that exists in a climate more arid than its normal range by virtue of its access to groundwater.

Phylogeography: The study of the historical processes that may be responsible for the contemporary geographic distributions of individuals.

Piezometer: A pressure-measuring device. This typically is an instrument that measures fluid pressure at a given point rather than integrating pressures over a well.

Piezometric surface: See 'potentiometric head or surface'.

Playa: An arid zone basin with no outlet, which periodically fills with water to form a temporary lake.

pmC: Percent modern carbon

Point water head: The sum of the elevation head and the pressure head calculated using the density of the water at the point sampled.

Polychory: Seed distribution by more than one agent.

Porosity: Pertaining to the voids within a sediment or rock; can also be called void fraction. Effective porosity is the porosity of a sediment or rock available to contribute to fluid flow through the rock or sediment.

Potential evapotranspiration: The amount of water that would evaporate and transpire from a surface if sufficient water was available to meet the demand.

Potentiometric head or surface: The level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface.

PPI: Pixel Purity Index

ppm: Parts per million

ppt: Parts per trillion

Precautionary principle: Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

Pressure head: Head caused by the pressure (energy) of the fluid.

Probability: Measure of the chance of occurrence expressed as a number between 0 and 1, where 0 is impossible and 1 is absolutely certain.

Proponent: The person or persons (who may be a body corporate) seeking approval to take water from prescribed water resources.

PSM: Permanent survey mark

Pugging: The trampling of wetland soils into mud by livestock often resulting in a very uneven surface of deep hoofmarks in which water pools and becomes stagnant.

QuickBird: Satellite operated by Digital Globe that captures very high-resolution multispectral imagery.

R8: Trimble GPS receiver

RADAR: Radio Detection and Ranging

Radiogenic: Related to a stable element that is product of radioactive decay.

Radionucleide: An atom with a nucleus that is unstable and is characterised by excess energy. The nuclide will disintegrate with the emission of corpuscular or electromagnetic radiations,

Ramsar Convention: This is an international treaty on wetlands titled The Convention on Wetlands of International Importance Especially as Waterfowl Habitat. It is administered by the International Union for Conservation of Nature and Natural Resources. It was signed in the town of Ramsar, Iran in 1971, hence its common name. The convention includes a list of wetlands of international importance and protocols regarding the management of these wetlands. Australia became a signatory in 1974.

Rayleigh Number: The ratio buoyancy forces to viscous resistance and dispersive/diffusive dissipation.

Recharge: The process by which water enters the groundwater system.

Recharge zone: The area of an aquifer or aquifer system where water enters the subsurface and eventually the phreatic zone.

Red Edge Position: The inflexion point (or maximum slope) between the red and infrared wavelength regions.

Residual risk: Risk remaining after risk treatment.

RGR: Relative growth rates

Rheology: The study of the flow of matter, primarily in the liquid state, but also as 'soft solids' or solids under conditions in which they respond with plastic flow rather than deforming elastically in response to an applied force.

Rhyolite: A pale fine-grained volcanic rock of granitic composition.

Rhythmites: Layers of sediment or sedimentary rock that are laid down with an clear periodicity and regularity.

RINEX: Receiver Independent Exchange Format

Risk: The effect of uncertainty on objectives.

Risk analysis: Process to comprehend the nature of risk and to determine the level of risk.

Risk assessment: Overall process of risk identification, risk analysis and risk evaluation.

Risk avoidance: Informed decision not to be involved in, or to withdraw from, an activity in order not to be exposed to a particular risk.

Risk categories: Overarching categories of risk which may include several sources of risk.

Risk criteria: Terms of reference against which the significance of risk is evaluated.

Risk identification: The process of finding, recognising and describing risks.

Risk management: Coordinated activities to direct and control an organisation with regard to risk.

Risk management framework: Set of components for designing, implementing monitoring, reviewing and continually improving risk management throughout the organisation.

Risk treatment: A process to modify risk.

RMS: Root mean square

RTK DGPS: Real-time kinematic differential global positioning system

Runoff: (1) Water from precipitation, snowmelt, or irrigation running over the surface of the Earth; (2) surface water entering rivers, lakes, or reservoirs; (3) a component of stream flow.

SA: South Australia

SAAE: South Australian Aquatic Ecosystem

SAALNRMB: South Australian Arid Lands Natural Resources Management Board

SA Geodata: State government database containing spatial and geophysical data

Salinity: The amount of solutes (dissolved materials) in water.

SAM: Spectral Angle Mapper

SARDI: South Australian Research and Development Institute

Sedgelands: Vegetation species associated with wetlands that have adapted to extreme environmental conditions such as drought and low availability of nutrients.

Sedimentological: Of, or pertaining to sediments or the study or sediments.

Semiarid: pertaining to climatic conditions in which the precipitation, although slight, is sufficient for growth of short sparse grass.

Senescence or senescent: The growth phase of a plant from maturity to death.

Silcrete: A silica indurated or cemented duricrust.

Siliciclastic: Clastic sediments composed of primarily siliceous minerals.

Sorption: The general process by which solutes, ions, and colloids become attached (sorbed) to solid matter in a porous medium. Sorption includes absorption and adsorption.

SpEC: Specific electrical conductance

Specific yield: The ratio, less than or equal to the effective porosity, indicating the volumetric fraction of the bulk aquifer volume that a given aquifer will yield when all the water is allowed to drain out of it under the forces of gravity.

Specific storage: The volume of water released per unit volume of aquifer for a unit decrease in hydraulic head.

Spectral: Relating to electromagnetic wavelengths; for remote sensing used in this study, spectral covers the region from the visible to the shortwave infrared.

Spectroradiometer: An instrument for measuring the radiant energy distribution in the electromagnetic spectrum.

Speleothem: A mineral deposit of calcium carbonate that precipitates from solution in a cave.

Spring: Individual wetlands comprising one or more vents and tails joined together by permanent wetland vegetation.

Spring complex: Clusters of spring groups that share similar geomorphological settings and broad similarities in water chemistry.

Spring group: Clusters of springs that share similar water chemistry and source their water from the same fault or structure.

Spring supergroup: Clusters of spring complexes.

Spring vent: A conduit or aperture through which groundwater discharges to the surface environment.

SRTM: Shuttle RADAR Topography Mission

SSPCA: Spectrally Segmented Principal Component Analysis

Sst: Sandstone

Stadial: A period of colder temperatures during an interglacial (warm period) separating the glacial periods of an ice age.

Static water level: The level of water in a well that is not affected by pumping.

Steady state: The condition in which properties in a system are not changing with time.

Stochasticity: Refers to systems whose behaviour is intrinsically non-deterministic, sporadic and categorically not intermittent.

Storage: Water contained within an aquifer or within a surface-water reservoir.

Storage coefficient: The volume of water an aquifer releases from or takes into storage per unit surface area of an aquifer per unit change in head.

Storativity: The volume of water released per unit area of aquifer for a unit decline in head. In a confined aquifer, storativity is essentially the specific storage times aquifer thickness. In an unconfined aquifer, storativity is essentially equal to the specific yield or the effective porosity.

Stratigraphical: Of, or pertaining to the study of stratigraphy.

Stratigraphies: Plural layers in sedimentary and layered volcanic rock

Stratigraphy: A branch of geology concerned with rock layers and layering (stratification). It is primarily used in the study of sedimentary and layered volcanic rocks.

Sub-basin: A smaller drainage basin within a larger drainage basin.

Subhydrostatic pressure: The pressure exerted by liquid at equilibrium that is less than the liquid's hydrostatic pressure.

Substrate: A layer of earth beneath the surface soil or subsoil.

Supergroups: Clusters of spring complexes; there are 13 supergroups across the GAB with three found in South Australia.

Superhydrostatic pressure: The pressure exerted by liquid at equilibrium that is greater than the liquid's hydrostatic pressure.

Surface water: (1) Water flowing over land after having fallen as rain or hail or precipitated in any another manner, or having risen to the surface naturally from underground; (2) Water of the kind referred to in (1) that has been collected in a dam or reservoir.

SWIR: Short-Wave InfraRed

SWP: Soil water potential

Synclinal: Of or pertaining to a syncline. A syncline is a trough-shaped fold of stratified rock (convex down) in which the strata slope upward from the axis.

Tails: Wetlands associated with flow away from the vent.

Taxa: General term for a group identified by taxonomy, which is the science of describing, naming and classifying organisms.

TDEM: Time Domain Electromagnetics

TDS: Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity.

Tectonics: A branch of geology that is primarily concerned with the structures within the earth's crust, with particular reference to the forces and movements that have operated in a region to create these structures.

TEM: Transient Electromagnetic

Terrane: A fault-bounded area or region with a distinctive stratigraphy, structure, and geological history.

Terrigenic: To be derived from the land

Tertiary aquifer: A term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago).

Thermal conductivity: The rate of heat flow per unit area for a unit thermal gradient normal to that area.

Thermogene: A process that produces heat.

TL: Thermoluminescence

Tomography: A technique for displaying a representation of a cross section through another solid object. In geology, this is usually done with seismic or another geophysical technique.

Total dissolved solids (TDS): The sum of all organic and inorganic dissolved matter in water.

Toxic: Relating to harmful effects to biota caused by a substance or contaminant.

TPS: Temperature, pH, Salinity meter

Tracer: A solute, suspended matter, or heat which is artificially or naturally induced to evaluate the rate and direction of groundwater flow.

Trachyte: A fine-grained volcanic rock consisting largely of alkali feldspar.

Transgressive: Pertaining to a geologic event during which sea level rises relative to the land and the shoreline moves toward higher topographic regions.

Transient: The condition in which properties of a system vary with time.

Transmissivity: The hydraulic conductivity of an aquifer unit, multiplied by its saturated thickness.

Travertine: A name used to describe a terrestrial calcareous sedimentary rock that typically precipitates from springwater.

Tufa: A name used to describe a terrestrial calcareous sedimentary rock that precipitates from springwater. It an be used to specifically describe a fine-grained micritic carbonate with textures highly influenced by microbial activity, precipitated at ambient and sub-ambient water temperatures.

UltraCam: A digital photogrammetric aerial camera.

Underground water: See 'groundwater'.

Unsaturated: The condition when the porosity is not filled with water.

Unsaturated zone: Generically, is considered equivalent to the vadose zone. This is the zone above the water table and the saturated portion of the capillary fringe where the pores are generally filled with both liquid water and air.

Upward leakage: The leakage of groundwater to strata located above the aquifer or to surface.

Upwardly-fining: A decrease in grainsize within a sedimentary unit in proportion to age.

U/Th: Uranium/Thorium ratio

Vadose Zone: In terrestrial environments, the portion of the shallow subsurface that is above the water table.

Velocity head: Head caused by the kinetic energy of the flowing fluid.

Vents: Individual point discharges of water from the GAB, varying in size and structure: some are discrete discharges of water as if coming from a pipe, while others may be several metres across with no clear point of discharge within the region—the spring vent is the minimum unit used when describing the number springs from a legislative perspective and in accordance with water allocation planning. See 'spring vent'.

VIS-NIR: Visible and Near Infrared

VHR: Very High Resolution

Volcaniclastics: Volcanic material that has been transported and reworked through mechanical action, such as by wind or water.

Volcanolithics: Sediments composed of fragments of volcanic rock.

WAP: Water allocation plan

Water allocation: (1) In respect to a water licence, means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (2) In respect to water taken pursuant to an authorisation under s.11, means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Water allocation plan (WAP): A plan prepared by a catchment water management board or water resources planning committee and adopted by the Minister in accordance with the Act.

Water-dependent ecosystems: Parts of the environment, species composition and natural ecological processes that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems.

Water table: A surface at or near the top of the phreatic zone (zone of saturation) where the fluid pressure is equal to atmospheric pressure.

Well: (1) An opening in the ground excavated for the purpose of obtaining access to groundwater; (2) An opening in the ground excavated for some other purpose but that gives access to groundwater; (3) A natural opening in the ground that gives access to groundwater.

Wetlands: Areas of permanent, periodic or intermittent inundation – whether natural or artificial, permanent or temporary – with water that is static or flowing; and is fresh, brackish or salty (including areas of marine water); the depth of which at low tides does not exceed six metres.

WGS84: World Geodetic System (1984)

WorldView-2: Satellite operated by Digital Globe that captures very high-resolution multispectral imagery.

ZoI: Zone of influence

μm: micrometres

$\delta^{13}C$: Carbon isotopic concentration

$\delta^{x}O$ (e.g. $\delta^{18}O$): Isotopic abundance ratio. Oxygen 18 isotope

σh: Principal maximum horizontal compressive stress

σV: Principal vertical stress

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Cover image:
HyMap airborne image of southern Francis Swamp Springs Complex and Warriner Creek, HyVista Corporation, 2009

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