

PUBLISHED VERSION

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'Allocating Water and Maintaining Springs in the GAB'

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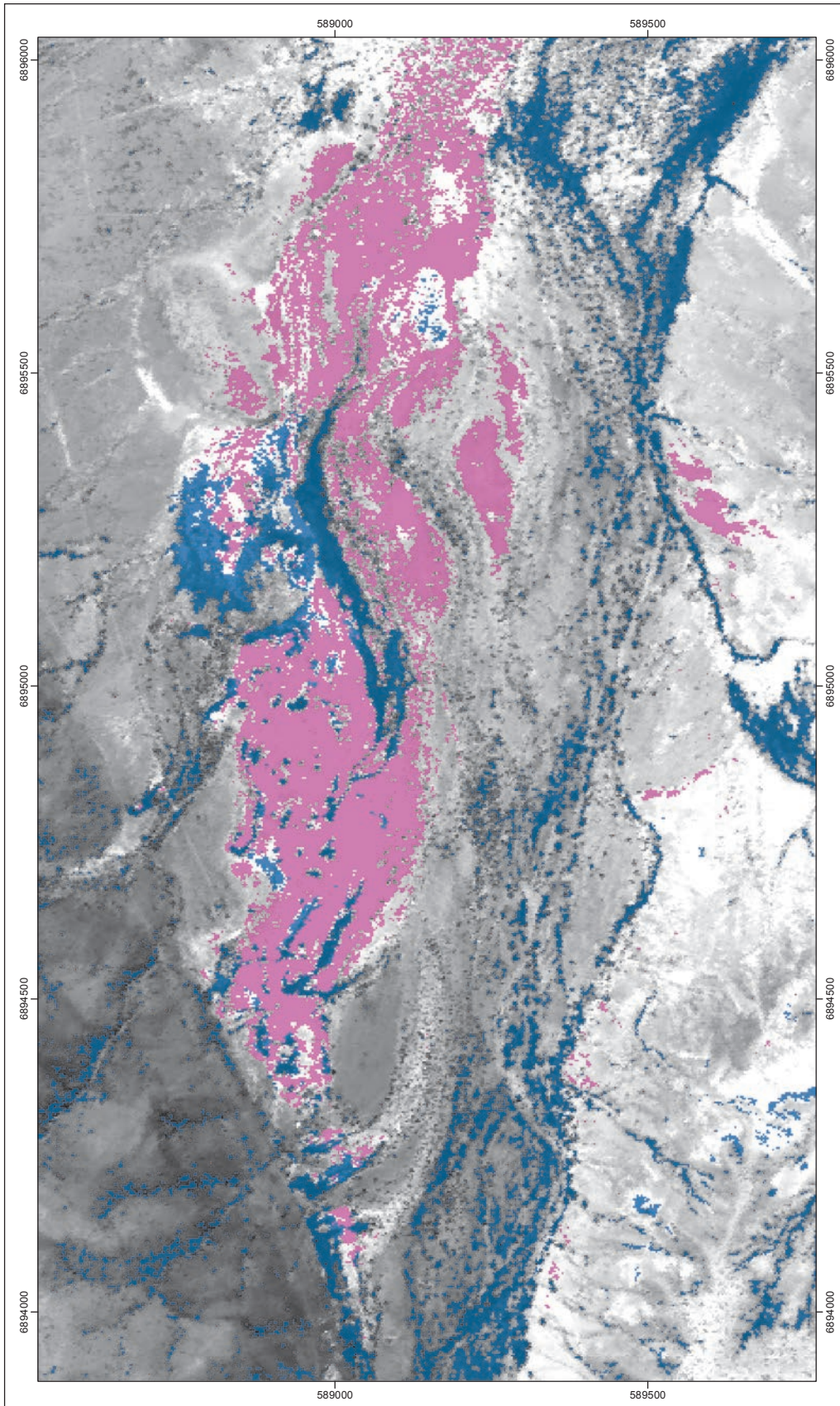
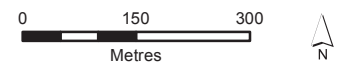


Figure 3.19: Distribution of wetted areas and of diffuse discharge, from spectral analysis of HyMap airborne hyperspectral imagery (April 2011)

Soil Moisture
Diffuse Discharge
Near Surface Moisture



Background image: HyMap, 665.7 nm, April 2011.
Produced by The University of Adelaide - School of Earth & Environmental Sciences
Map Projection: UTM Transverse Mercator
Map Datum: Geocentric Datum of Australia 1994
Date: January 2012





Photo: Megan M. Lewis

Locating and quantifying fish habitats

Freshwater fisheries ecologists and natural resource managers wished to identify the distribution and extent of outflowing spring surface water for the Mt Denison Spring Complex, which is the habitat for native fish populations and the introduced Mosquito Fish (*Gambusia* sp.). Analysis of the airborne and satellite images using vegetation and water indices provided an efficient means of locating these habitats, documenting their distribution and quantifying their extent (Figure 3.20). This showed that to the north of the complex there are several large, deep waterholes in the course of Peake Creek, while to the south shallow water underlies most vegetation on spring tails or spreads in thin films across extensive impervious

travertine sheets between the springs. From these distributions, total areas of open water for each of the selected springs were computed and employed to estimate the size of fish populations.

Connectivity between the spring habitats and nearby ephemeral streams was also of interest, as it could influence native fish dispersal. Interpretation and comparison of HyMap images captured in dry conditions (March 2009) and after high rainfalls (April 2011) showed that the main southern Freeling Spring (EFS070/EFS071) may be connected to the ephemeral creek further north under flood conditions. This provided visual evidence that potential contamination of the southern Freeling Springs with Mosquito Fish is feasible and presents a real threat to rare and relic endemic fish populations in the springs.

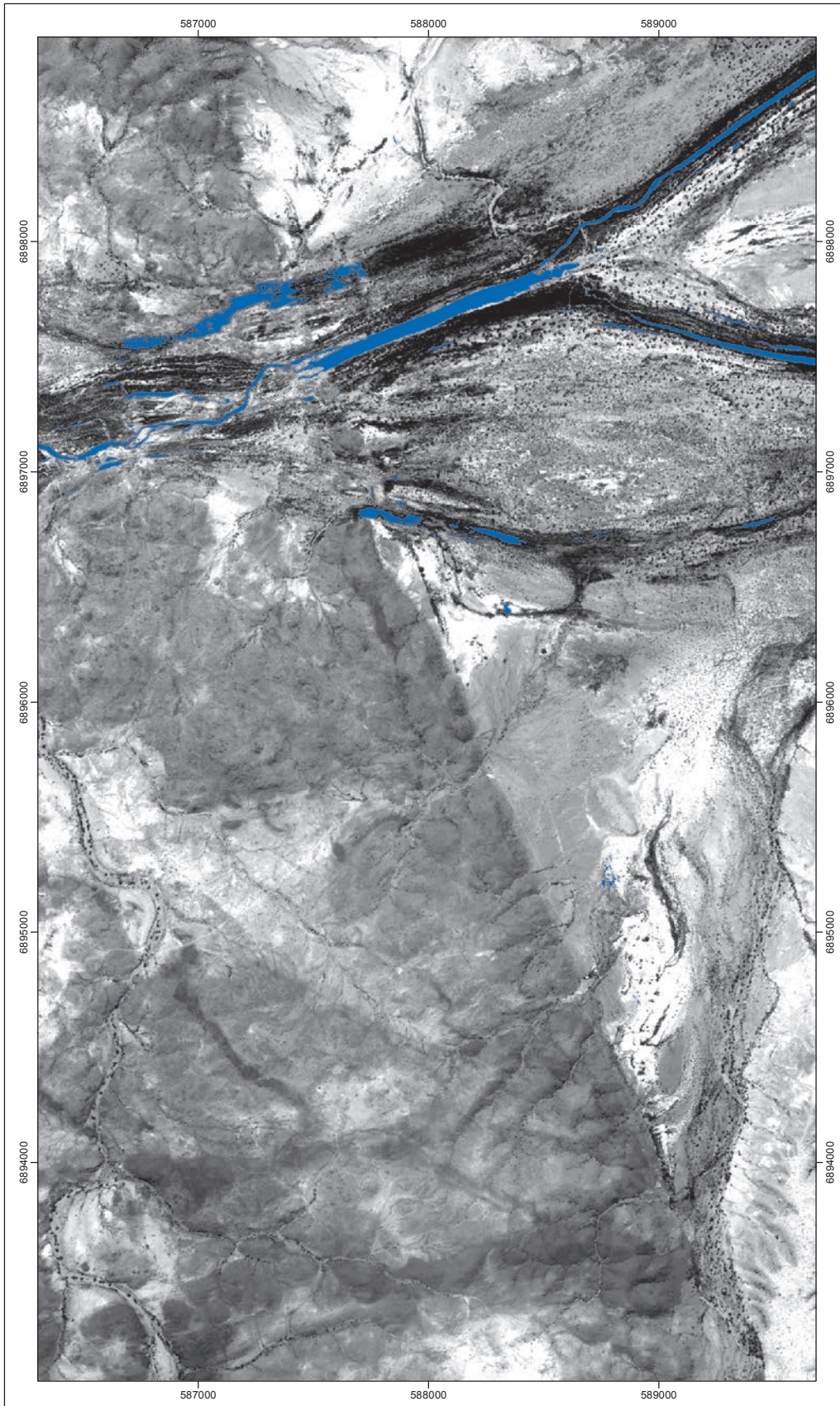
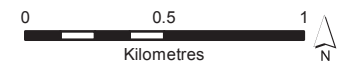


Figure 3.20: Distribution of standing water within Freeling and Freeling North spring groups, Peake Creek and *Inthunintjunha* waterhole, from Normalised Difference Water Index applied to HyMap airborne hyperspectral imagery (April 2011)

Water index
■ Standing Water



Background image: HyMap, 665.7 nm, April 2011.
Produced by The University of Adelaide - School of Earth & Environmental Sciences
Map Projection: UTM Transverse Mercator
Map Datum: Geocentric Datum of Australia 1994
Date: January 2012





Photo: Megan M. Lewis

Big Blyth Bore capping and spring wetland response

Uncontrolled artesian water flowing from bores can reduce aquifer pressure and have adverse impacts on nearby natural springs. Studies at Freeling Springs and Big Blyth Bore 15 km to the east (latitude 28.05° S, longitude 136.06° E), aim to quantify these impacts. Satellite and airborne remotely sensed images were acquired near-simultaneously with field data in April and May 2011 to provide baseline measurements of the area of wetland associated with the springs and bore. At that time, uncontrolled flow of approximately 1000 ML per annum from Big Blyth Bore supported an estimated

424.8 ha of wetlands, comprising a large, relatively homogenous expanse of Bulrush (*Typha domingensis*), extending north-west from the bore into the nearby ephemeral creek system (Figure 3.21). Interpretation of archival Landsat satellite images helped identify the vegetation fed by flows from the bore.

Big Blyth Bore was capped in October 2011 and the remote sensing study of wetlands at the Freeling Spring Group will be repeated over time to build on the baseline information developed in the AWMSGAB Project to provide valuable information about response of the natural wetlands to increased aquifer pressure in the region.

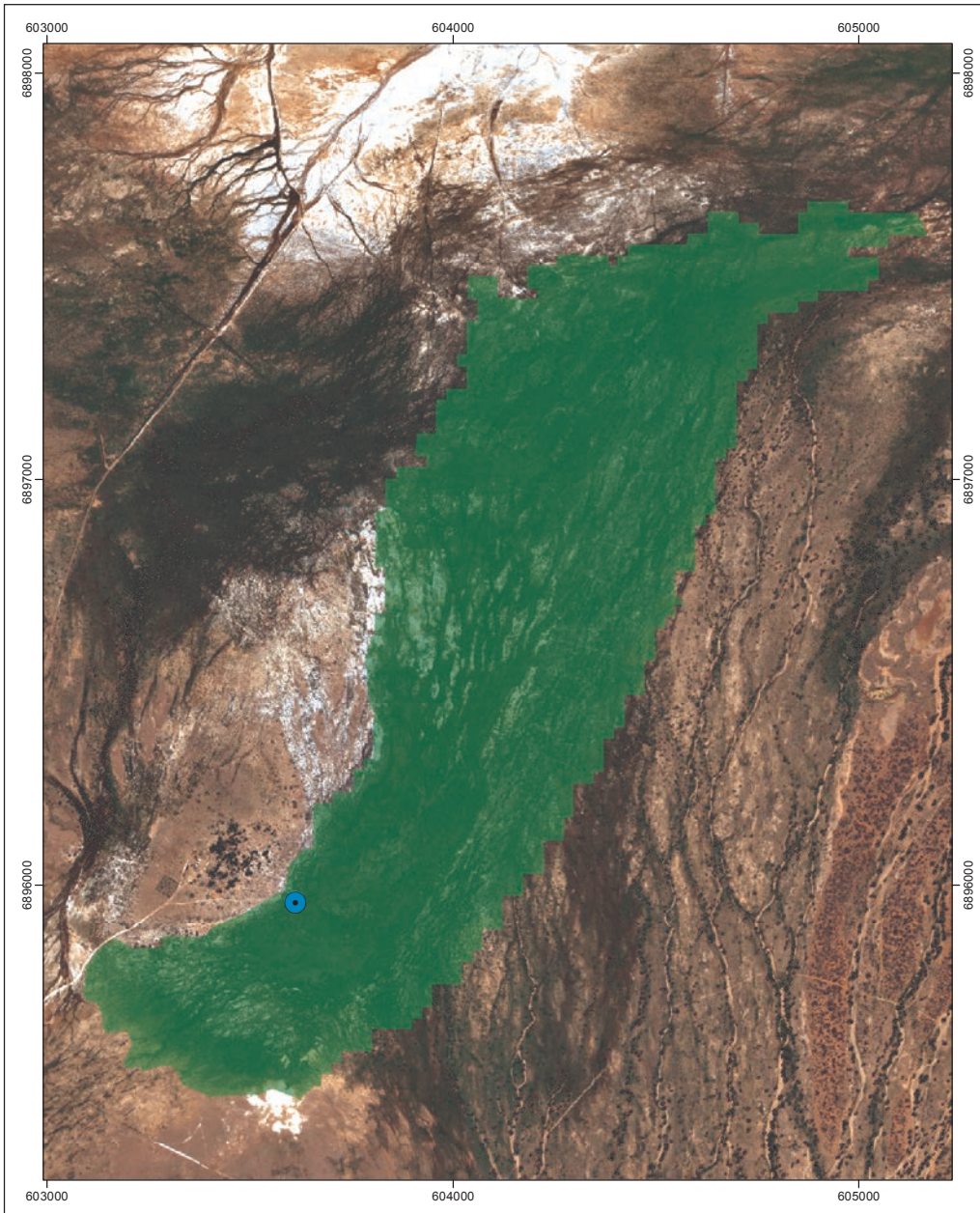


Figure 3.21: Extent of wetland area at Big Blythe Bore, derived from NDVI threshold applied to WorldView-2 multispectral satellite imagery (April 2011)

Legend
● Big Blythe Bore
■ Bore Wetland Vegetation

0 250 500
Metres

Background image: WorldView-2 True Colour, April 2011
Produced by The University of Adelaide - School of Earth & Environmental Sciences
Map Projection: UTM Transverse Mercator
Map Datum: Geocentric Datum of Australia 1994
Date: January 2012



3.7. Hermit Hill Spring Complex

Hermit Hill is one of the most diverse spring complexes on the western margin of the GAB, comprising 12 active spring groups, each with a unique geomorphic setting, surface expression and botanical composition. The complex is centred around Hermit Hill, an outcrop of the Adelaide Geosyncline, located at latitude 29.60° S and longitude 137.41° E. It lies within the Stony Plains IBRA region, with surrounding plains of low open chenopod shrublands. Hermit Creek encircles the east and northerly flanks of Hermit Hill, its course bisecting several of the spring groups.

This study surveyed 1144 vents within the entire Hermit Hill Spring Complex (Figure 3.22, Table 3.5). The majority of these springs surround the north and easterly base of Hermit Hill and consist of four main spring groups; Old Woman, Old Finnis, West Finnis and Hermit Hill and one solitary spring, Finnis Well. Most of the remaining spring groups form a chain running south and west of Hermit Hill and comprise, in sequence from the hill, the groups Dead Boy, Sulphuric, Bopeechee, Bopeechee North, Bopeechee Mound, Beatrice and Venebles. In addition, a small number of isolated springs are located north-west of Hermit Hill at North West Spring Group and south-east of Hermit Hill at Pigeon and Pigeon North Spring Groups.

Table 3.5: Spatial characterisation of Hermit Hill Springs Complex

Spring group code	Spring group names	Aboriginal spring group name	Number of vents	Elevation (m above MSL)				
				Mean	Maximum	Minimum	Range	Standard deviation
HBM	Bopeechee Mound	Not Known	39	10.872	12.849	7.014	5.835	1.302
HBN	Bopeechee North	Not Known	39	5.584	7.632	2.529	5.103	1.535
HBO	Bopeechee	Pupitji	62	2.497	4.467	0.828	3.639	0.844
HBS	Beatrice	Not Known	15	13.007	14.576	9.745	4.831	1.357
HDB	Dead Boy	Thutirla Kumpira	11	0.920	3.791	0.327	3.464	0.970
HFL	Finniss Well	Not Known	1	10.230	10.230	10.230	0.000	NA
HHS	Hermit Hill	Ngarlamina	429	1.455	7.754	-1.486	9.240	1.707
HNW	North West	Not Known	56	9.961	12.552	7.047	5.505	1.447
HOF	Old Finnis	Munarinha	266	2.070	4.144	0.413	3.731	0.756
HOW	Old Woman	Paparla	45	3.357	4.413	1.391	3.022	0.689
HPH	Pigeon Hill	Murla-murlaparanha	1	3.857	3.857	3.857	0.000	NA
HPN	Pigeon Hill North	Not Known	1	4.928	4.928	4.928	0.000	NA
HSS	Sulphuric	Not Known	56	1.266	3.728	-0.283	4.011	0.777
HVS	Venebles	Not Known	1	14.883	14.883	14.883	0.000	NA
HWF	West Finnis	Wibma-malkara	122	2.114	4.112	0.548	3.564	0.585

This spring complex is within the impact zone of Wellfield A, operated by BHP Billiton to provide water for the Olympic Dam Mine. Extraction of water from Wellfield A has resulted in the extinction of several spring groups in the area, including Venebles in this complex (Fatchen & Fatchen 1993). In the past, reinjection of water around the Hermit Hill and Lake Eyre South complexes has been attempted to mitigate the impacts of drawdown on the springs (Kinhill Engineers 1997; Mudd 2000).

The total extent of the wetlands within the 12 spring groups, determined from the NDVI applied to HyMap imagery captured in March 2009, was 34.94 ha (Figure 3.23, Table 3.6). A regression analysis between on-ground estimates of vegetation cover and image NDVI was used to establish an appropriate threshold above which NDVI values were considered to be indicative of wetland vegetation (Appendix 2).

Table 3.6: Area of wetlands for spring groups in Hermit Hill Spring Complex (March 2009)

Spring group	Spring wetland area (ha)
Beatrice	0.19
Bopeechee	3.83
Bopeechee Mound	0.12
Bopeechee North	0.23
Dead Boy	0.13
Finniss Well	0.23
Hermit Hill	12.93
North West	2.46
Old Finniss	6.2
Old Woman	1.57
Sulphuric	1.31
West Finniss	5.74

Two large spring groups within the Hermit Hill Spring Complex, West Finniss and Hermit Hill, are highlighted to illustrate the capabilities of the HyMap imagery to map a range of spring features (Figure 3.24). West Finniss is located to the west of Hermit Hill and has relatively low lying and flat terrain. The wetland vegetation forms an almost circular formation, with large, well defined springs on the north-east and north-west fringes of the group. Other springs within the West Finniss Spring Group are largely interconnected smaller springs with less well defined surface expression. The Hermit Hill group is located in the north of the complex, forming an elongated arc between the base of the outcropping Hermit Hill and the intermittent river bed. The group consists of large expanses of spring wetland vegetation fringing an extensive groundwater and runoff-fed flow channel. Smaller clusters of interconnected springs are nestled at the base of the outcropping hill and are more likely to be fed from its runoff rather than groundwater (Figure 3.25).

Mixture tuned matched filtering analysis was applied to the hyperspectral imagery to discriminate and map dominant species and communities for all spring groups (Appendix 2 includes details of methods). The resultant mapping was verified by botanical survey data, field observations, RTK DGPS spring vent data, and interpretation of digital aerial photography with a 30 cm resolution.

The two focal spring groups, West Finniss and Hermit Hill, both exhibit considerable floristic diversity at the spring group scale (Table 3.7, Figure 3.26).

Spring group and vegetation type	Vegetation area (ha)
West Finniss	5.74
<i>Phragmites australis</i>	1.34
<i>Cyperus laevigatus</i> and <i>Fimbristylis</i> sp.	0.41
<i>Sporobolus virginicus</i>	0.19
<i>Frankenia</i> sp.	0.66
Hermit Hill	12.93
<i>Phragmites australis</i>	1.11
<i>Cyperus laevigatus</i>	2.4
<i>Baumea juncea</i>	0.53
<i>Gahnia trifida</i>	1.25

The West Finniss Group is characterised by dense homogenous stands of *Phragmites australis*, mainly confined to or surrounding spring vents, with sparser patches to the north-east, covering a total area of 1.34 ha. The Hermit Hill Group is also characterised by similarly dense stands of reeds, restricted to larger spring vents of the northern portion of the spring group and a few smaller springs in proximity to the outcropping hill, covering a total area of 1.11 ha.

Bore Drain Sedge (*Cyperus laevigatus*), another dominant vegetation type successfully mapped at the West Finniss group, is predominant along spring tails, often occurring in proximity to defined spring flow channels, covering a total area of 0.41 ha. The species dominates the extensive tails of the two well-defined springs on the north-east and western fringes of the spring group. In the Hermit Hill group *Cyperus laevigatus* traverses the interconnected spring tails to the south-east of the more northern springs in this group, which also have the sedge present along their flow channels.

Baumea juncea and *Gahnia trifida*, two additional wetland species which are prevalent at the Hermit Hill springs, were also mapped. Both vegetation types are restricted to the smaller clusters of springs located at the flanks of the outcropping hill (Figure 3.26). Total areas covered for *Baumea juncea* and *Gahnia trifida* are 0.53 ha and 1.25 ha, respectively. Although the mapping of these two vegetation types was verified with recordings from field botanical survey plots and field observations, it should be interpreted with caution because of the dispersed and limited size of the stands and their sparse cover.

Sea Couch (*Sporobolus virginicus*) and Sea Heath (*Frankenia* sp.), more characteristic of saline diffuse discharge areas surrounding spring-fed wetlands, had dispersed distributions throughout the West Finniss Group (Table 3.7, Figure 3.26). *Frankenia* sp., which occurs in low open hummocky formations, is confined to locations further away from the spring vents and flow channels where conditions are a little dryer. *Frankenia* at West Finniss is present in



Photo: Megan M Lewis

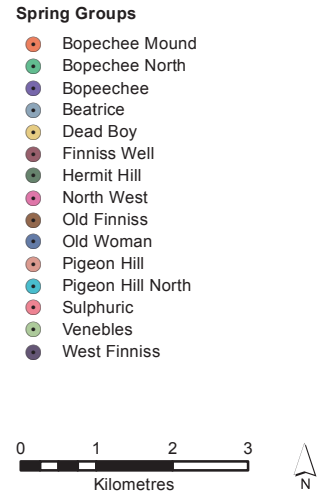
dispersed, sporadic patches on the southern and north-west fringes of springs, in the vicinity of perennial vegetation. *Sporobolus virginicus* is mainly present on the dryer fringes of spring tails, predominantly along the south-western fringes of the West Finniss Group.

The areas of near-surface moisture for the entire Hermit Hill Springs Complex and two focal groups, West Finniss and Hermit Hill, are extensive, as identified by the NDSMI applied to HyMap imagery (Figure 3.27 and Appendix 2). At West Finniss, this zone encompasses the spring flows and wetland vegetation, being most prevalent to the north-east and north-west. A more restricted spatial distribution of near-

surface moisture is evident in the Hermit Hill Group, where wetted areas underlie and extend somewhat beyond the spring vegetation (Figure 3.27).

Surrounding these wetted areas of high soil moisture, more extensive areas of salinisation and evaporite crust are evident at both spring groups (Figure 3.27). These zones of diffuse discharge can extend tens of metres from the spring fringes, and are most extensive at West Finniss. In the Hermit Hill Group areas of surface salinisation are less extensive, possibly because of the influence of surface runoff from the elevated ground of Hermit Hill immediately to the south and occasional flushing by the westerly flowing Hermit Creek.

Figure 3.22: Surveyed springs and spring groups in Hermit Hill Spring Complex



Background image: Landsat, True Colour, 2006.
 Produced by The University of Adelaide - School of Earth & Environmental Sciences
 Map Projection: UTM Transverse Mercator
 Map Datum: Geocentric Datum of Australia 1994
 Date: January 2012

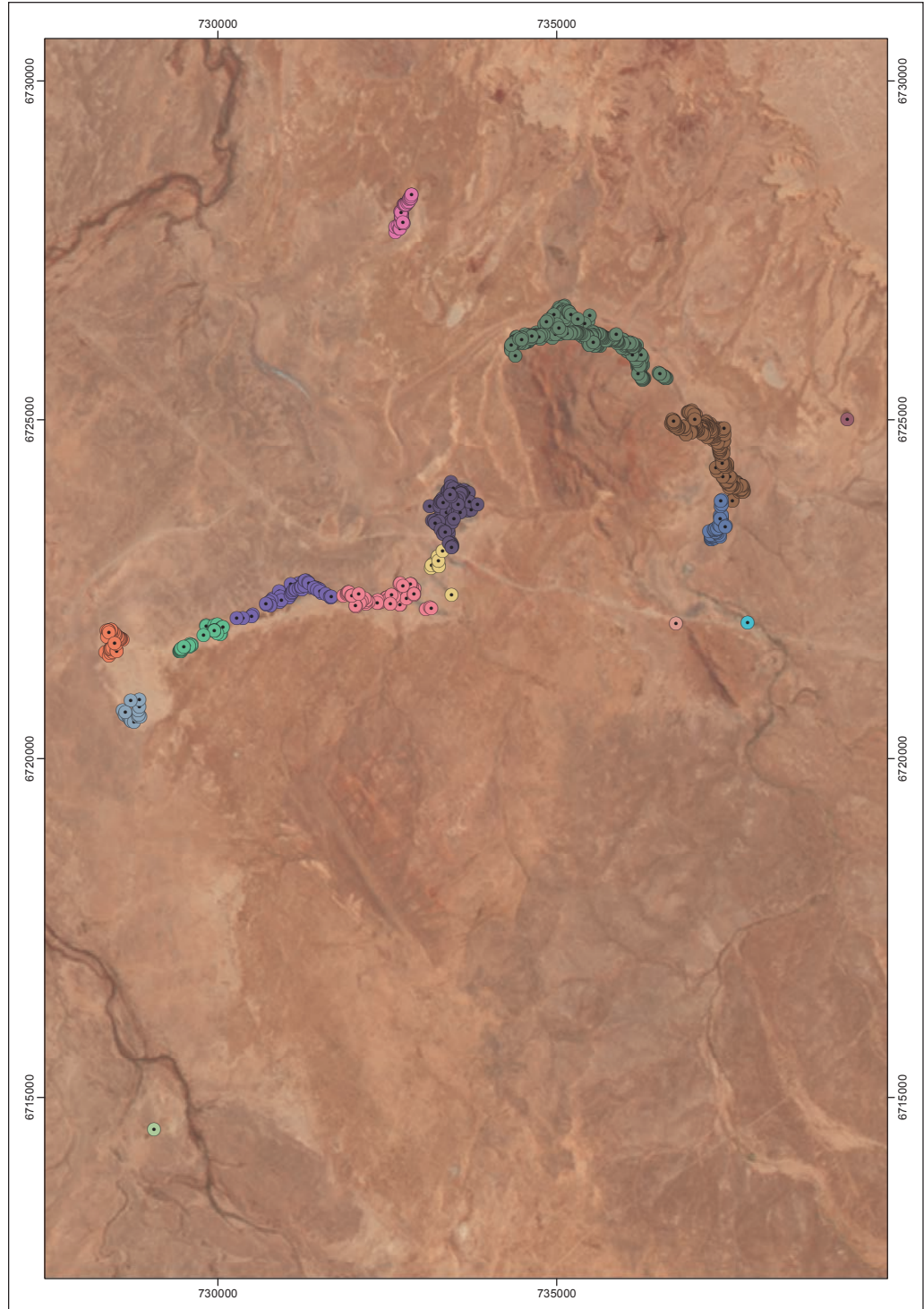
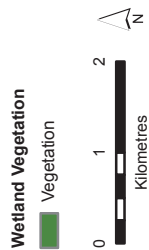


Figure 3.23: Distribution of wetland vegetation at Hermit Hill Springs Complex, from NDVI analysis of HyMap airborne hyperspectral imagery (March 2009)



Produced by The University of Adelaide - School of Earth & Environmental Sciences
 Map Projection: UTM Transverse Mercator
 Map Datum: Geocentric Datum of Australia 1994
 Date: January 2012

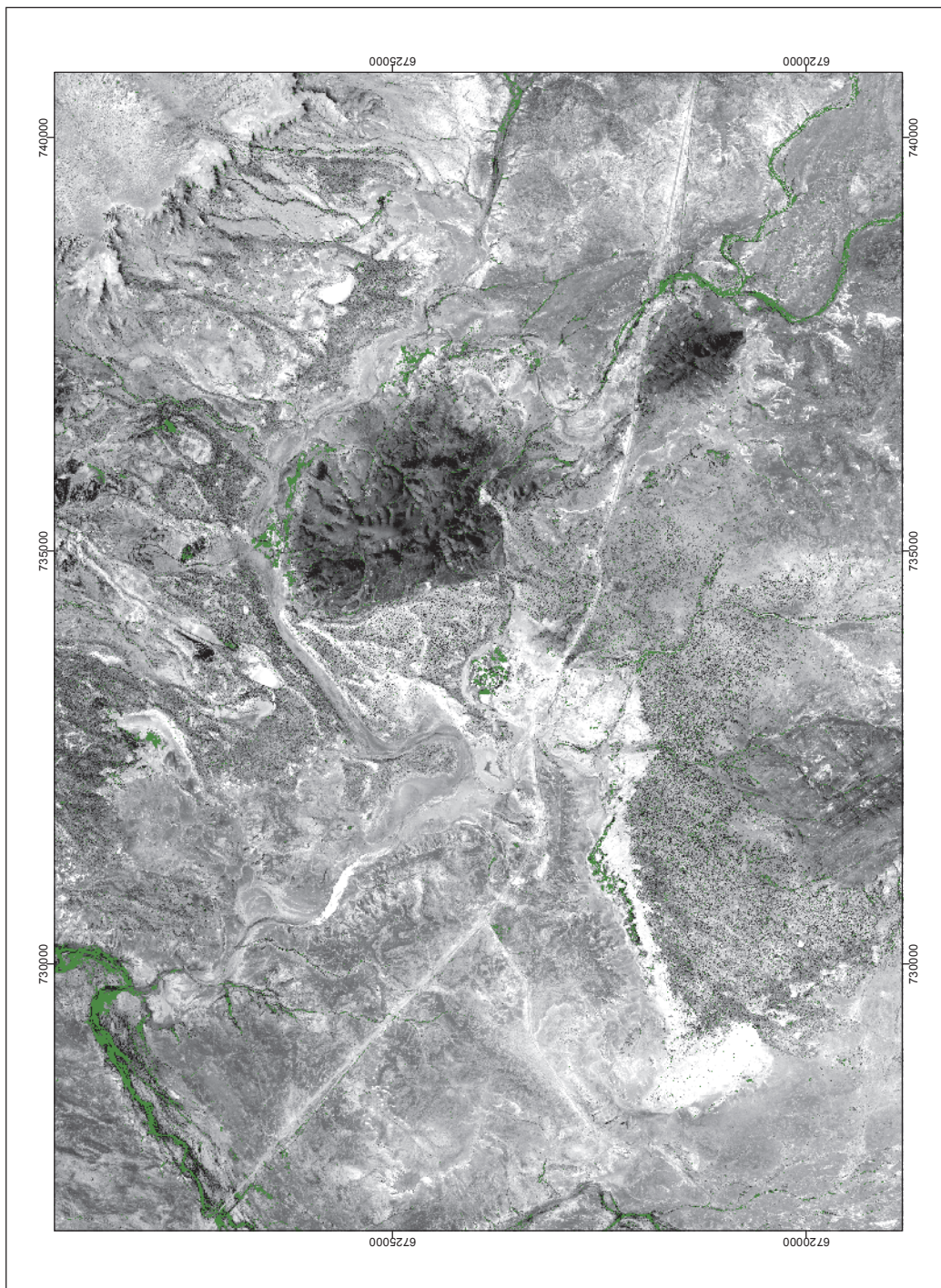
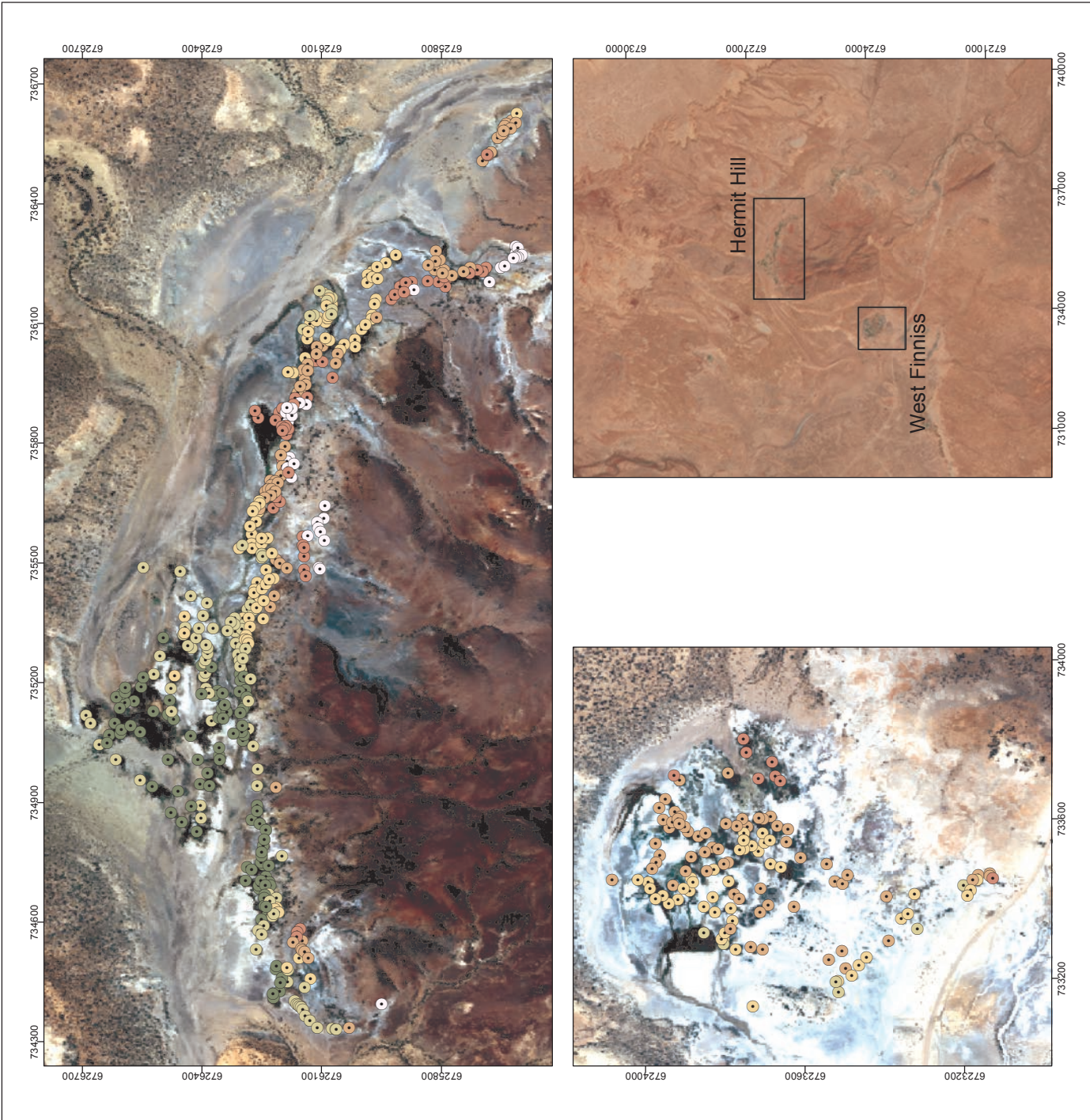
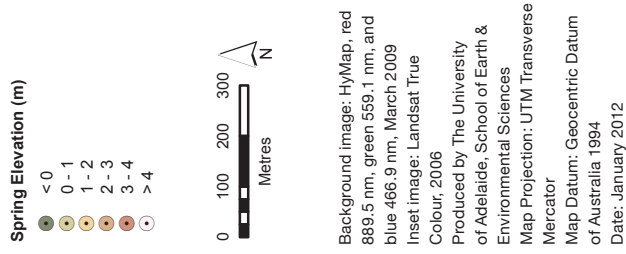


Figure 3.24: Distribution of surveyed spring vents in Hermit Hill and West Finniss spring groups



Allocating Water and Maintaining Springs in the Great Artesian Basin

Figure 3.25: Distribution of wetland vegetation in Hermit Hill and West Finniss spring groups of Hermit Hill Springs Complex, from NDVI analysis of HyMap airborne hyperspectral imagery (March 2009)

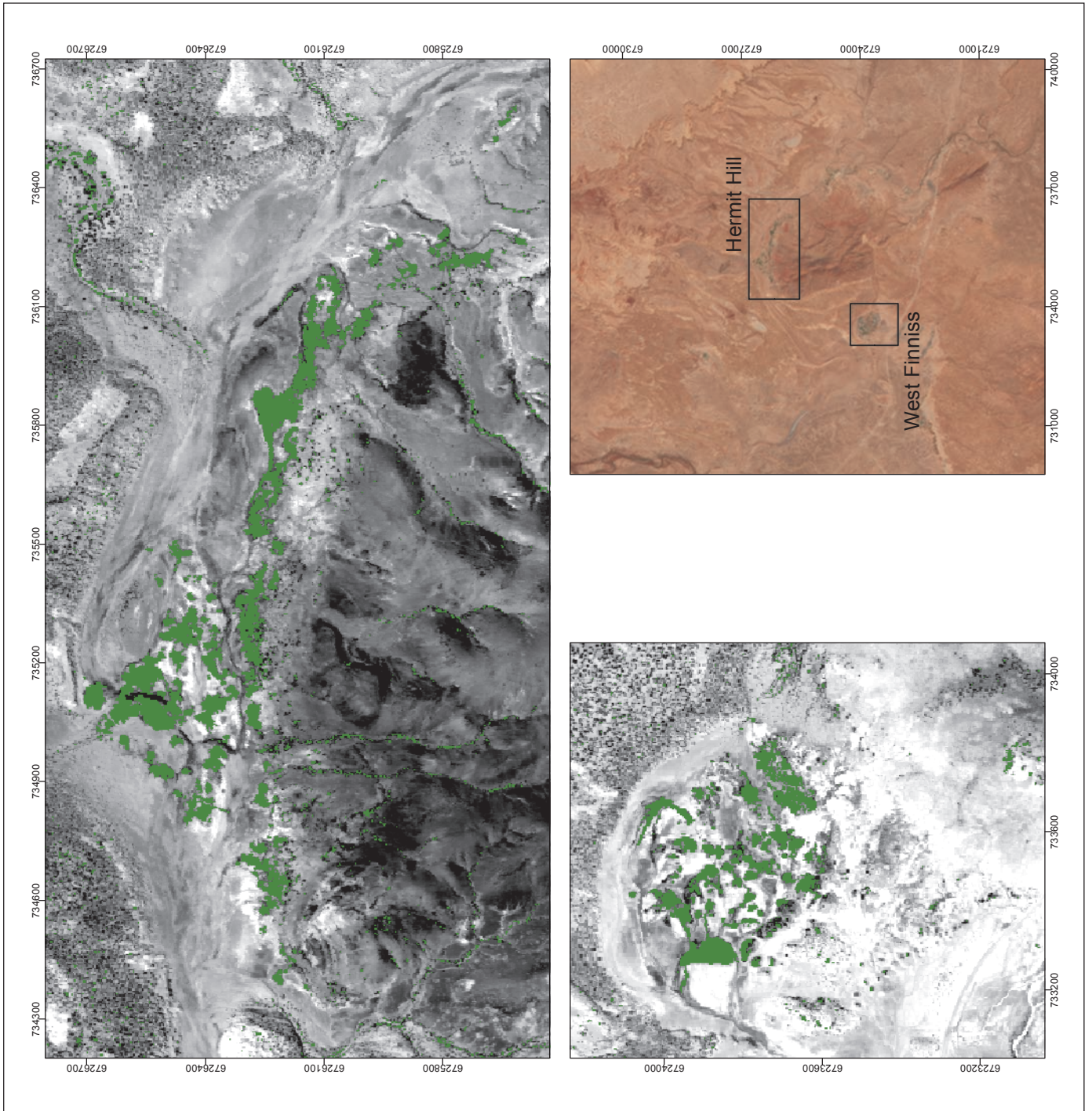
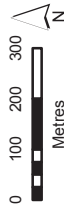


Figure 3.26: Distribution of wetland vegetation types, from spectral analysis of HyMap airborne hyperspectral imagery (March 2009)

- Vegetation
- Baumea juncea*
 - Phragmites australis*
 - Gahnia trifida*
 - Cyperus laevigatus*
 - Sporobolus virginicus*
 - Frankenia*
 - Cyperus laevigatus and Fimbristylis*



Background images: HyMap, 665.7 nm, March 2009
 Inset image: Landsat True Colour, 2006
 Produced by The University of Adelaide, School of Earth & Environmental Sciences
 Map Projection: UTM Transverse Mercator
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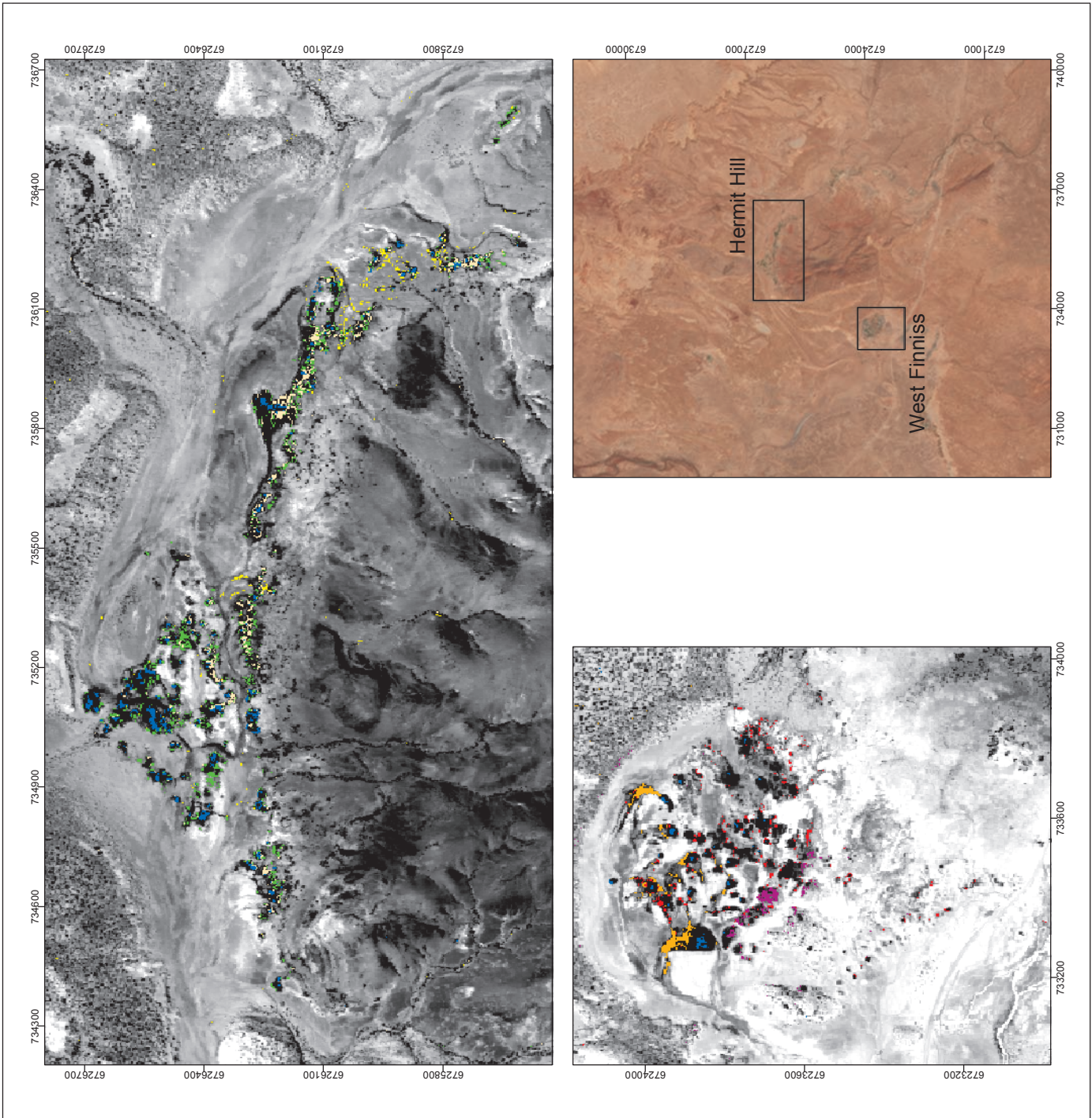
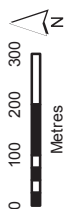
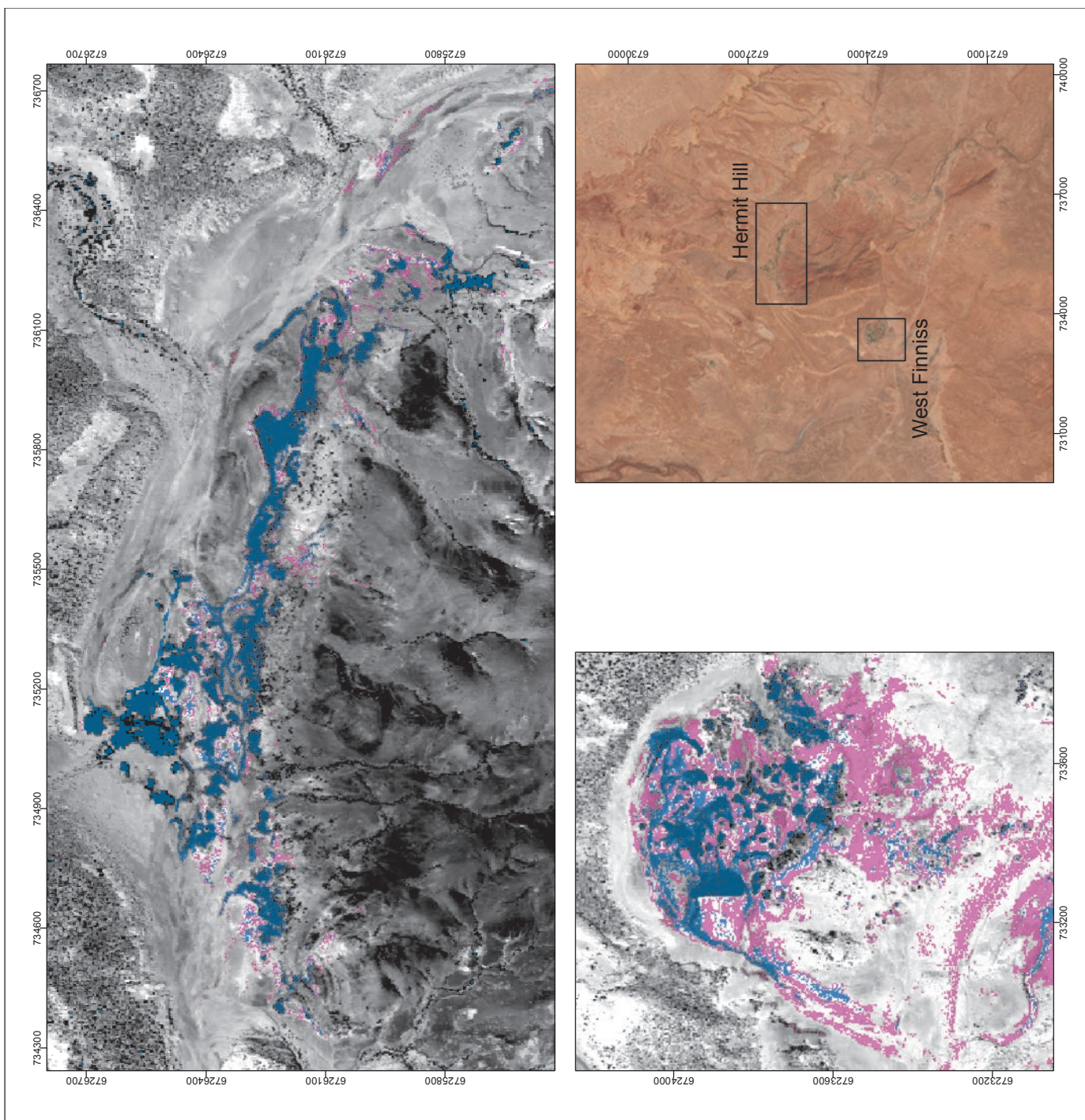


Figure 3.27: Distribution of wetted area and salinisation, from spectral analysis of HyMap airborne hyperspectral imagery (March 2009)

Surface Moisture
 Diffuse Discharge
 Near Surface Moisture



Background images: HyMap, 665.7 nm, April 2011.
 Inset image: Landsat True Colour, 2006
 Produced by The University of Adelaide, School of Earth & Environmental Sciences
 Map Projection: UTM Transverse Mercator
 Map Datum: Geocentric Datum of Australia 1994
 Date: January 2012





3.8. Conclusions

A new, comprehensive set of records has been acquired on the number, distribution and status of western margin GAB springs from a highly accurate RTK DGPS survey. This data provides a wealth of previously unknown information about the number of springs; there are 4516 springs in the region, many more than the 900 originally estimated. The survey precisely recorded the locations of the springs and clearly demonstrates the wide range of spring formations, flow status and associated landscape settings. Each spring complex has a distinctive and unique character. For example, the spatial concentration of springs varies enormously between complexes; Hermit Hill Complex has 1144 spring vents distributed in groups dispersed over a small area, contrasting with the far fewer 145 vents with high volumes of flow over an extensive area at Dalhousie Springs Complex.

In addition, the flow status of GAB springs has been recorded in detail, providing valuable information on the presence of active and extinct springs. Coupled with the detailed and highly accurate positional and height data, this provides new insights into the evolution and vulnerability of springs, primarily to anthropogenic groundwater extractions.

Hyperspectral imagery has revealed wide-ranging characteristics of four distinctly different spring complexes. Of particular note is the floristic diversity and variability in spring vegetation composition, as well as differences in the geomorphic setting and terrain between the spring complexes.

Dalhousie Springs Complex has very extensive wetlands (over 1000 ha) radiating out from springs concentrated over the fractures and dome of the Dalhousie Anticline, surrounded by considerable areas of high soil moisture and diffuse discharge. White Tea Tree (*Melaleuca glometata*) occurs only in this spring complex, forming dense low forests near the head of major springs, while extensive reedbeds of *Phragmites australis* traverse the plains, extending up to 10 km from vents.

Francis Swamp Springs Complex presents a marked contrast, with limited numbers of free-flowing springs and wetlands, surrounded by over 3500 ha of surface evaporite crust, indicative of diffuse groundwater discharge. There are geographic zones with many extinct springs within the complex, accompanied by evidence of extensive near-surface moisture, suggesting stages in the evolution and decline of the complex.



Photo: Megan M Lewis

Freeling Springs in the Mt Denison Spring Complex is characterised predominantly by springs and seeps emerging near the base of the Denison Range, forming extensive carbonate terraces, mounds and pools, and one large spring that maintains the permanent *Inthunintjunha* waterhole. The springs vary in size, with the more extensive forming braided wetlands dominated by *Phragmites australis*. The wetlands are floristically diverse, with composition varying from other complexes, including species not recorded at other sites, for example *Cyperus gymnocaulos*. The springs are in close proximity to Peake Creek and other intermittently-flowing watercourses, with potential for interchange of fish and aquatic species.

Hermit Hill Complex comprises a large number of springs clustered in a chain of groups centred around Hermit Hill. The spring groups are varied in surface expression and wetland vegetation types, ranging from interconnected and braided wetlands within saline flats to isolated and more clearly demarcated springs fringing the Hermit Hill outcrop.

Although these spring complexes and groups each have distinctive character, hyperspectral analysis reveals that there are some constants

across most of the spring environments. Zones of high surface moisture (the wetted area) and diffuse discharge are present at all springs, extending beyond the vegetated spring-fed wetlands. The wetted area generally occurs closest to spring discharge zones and surrounding saturated substrate, while the diffuse discharge usually surrounds this with lower levels of soil moisture and saline surface expressions. The extent of these zones varies considerably between springs, and is most extensive at Francis Swamp Spring Complex.

Phragmites australis is present across all spring groups, although its abundance varies from site to site. Where present, it is always in proximity to spring vents and on out-flowing tails. Groundwater-fed spring vegetation is extensive at nearly all sites, with the exception of Francis Swamp, although its composition and extent varies within complexes and groups.

A range of advanced remote sensing analyses, both multispectral and hyperspectral, in the form of waveband indices and spectral filtering and matching, has revealed rich new baseline information such as vegetation extent, distribution and composition, as well as associated saline surface expressions and surrounding geomorphic landscape setting.

Temporal dynamics of spring complexes

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4. Temporal dynamics of spring complexes

4.1. Introduction

Chapter 3 documents the spatial extent, surface characteristics and diversity of selected representative spring groups and complexes, drawing on new analyses and interpretations of remote sensing and spatial information. However, Great Artesian Basin (GAB) spring-fed wetlands and associated environments are not static, and it is important to understand how they vary in space and time to provide robust baselines against which future changes can be assessed. While hydrological monitoring provides information about historic variations in artesian flow at selected springs, information about how wetland extent, species composition and seasonal development change over time is lacking.

Addressing this gap in understanding of spring dynamics, this chapter documents changes in wetlands and groundwater discharge within and between years, drawing on time-series and comparisons of remotely sensed imagery.

Specific objectives are to:

- characterise the seasonal phenology and variability of spring vegetation types, compare them with surrounding dryland and ephemeral riverine ecosystems and relate them to climatic influences
- document variation and trends in the wetland vegetation area of selected large spring complexes over as long a period as possible
- provide spatially detailed quantification of changes in the extent and distribution of perennial wetland associated with the springs and to relate these to climatic, spring flow and ecological processes
- compare surface characteristics of selected springs for two recent periods, March 2009 and May 2011, to better understand spatial variations in vegetation and diffuse discharge in response to changing environmental conditions.

4.2. Seasonal variability of wetland vegetation

The study of seasonal phenology, intra- and inter-annual variability utilised Moderate Resolution Imaging Spectroradiometer (MODIS) Normalised Difference Vegetation Index (NDVI) satellite image data, which are freely available at high temporal frequency. The study of vegetation phenology focused on the dominant wetland and surrounding vegetation types at Dalhousie Springs Complex and aimed to:

- determine if photosynthetic activity in the wetland vegetation can be discriminated from surrounding land with this medium resolution imagery
- characterise the intra- and inter-annual growth responses of the dominant wetland vegetation types and relate them to climatic influences.

These studies have been published as Petus *et al.* (2012a, b) and further details of the data and methods are provided in Appendix 2.

4.2.1. Vegetation phenology

Areas representative of the dominant vegetation types at Dalhousie Springs were geographically located with reference to air photos, field observation and site-specific knowledge. The nearest corresponding MODIS pixels were selected and NDVI time-traces produced for these locations. The MODIS imagery extended from July 2002 to May 2010 in 16-day NDVI composites, and provided 180 records for each sample location. Insofar as possible, each MODIS pixel represented a single relatively homogeneous vegetation type. Wetland vegetation types sampled were White Tea Tree (*Melaleuca glomerata*), Common Reed (*Phragmites australis*) and ephemeral sedgeland of the spring tails, while surrounding landscape samples included areas of saline diffuse discharge, arid shrublands of the uplands and ephemeral river courses.

Overall, spring vegetation photosynthetic activity traces are clearly differentiated from the surrounding arid and saline land responses by higher average and total levels of greenness. The wetland vegetation, *Phragmites* and sedgeland in particular, show gradual and periodic variations in greenness which contrasts with the irregular and abrupt increases of the upland and riverine ecosystems (Figure 4.1).

Saline, arid shrubland and riverine sites

The saline diffuse discharge areas, some with very sparse halophytic shrubs, are characterised by very low levels of greenness, with no discernible variation within and between years. By comparison, the dryland and riverine vegetation communities show higher baseline levels of greenness, with irregular, rapid increases, followed by slower decline in greenness levels (Figure 4.1). The timing of these pulses in greenness is similar for both ecosystems, and generally follows regional rainfall events (Figure 4.2); rains lead to rapid growth of ephemeral plants in the uplands, while the river bed and bank vegetation responds to rain and stream flows. The higher level of NDVI response in the riverine ecosystems reflects the denser perennial and ephemeral vegetation that is supported. In the upland and riverine communities, after most substantial rainfall events, NDVI is strongly correlated with rainfall totals in the preceding seven days (correlation coefficients of 67% for uplands and 72% for riverine vegetation). Increases observed in greenness time-traces in 2004 and 2005 are likely to be in response to localised rainfall near Dalhousie Springs Complex that was not recorded at Hamilton Station, which is 80 km to the west.

Spring-fed wetland sites

By contrast with the surrounding land, the majority of the wetland vegetation communities of Dalhousie Springs Complex are characterised by high periodicities in vegetation greenness.

Phragmites australis sites show high average, minimum and maximum NDVI, a result of the dense perennial reedbeds with high plant cover and biomass. They have regular periodic variations of greening and senescence, with strong periodicities around six and 12 months; maximum greenness occurs between October and May, with a sharp decline in NDVI as the plants dry off after May, to a minimum of photosynthetic activity in July. This seasonal

phenological cycle varies little between years, as illustrated by the multi-year time-trace examples in Figure 4.1. This relatively regular annual cycle of *Phragmites* phenological development is controlled mainly by temperature, with development of new shoots and flower heads in the warmest months of the year, seeding in April to June, and senescence in the coolest winter months; 67% of the variance in mean NDVI is explained by monthly mean temperatures, with rainfall having a much smaller influence.

A. Spring-fed vegetation: Common Reeds, White Tea Tree and ephemeral sedgeland

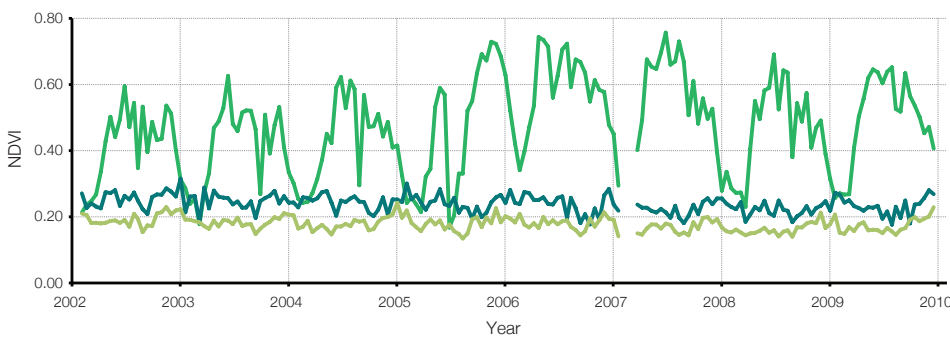
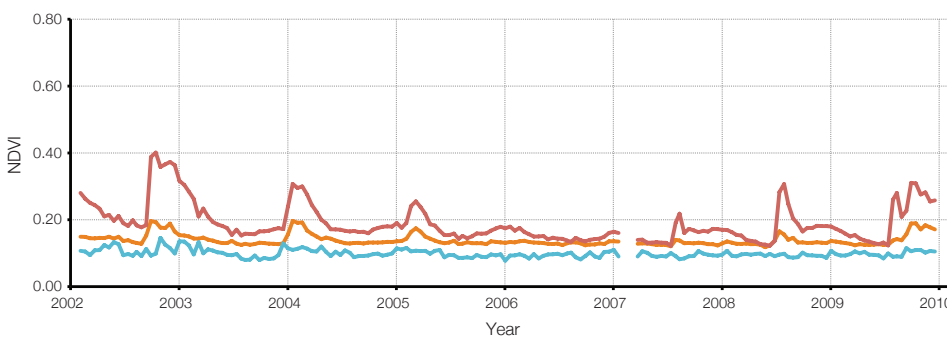


Figure 4.1: NDVI greenness profiles for Dalhousie Springs Complex (2002–2010) derived from MODIS satellite imagery

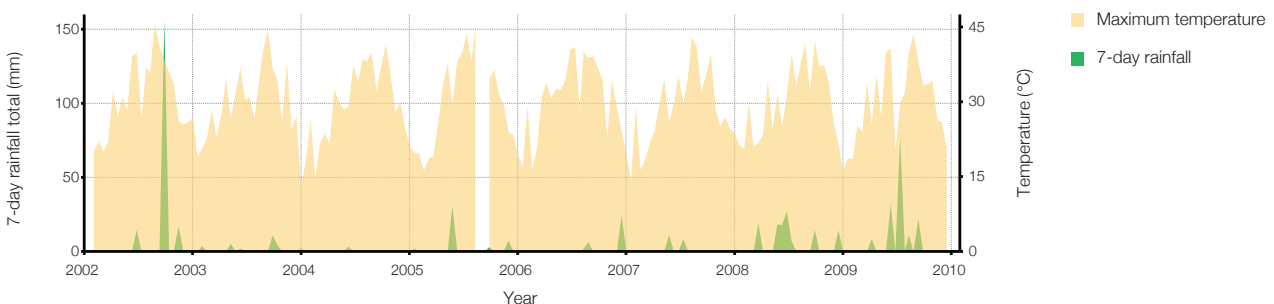
— Common Reeds
— White Tea Tree
— Ephemeral sedgeland

B. Arid shrubland, saline and riverine sites



— Dryland
— Saline
— Riverine

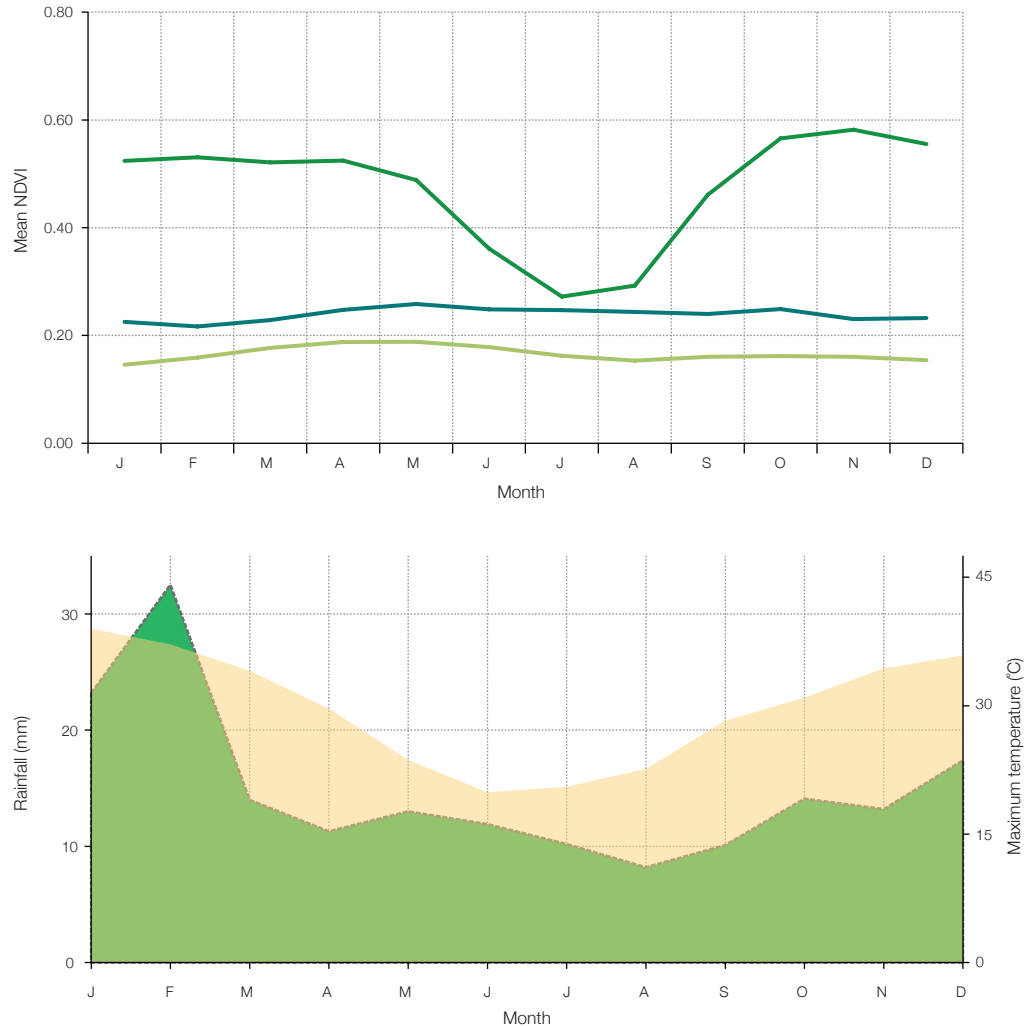
C. Cumulative rainfalls measured at Hamilton Station seven days before the satellite acquisition and maximum temperature at Oodnadatta



— Maximum temperature
— 7-day rainfall

Figure 4.2: Phenologies of Common Reeds, White Tea Tree and ephemeral sedgeland derived from MODIS satellite imagery in relation to mean monthly rainfall and maximum temperature at Oodnadatta Airport meteorological station

- Common Reeds
- Ephemeral sedgeland
- White Tea Tree
- Mean rainfall
- Mean maximum temperature



The ephemeral sedgeland are characterised by much lower levels of greenness, with little variation within and between years. Like *Phragmites*, there are fluctuations at six- and twelve-monthly intervals (Figure 4.1), although the range of variation is much lower. The growing season is between March and July, with a decline to lower levels of greenness from August to January. The mean NDVI values are negatively correlated with temperature and rainfall, with 44% of the variance in NDVI explained by temperature (Figure 4.2).

Finally, the dense canopies of the evergreen White Tea Trees are characterised by intermediate NDVI values, with little variation

within and between years. Although these trees are reported to flower sporadically in summer (Cunningham *et al.* 1981), there is little evidence of variations in photosynthetic activity or canopy cover throughout the year.

4.2.2. Conclusions

The relatively coarse ground resolution of the MODIS NDVI imagery, at approximately 6.25 ha, required careful selection of homogenous sample sites representative of the Dalhousie Springs Complex vegetation types. However, the resulting patterns that have emerged from the NDVI time-traces demonstrate that this form of remote sensing is suitable for characterising the seasonal and longer term growth patterns of the

dominant wetland vegetation types at Dalhousie Springs Complex. The wetlands have distinctive levels and cycles of greening and drying that clearly distinguish them from surrounding rain-fed arid, riverine and halophytic vegetation communities.

It appears that seasonal greening of the Dalhousie Springs Complex spring-fed vegetation is strongly related to climatic influences. *Phragmites australis* phenology is controlled by mean monthly temperature and rainfall and is characterised by the higher NDVI values recorded. Conversely, temperature increase during the summer appears to restrict the growth of the ephemeral sedgeland. White Tea Trees are evergreen and show little intra-annual variability in greenness. By contrast, vegetation growth in riverine and upland ecosystems appears to be controlled by sporadic rainfall events and is characterised by sharp NDVI increases after rainfall. Saline substrates with little or no halophytic vegetation had negligible NDVI response.

4.3. Long-term dynamics of wetland vegetation area

A further aim of the study was to investigate the spatial and temporal dynamics of selected spring complexes over as long a period as possible. Objective information about longer term variation and trends in the vegetated wetland area will help design monitoring programs and interpretation of future changes to spring environments. This study focused on trends in wetlands at Dalhousie and Hermit Hill Springs complexes.

4.3.1 Methods

MODIS imagery from February 2000 to May 2011 was used in the form of NDVI 16-day composites. Two approaches were used to monitor changes in the wetland vegetation; time-series of average NDVI within defined areas encompassing the wetlands (Dalhousie and Hermit Hill) and time-series of the area

over a threshold value of NDVI (Dalhousie). This threshold was chosen to delineate wetland vegetation from the surrounding arid landscape and was determined by the study of the dominant vegetation species at Dalhousie Springs Complex (Section 3.4). The resulting time-series of NDVI are indicative of variations in total photosynthetic activity within the defined wetland areas ($\text{Mean}_{\text{NDVI}}$), and in extent of the wetlands ($\text{Area}_{\text{NDVI}}$). To understand climatic influences on the wetland vegetation response, the NDVI time-traces were related to monthly rainfall totals recorded at the nearest meteorological stations: Hamilton Station for Dalhousie and Marree for Hermit Hill.

Parts of these studies have been published as Petus *et al.* (2012a, b) and further details of the data and methods are provided in Appendix 2.

4.3.2. Dalhousie Spring Complex

The area of photosynthetically active wetland vegetation at Dalhousie Spring Complex is highly dynamic within and between years; annual pulses of expansion and contraction of wetland area occur, although they vary considerably in magnitude over the eleven year period (Figure 4.3). Wetland area was greatest in 2000, followed by notable maxima in March 2001 and March 2002, then a marked decline to a minimum in July and August 2008, with slight increases evident in 2010. There is a close relationship between the trends in wetland area and average rainfall in the preceding six months. Extended wetland areas recorded before 2002 were the response to very high rainfalls in 2000 and 2002, whereas the minimum vegetation extent observed in 2008 is clearly linked to dry climatic conditions recorded that year (370 mm 6-monthly cumulative rain in 2000 versus 129 mm in 2008).

The intra-annual patterns of the NDVI were related to the phenology of the different wetland vegetation types using multiple correlations. At the monthly scale, the mean pattern of $Area_{NDVI}$ is clearly explained by the phenology of the two most widespread and dynamic wetland vegetation types in the Dalhousie Springs Complex, the *Phragmites australis* reeds and ephemeral sedgeland. The mean monthly $Area_{NDVI}$ index was strongly correlated to mean monthly NDVI values for MODIS pixel samples representative of these two vegetation types (multiple correlation coefficient of 0.81). The simulated $Area_{NDVI}$ reconstructed from the multiple regression equation and the measured values are highly consistent (Figure 4.3), with the coefficients of regression indicating a higher weighting for the ephemeral vegetation relative to the *Phragmites*. The contribution of these two wetland types is consistent with their relative areas within the wetland communities at Dalhousie Springs Complex.

The extent of wetland vegetation for the whole Dalhousie Springs Complex is characterised by an initial notable increase around May and a smaller increase in October/November, representative of the ephemeral sedge and *Phragmites* phenologies (Figure 4.3). Inclusion of the mean monthly NDVI values from a site representative of White Tea Tree did not particularly strengthen the relationships between vegetation phenologies and the wetland area response because the species varies very little in seasonal greenness and occupies a relatively minor proportion of total wetland area at Dalhousie Springs Complex.

4.3.3. Hermit Hill Spring Complex

Because the spring groups comprising Hermit Hill Spring Complex are geographically dispersed and much of the intervening landscape is well vegetated, it was not possible to monitor changes in wetland area using the NDVI threshold approach. Instead, intra- and inter-annual variations in wetland plant growth and area are represented by time-series of $Mean_{NDVI}$. Areas encompassing the largest spring groups were combined to examine overall vegetation response for Hermit Hill Complex using MODIS Aqua NDVI from July 2002 to June 2011 (Figure 4.4).

There are annual pulses of plant growth, peaking in April to June, although the magnitude and duration of greening varies between years. Minima in $Mean_{NDVI}$ corresponding to senescence and die-back of *Phragmites* and sedges, tend to occur in August, but in some years are delayed until mid-summer, or do not occur at all. Between 2002 and 2011, the trend in wetland development was relatively stable, with some decline from 2007 to 2009, but very marked increases to record highs in 2010 and 2011. Rainfall clearly has a strong influence on the growth of the wetland plants; the trend in mean NDVI closely follows mean rainfall for the preceding six months and the major increases in 2010 and 2011 have been in response to extremely high total rainfalls in those years (Figure 4.4).

A. Time-series wetland area ($Area_{NDVI}$)

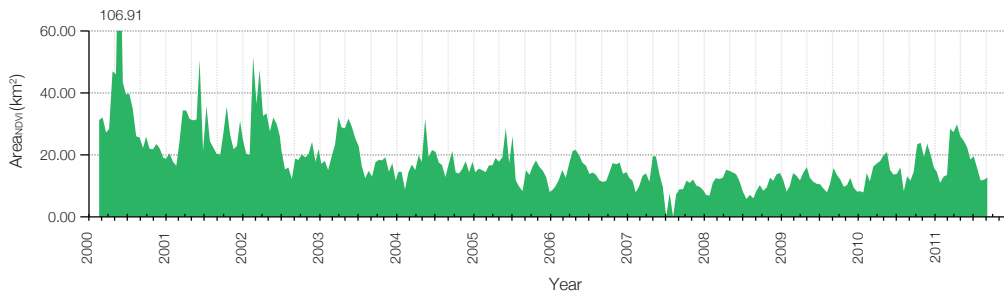
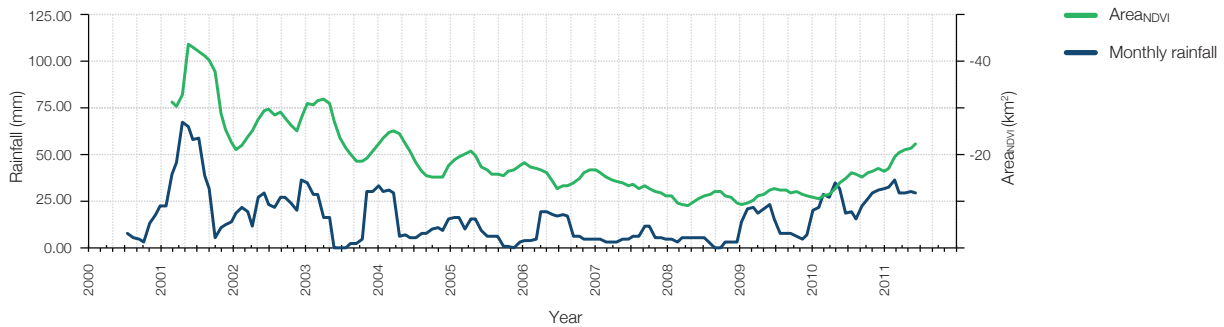


Figure 4.3: Trends in wetland vegetation area for Dalhousie Springs Complex (2000–2011) derived from MODIS satellite imagery

■ $Area_{NDVI}$

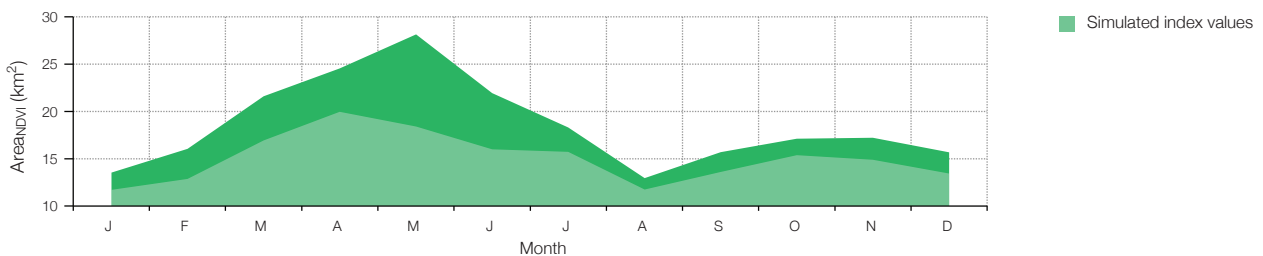
B. Six-monthly moving average trendlines for $Area_{NDVI}$ and monthly rainfall recorded at Hamilton Station



— $Area_{NDVI}$

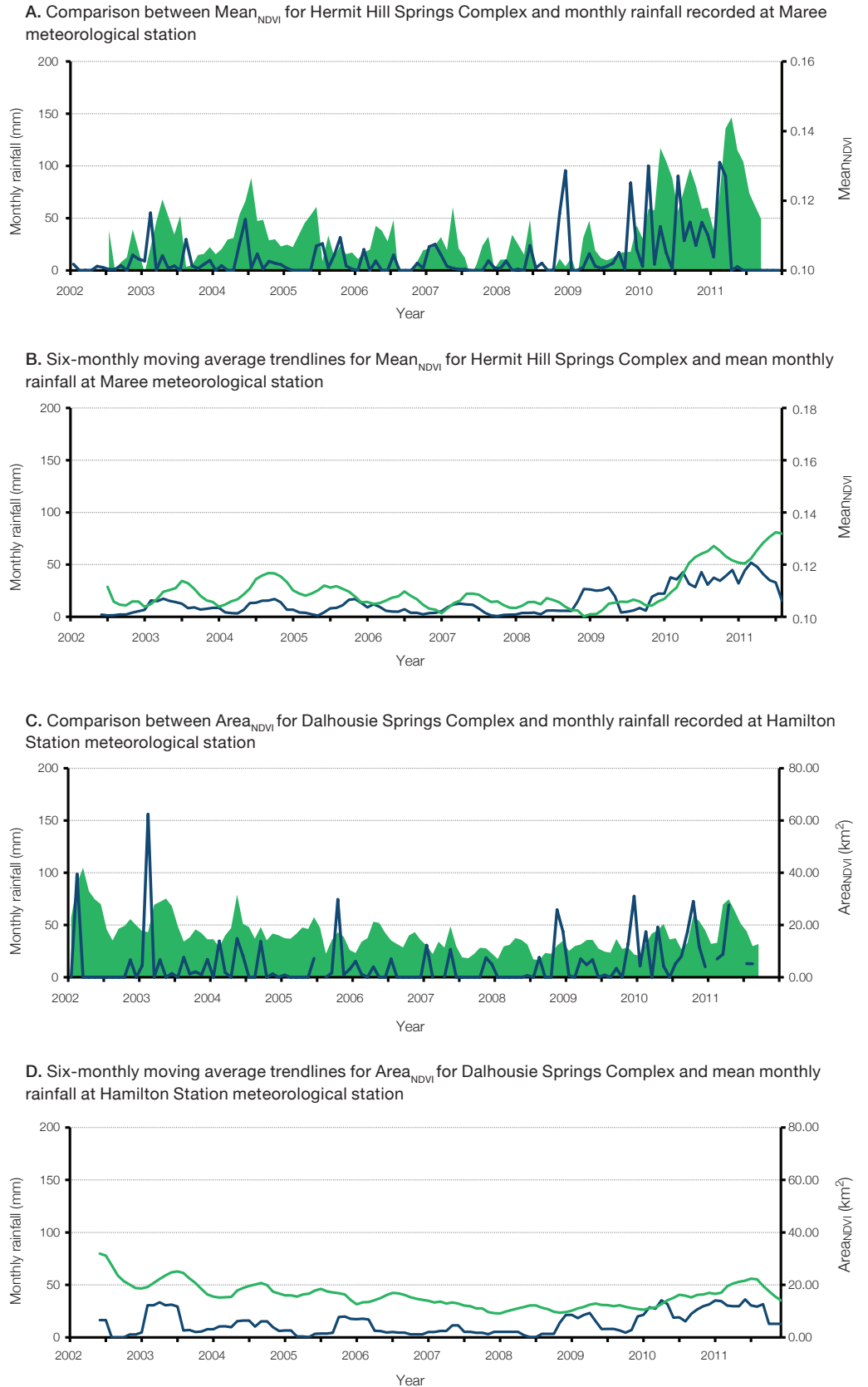
— Monthly rainfall

C. Comparison of mean monthly observed $Area_{NDVI}$ and simulated index values reconstructed from multiple correlations



■ Simulated index values

Figure 4.4: Comparisons of monthly rainfall with Mean_{NDVI} and Area_{NDVI} derived from MODIS satellite imagery



4.3.4. Conclusions

The MODIS NDVI time-series, analysed as $Mean_{NDVI}$ or $Area_{NDVI}$, was able to quantify the intra- and inter-annual variability of wetland vegetation at two large spring complexes in the GAB. Seasonal fluctuations occur and are largely driven by the phenology of the dominant vegetation species within the wetlands. Underlying this short-term fluctuation, decade-long trends in wetland area and development are strongly influenced by total rainfall in the preceding six months to one year. At Dalhousie, wetland area was greatest between 2000 and 2003 and declined markedly over the following years until 2009. Increases in wetland area in 2010 and 2011 have occurred in response to high rainfalls in those years. At Hermit Hill, development of the wetlands remained relatively constant from 2002 to 2009 and increased markedly in 2010 and 2011, also in response to high rainfalls in those years.

4.4. Changes in distribution of wetlands: Dalhousie Spring Complex

The aims of this section were to:

- provide detailed delineation of the extent and distribution of perennial wetlands associated with the springs using very high-resolution satellite imagery
- discriminate perennial from ephemeral wetlands and surrounding dryland vegetation
- quantify changes in the wetlands over time, relating to climatic, spring flow and ecological processes.

The study focused on the Dalhousie Springs Complex. Details of this study have been published by White and Lewis (2011).

4.4.1. Methods

Three epochs of QuickBird very high spatial resolution multispectral satellite imagery (Table A2.1, Appendix 2) were acquired to explore the spatial and temporal dynamics of Dalhousie Springs Complex wetland vegetation: December 2006, May 2009 and May/June 2010. The very

high spatial resolution of this imagery enabled precise delineation of the extent and nature of change in wetland vegetation. The study periods were chosen to capture the wetland vegetation during seasons of maximum greenness (Section 4.3).

A focal study area encompassing wetland vegetation associated with spring flows and, excluding non-spring or dryland vegetation, was defined through flow and catchment analysis of the Shuttle RADAR Topography Mission Digital Elevation Model (Australian 2010 release) (Section 3.4, Figure 3.4). This boundary provided a consistent basis for calculations of wetland area and for comparing changes in wetland extent.

Vegetation cover and composition were recorded within sample plots representative of the range of vegetation types and cover within the Dalhousie Springs Complex. Ten sample plots of 9x9m were recorded, designed to allow for the spatial resolution and geometric accuracy of the imagery, as well as the scale of variation within vegetation stands. Sample plots were located with field DGPS measurements to enable accurate identification in the imagery. Interpretations of wetland extent and change shown by the QuickBird image analysis were further assisted by digital colour aerial photography (acquired in March 2009) and by detailed knowledge of the Dalhousie Springs, wetland communities, their management and history.

The NDVI was calculated for the three QuickBird images. A regression relationship was established between QuickBird image NDVI values and percentage vegetation cover measured in the field sample plots and, from this relationship, an NDVI threshold was determined which separated wetland from dryland vegetation. Perennial wetland composed of tall, dense, homogenous reedbeds of Common Reed (*Phragmites australis*), Date Palm (*Phoenix dactylifera*) and White Tea Tree (*Melaleuca*

glomerata) with over 80% canopy cover and exhibited the highest NDVI values. Sedgeland with 40–60% canopy cover had moderate NDVI values, while halophytic and arid vegetation with less than 30% canopy cover had the lowest NDVI values. A threshold of NDVI = 0.35 was used to differentiate wetland from dryland vegetation (see break-out box, pp.26-27). This method should be considered in the context that NDVI can become less reliable at lower levels of vegetation cover and with increased soil moisture, which is evident within these wetland environments.

The resultant mapping of wetland vegetation was compared for the three image dates using multiple-date digital image subtraction and display techniques. The temporal dynamics of wetland vegetation extent was interpreted for the entire Dalhousie Springs Complex and for two springs known to be influenced by land management practices and changes in flow rates.

4.4.2. Changes in wetland area

Comparison of the three epochs of imagery shows that overall the wetlands remained relatively stable in distribution, although most spring wetlands increased in extent from vent to tail (Figure 4.5). Total wetland area, calculated as area over the NDVI threshold, increased from 607 ha in December 2006, to 913 ha in May 2009 and 1285 ha in May 2010. Within this overall increase in wetland area there were notable changes in some spring tails, the largest being the extensive increase in the northern extremities of the large northern spring (DCA001).

The 50% increase in total mapped wetland area from December 2006 to May 2010 and 40% increase between May 2009 and May 2010 can

be explained by the interplay of seasonality, rainfall and climatic conditions and vegetation regeneration in response to disturbance. The greenness and extent of the wetlands fluctuate markedly throughout the year and are at a maximum in May, the conditions captured by the 2009 and 2010 images, whereas plant growth is less extensive in December (Section 4.2). Antecedent rainfall also has a strong influence on overall wetland greenness and area. Conditions prior to the November 2006 image were dry, particularly from August 2006, following several years of low rainfall; the area of wetland mapped at this time was the lowest. By contrast, extremely high rainfalls occurred in the six months preceding the May 2009 and May 2010 images. Major rains fell in November and December 2008 (65 mm and 45 mm at Hamilton; 72 mm and 40 mm at New Crown), with follow-up rains in March to May 2009. Similarly, very high rainfall events occurred in November and December 2009 and February 2010, with monthly totals of 32 mm, 77.5 mm and 43.5 mm (Hamilton) and 10 mm, 20 mm and 96.4 mm (New Crown). The wetlands showed marked increases in area after these high rainfalls. In addition, seasonal changes in wetland vegetation growth are a further contributor to the differences documented here.

The most marked changes in the wetland extent over this 3.5 year period are evident at the spring tails. Two springs, DCA001 and DFA009 were identified for more detailed interpretation of the changes between image dates.

Spring DCA001

Spring DCA001 is the largest spring within the Dalhousie Spring Complex. There was a dramatic increase in area in the northern portion of its tail of 52.7 ha between December 2006 and May 2009 and 86.8 ha between May 2009 and

Photo: Laura Crossey



May 2010 (Figure 4.6). The main wetland area close to the spring did not change in magnitude or distribution over this period. Overall changes in wetland area were accompanied by differential increases and decreases in NDVI, which can be interpreted as changes in vegetation cover, biomass and greenness. The smaller area for this spring in December 2006 was the result of an extensive fire caused by a lightning strike in early 2006 which burnt approximately 200 ha of the wetland. Following the fire, green vegetation cover decreased markedly (2006 to 2009) then regenerated more gradually (2009 to 2010).

In addition to this large area of change, the NDVI comparisons provide evidence of more localised increases and decreases in plant growth. Preferential flow paths of spring water changed after vegetation reduction following fire and sparse samphire shrublands in the south-east and south-west extremities of the spring greened up. Between May 2009 and May/June 2010, some decrease in NDVI was apparent over the central and southern portions of this

wetland. This is likely because the 2010 imagery captured the *Phragmites* reeds at a slightly later and drier stage in their seasonal growth cycle (Section 4.2) and because the dense stands were declining towards the end of their four- to five-year growth cycle (Roberts 2011). The drying of the dense reedbeds was confirmed by comparison of spectral reflectance profiles in the 2009 and 2010 QuickBird images; a decrease in chlorophyll absorption, indicative of reduced photosynthetic activity, was seen in this region.

Because spring DCA001 accounts for almost 21% of the total wetland area at the Dalhousie Spring Complex, the increases in vegetation following the 2006 fire (a 26% increase in vegetated area between December 2006 and May 2009) contributed substantially to the overall increase in wetland area for the whole complex. Similarly, the 43% increase in area of this large wetland substantially contributed to the overall increase in total wetland area for the whole complex between May 2009 and May/June 2010.