Spring DFA009

Spring DFA009 provides an excellent illustration of the short-term dynamic nature of vegetation on spring tails in the Dalhousie Springs Complex. Overall this wetland increased by 7.5 ha from December 2006 to May 2009 and by 14.4 ha between May 2009 and May 2010. There were substantial changes in the braided flow paths of the main spring tail, with increases in vegetation on the western margin between 2006 and 2009, followed by increases on the eastern margins between 2009 and 2010. These changes in areas of greenest vegetation suggest shifts in spring flow paths of 70–200 m in some areas (Figure 4.7).

Noteworthy regions of decreased vegetation vigour are also evident around the western and southern extremities of the densely vegetated spring head. Most obvious is a general increase in NDVI throughout the spring tail, particularly on the eastern fringes and southern extremity of the wetland between May 2009 and May 2010. Moreover, localised reductions in NDVI within the vegetation surrounding the spring vent are also apparent and are likely due to shadowing by the dense White Tea Tree canopies or the presence of standing water.

4.4.3. Conclusions

While medium-resolution, high temporal frequency satellite images provide evidence of seasonal and decadal trends in the wetlands (Section 4.3), this high-resolution study provides precise and accurate measurements of wetland area and distribution, giving an objective basis for assessing short-term changes in wetland status and condition. Mapping wetland vegetation through digital analysis of very high resolution multispectral satellite imagery repeated over three years and under varying climatic conditions considerably enhances understanding of the spatial and temporal variability of the Dalhousie Springs Complex springs. It provides a strong baseline for future monitoring of the wetlands at the Dalhousie Springs Complex and demonstrates methodologies that can be implemented for future monitoring.

The NDVI threshold method successfully discriminated spring wetland perennial and ephemeral vegetation from the surrounding dryland vegetation. The wetland vegetation patterns revealed through this study are complex, with major wetlands and inter-braiding spring tails documented at very high spatial resolution. Short-term changes in the area, distribution and growth of spring-fed wetlands are evident, influenced by ecological processes, vegetation management practices, seasonal conditions and natural flow variations. Changes in total wetland extent derived from the QuickBird imagery marry well with the field botanical and rainfall records and knowledge of wetland vegetation phenology of the site.

4.5. Changes in spring environments: Hermit Hill Spring Complex

Comparisons of vegetation and surface expressions associated with springs were made using features mapped from analysis of HyMap airborne hyperspectral imagery acquired in March 2009 and April 2011. These comparisons illustrate the nature and extent of specific changes that take place within spring complexes and groups over relatively short periods and in response to changing seasons and weather. The imagery acquired in March 2009 recorded the springs and surrounding landscapes in very dry conditions (the arid regions of the western margin of the GAB had experienced below average rainfalls for five years), whereas the April 2011 imagery followed two years of very high rainfall in the region.

These comparisons focus on Hermit Hill Spring Complex and the Hermit Hill and West Finniss spring groups.

4.5.1. Methods

The total extent of wetland vegetation for the spring complex was determined from the hyperspectral imagery using the NDVI. An NDVI threshold (0.17 in March 2009 and 0.14 in April 2011) was established, above which NDVI values were considered to be indicative of wetland vegetation. This threshold was determined from a linear regression relationship between field estimates of vegetation cover and image NDVI. The NDVI technique was employed to provide consistency and comparison of wetland vegetation extent and distribution between sites and dates of image capture.

Dominant vegetation species and communities were discriminated and their distributions mapped using mixture tuned matched filtering analysis of the two dates of hyperspectral imagery. The mapped distributions were verified with records from botanical survey plots and field observations.

Areas of high surface moisture (wetted areas), including spring vegetation and wet substrate were defined using the NDSMI (Appendix 2). The same index ranges were used for both dates of imagery to enable comparisons of the areas defined by the index. Zones of diffuse discharge were defined using spectral angle mapping, applying the same spectral similarity threshold to the 2009 and 2011 imagery for both spring groups.

Fuller details of the methods are provided in Appendix 2.

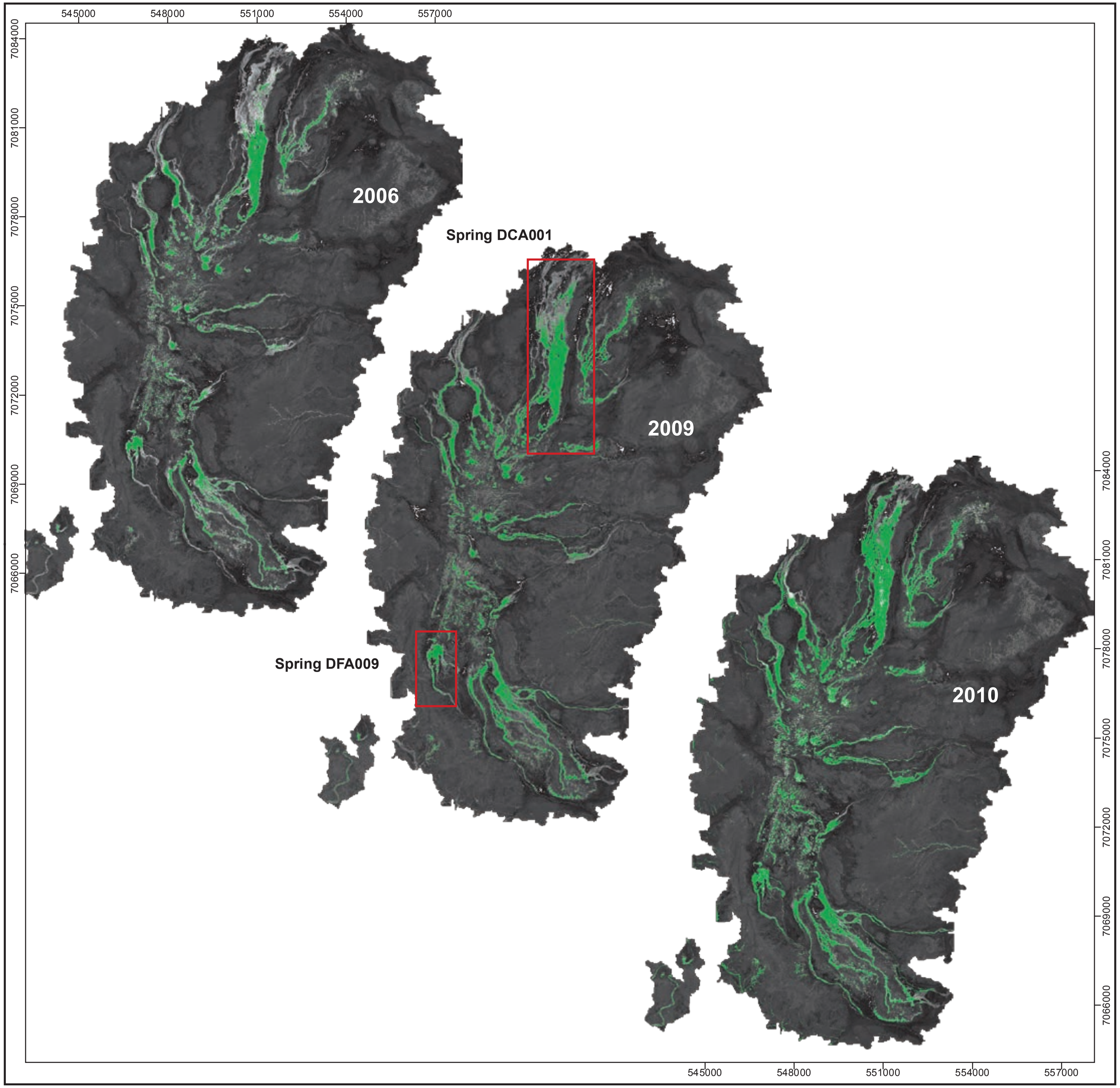


Figure 4.5: Extent of wetland area, from NDVI analysis of three epochs of QuickBird multispectral satellite imagery

Vegetation Index
High
Low
Vegetation
Focal Springs

0 2.5 5
Kilometres
N

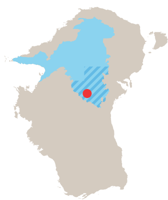
Produced by The University of Adelaide, School of Earth & Environmental Sciences
Map Projection: UTM Transverse Mercator
Map Datum: Geocentric Datum of Australia 1994
Date: January 2012

Figure 4.6: Change over time of spring DCA001 from NDVI analysis of QuickBird

Vegetation Index
High
Low
NDVI increase
NDVI decrease

0 300 600 900
Metres
N

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



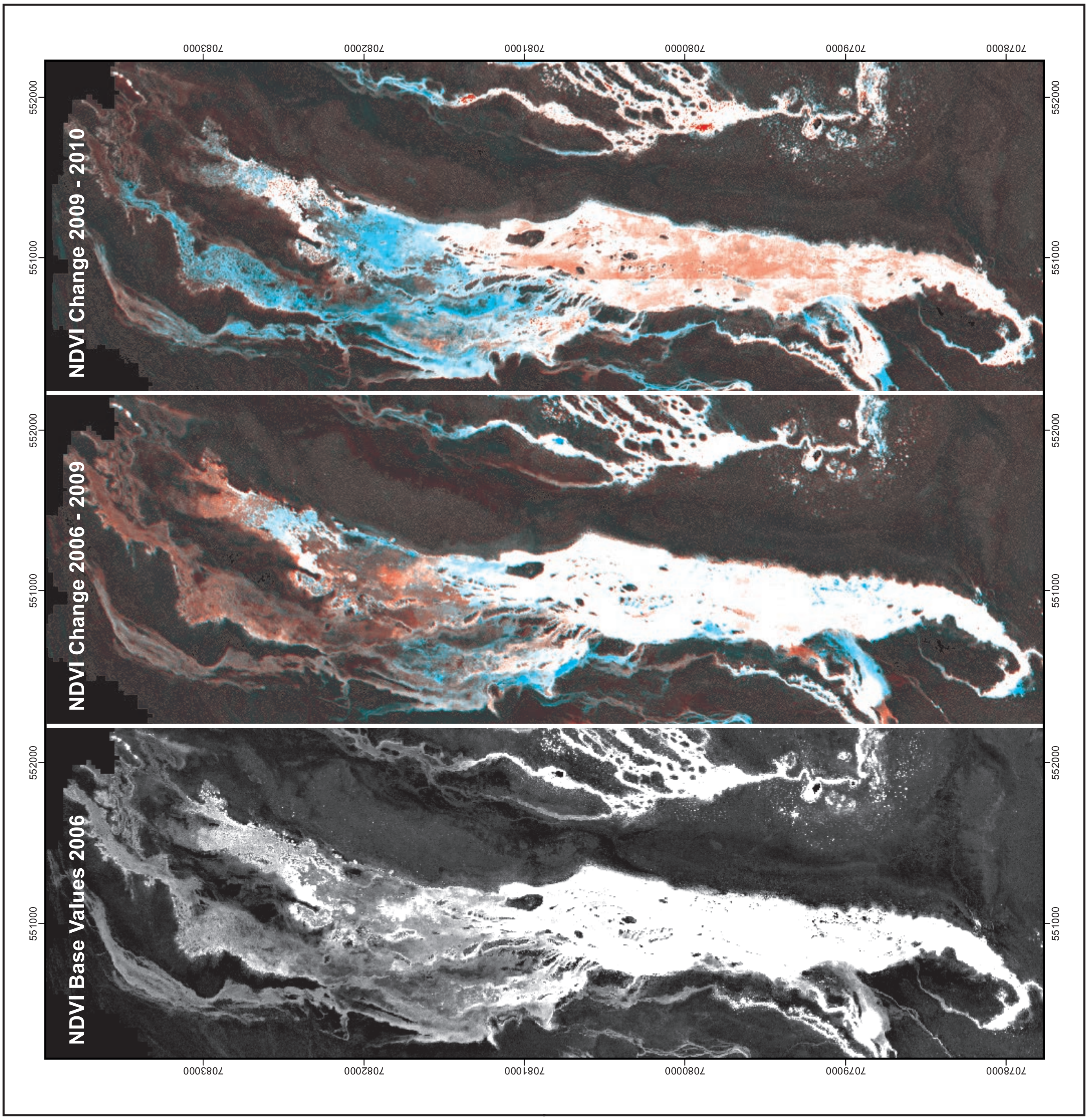
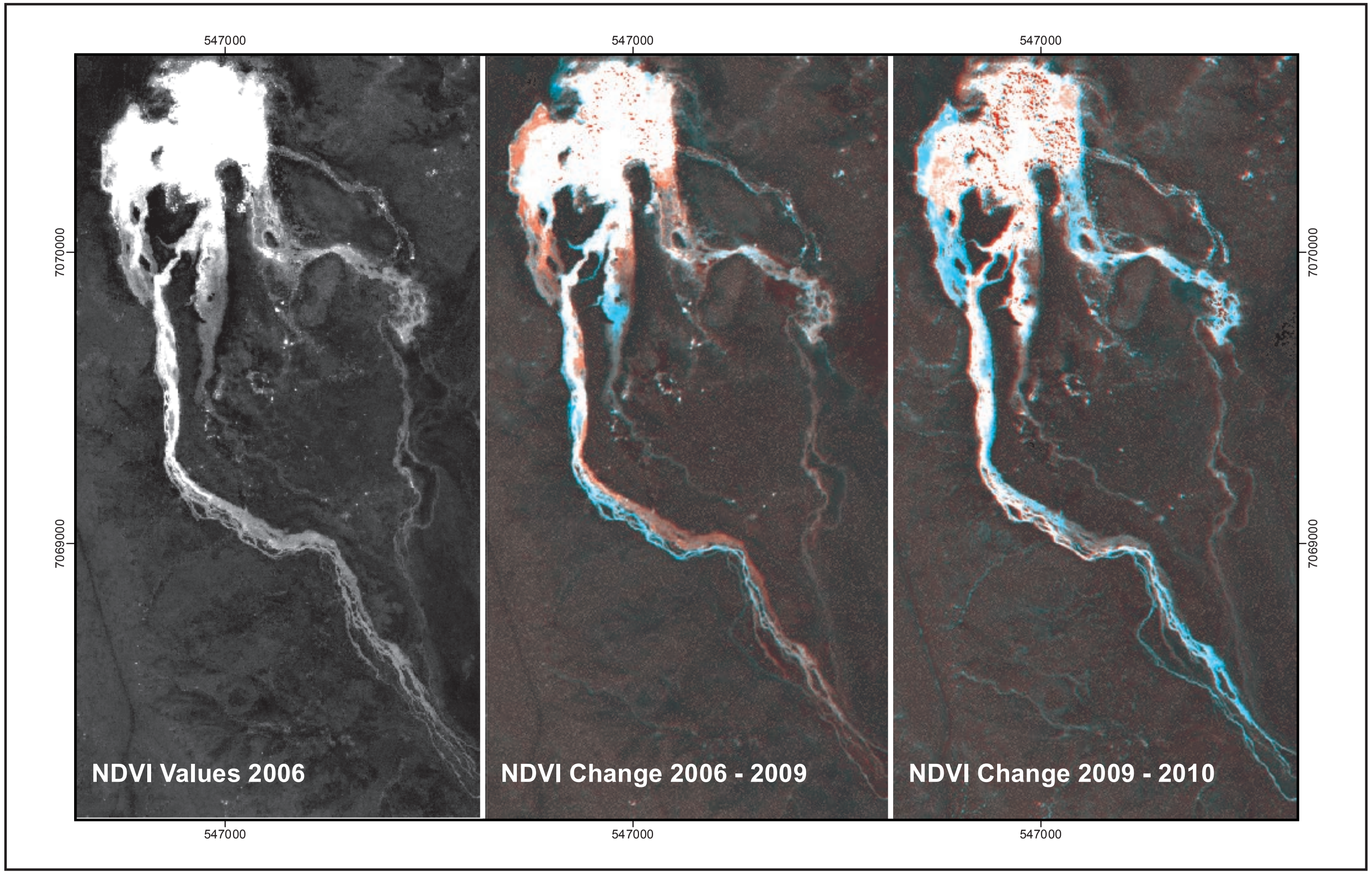


Figure 4.7: Change over time of spring DFA009 from NDVI analysis of QuickBird multispectral satellite imagery



Vegetation Index
High
Low
NDVI increase
NDVI decrease

0 300 600
Metres
N

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

4.5.2. Spring wetland extent

The most notable change between the two dates of imagery is the substantial greening-up in April 2011 of the dryland vegetation communities surrounding the springs. Perennial shrubs, ephemeral grasses and forbs all show much higher levels of photosynthetic activity in response to high rainfalls in the two years prior to the image capture. By contrast, changes in the greenness and extent of the spring-fed wetlands are less pronounced.

For the entire Hermit Hill Complex, combining the 12 spring groups captured, the total extent of photosynthetic vegetated wetland increased from 34.94 ha in March 2009 to 39.99 ha in April 2011, an overall increase of 12.6% (5.05 ha) (Table 4.1). Spring groups varied in response, with the majority exhibiting a relative increase between 2009 and 2011 and others either decreasing or remaining relatively static. Spring groups which increased in wetland area over the two years were Old Finniss, Old Woman, Hermit Hill, Dead Boy, Sulphuric, Bopeechee, Bopeechee Mound, Finniss Well and Beatrice (Table 4.1).

The increases in wetland area can be seen as overall expansion of the extent of springs within these groups; in the majority there is increased connectivity between individual springs and in some cases extensions of spring tails. A good example of increased connectivity and extension of spring tails within a spring group can be seen at the Hermit Hill Group (Figure 4.9).

The spring groups displaying little change or relative decreases in wetland area during this period include Bopeechee North, West Finniss and North West springs. A possible explanation for the apparent lack of change or decrease in spring wetland extent is the presence of standing water or wet areas within these groups, following the recent heavy rainfall; the low NDVI associated with these areas would decrease overall NDVI.

At West Finniss (Figure 4.10) there was an apparent decrease in photosynthetic *Phragmites australis* stands on the eastern extremities of the spring group, which may be due to the April 2011 image depicting the senescence of the reeds later in the growing season, compared with the earlier March 2009 imagery. Although overall there was a minor decrease in wetland area, there was an increase in connectivity between individual springs and extension of spring tails, particularly for the north-eastern most spring in this group.

Table 4.1: Changes in wetland extent for spring groups, Hermit Hill Spring Complex (March 2009 to May 2011)			
Spring group	Wetland area (ha) 2009	Wetland area (ha) 2011	Change in area (ha) 2009-2011
Beatrice	0.19	0.33	0.14
Bopeechee	3.83	6.11	2.28
Bopeechee Mound	0.12	0.41	0.29
Bopeechee North	0.23	0.29	0.06
Dead Boy	0.13	0.21	0.08
Finniss Well	0.23	0.41	0.18
Hermit Hill	12.93	13.58	0.65
North West	2.46	1.72	-0.74
Old Finniss	6.2	7.61	1.41
Old Woman	1.57	2.05	0.48
Sulphuric	1.31	2.24	0.93
West Finniss	5.74	5.03	-0.71

4.5.3. Wetland vegetation composition

The two focal spring groups, West Finniss and Hermit Hill, both exhibit considerable floristic diversity within the spring group. Changes in vegetation composition between 2009 and 2011 are particularly notable at West Finniss (Table 4.2, Figure 4.10).

The West Finniss Group comprised dense homogenous stands of *Phragmites australis* in 2009, which decreased considerably (1.16 ha) in 2011 (Table 4.2, Figure 4.10). Conversely, a marked increase (0.64 ha) in *Cyperus laevigatus* occurred, particularly at the larger spring tails in the northern portion of the spring group. *Sporobolus virginicus* continued to exhibit a dispersed and confined distribution at West Finniss, located further away from the spring vents and flow channels to the south-east where conditions are drier, increasing by 0.16 ha between 2009 and 2011. *Frankenia* sp. at West Finniss is present in dispersed, sporadic patches on the southern and north-west fringes of springs, decreasing in area by 0.28 ha between 2009 and 2011.

At Hermit Hill Group, *Phragmites australis* retained the same spatial distribution, although increasing in extent by 0.62 ha between 2009 and 2011 (Table 4.2, Figure 4.11). *Cyperus laevigatus*, another dominant species within this spring group, remained relatively constant in area between the two image capture dates, although it expanded within the tails of the northern springs and smaller springs clustered at the base of the outcropping hill. The distribution of *Baumea juncea* and *Gahnia trifida*, on the other hand, changed little, predominanting around around the flanks of the outcropping hill in the smaller springs, while *Gahnia trifida* remained relatively stable in extent between 2009 and 2011. *Baumea juncea* decreased considerably between the two image capture dates.

4.5.4. Wetted area

Both West Finniss and Hermit Hill spring groups have extensive zones of near-surface moisture or wetted areas, which increased in extent, although changed in surface form between 2009 and 2011. At West Finniss there is a general expansion in wetted area adjacent to the springs, particularly around their fringes. Increases in wetted area are also evident along spring tails with increased connections, as well as extended wetted areas along ephemeral creek channels (Figure 4.12). These increases in wetted area are most likely the result of notable rainfall events in 2010 and 2011. In contrast, the wetted areas mapped in 2009 at Hermit Hill changed little in 2011, although extensive new areas became apparent to the north and east of the spring group.

4.5.5. Diffuse discharge

Changes in the surface expression of diffuse evaporative discharge surrounding the wetted area regions at West Finniss are evident between the 2009 and 2011 image captures, with expansion of the diffuse discharge zone to the north and west and a reduction to the south. For the Hermit Hill Group, zones of diffuse discharge were detected in the same localities and spatial distributions in both 2009 and 2011, although marked expansions in the extent of these features is evident to the south-east and western extremities of this group (Figure 4.13). Increases in the extent of diffuse discharge at both sites are most likely due to notable rainfall events in 2010 and 2011.

Table 4.2: Comparison of areas of wetland vegetation types, West Finniss and Hermit Hill spring groups (March 2009 and May 2011)

Spring group and vegetation type	Vegetation area (ha) 2009	Vegetation area (ha) 2011	Change in area (ha) 2009–2011
West Finniss	5.74	5.03	-0.71
Phragmites australis	1.34	0.18	-1.16
Cyperus laevigatus and *Fimbristylis* sp.	0.41		
Cyperus laevigatus and *Baumea juncea*		1.05	
Sporobolus virginicus	0.19	0.35	
Frankenia sp.	0.66	0.38	0.28
Hermit Hill	**12.93**	**13.58**	**0.65**
Phragmites australis	1.11	0.49	-0.62
Cyperus laevigatus	2.4	2.53	0.13
Baumea juncea	0.53	0.9	0.54
Gahnia trifida	1.25		
Gahnia trifida and *Fimbristylis* sp.		0.71	

4.6. Implications and recommendations

Knowledge of wetland plant phenologies has important implications for spring monitoring programs. It identifies the seasons of minimum and maximum greenness within the wetlands, which should be taken into account when planning and interpreting field and other image-based assessments of these ecosystems. It is important that sampling which aims to monitor the wetlands over time be conducted at a consistent time of year in order to minimise seasonal variability.

Understanding wetland phenology is also particularly important when determining the relationship between groundwater discharge and the wetland area a spring supports; this fundamental relationship underlies the shorter term fluctuations in wetland greenness and area caused by seasonal changes. The seasonal timing of wetland area measurements should be considered when interpreting flow to wetland area relationships.

Where spring-fed wetlands are extensive, it is possible to identify them by their characteristic temporal response using MODIS time-series, even though the communities cannot be precisely delineated for mapping purposes at this resolution. This has valuable implications for natural resource survey and inventories that aim to locate and document the occurrence of spring ecosystems. Higher levels and regular pulses of vegetation greenness distinguish the spring-fed wetlands from riparian and dryland vegetation in this arid environment.

Photo: Megan M Lewis

Long-term trends in wetland area within two large spring complexes have been documented for the first time in this study and the influence of rainfall on the wetlands has been identified. Ongoing monitoring of wetland area as an indicator of spring ecosystem status needs to acknowledge the strong influence of season and preceding rainfall on extent and greenness of the wetlands. Definition of baseline conditions for these springs must incorporate the inter-annual variations and longer term trends seen here. Assessment of changes in spring vegetation in response to changes in aquifer pressure must be interpreted within the context of these longer term trends. The new understanding of spring temporal dynamics has clear benefits for monitoring programs; it establishes the range of natural variation over time and could be used to define warning thresholds of extreme change.

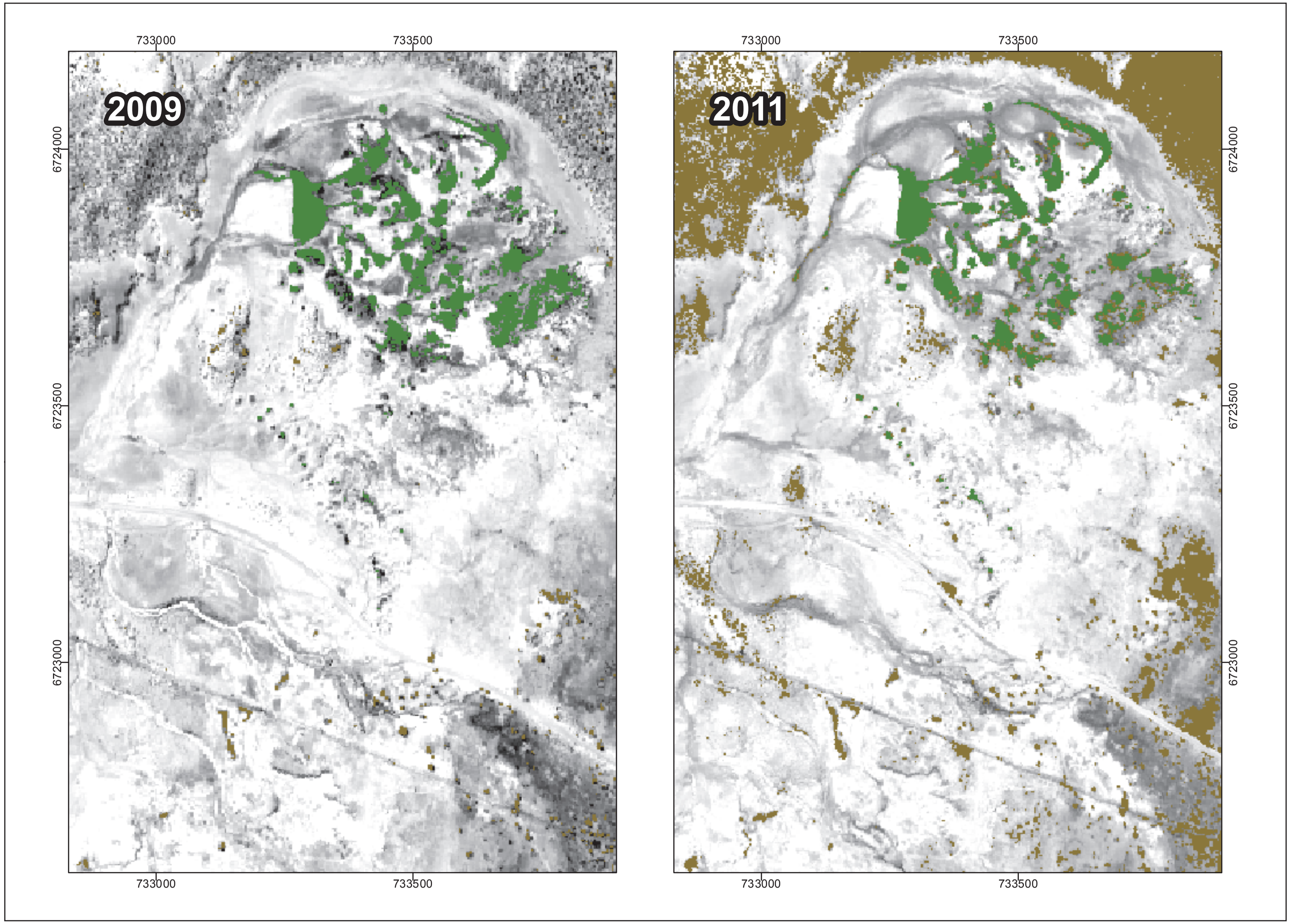


Figure 4.8: Comparison of distribution of vegetation, West Finniss Spring Group, from NDVI analysis of HyMap airborne hyperspectral imagery (March 2009 and April 2011)

Vegetation

- Wetland Vegetation
- Dryland Vegetation

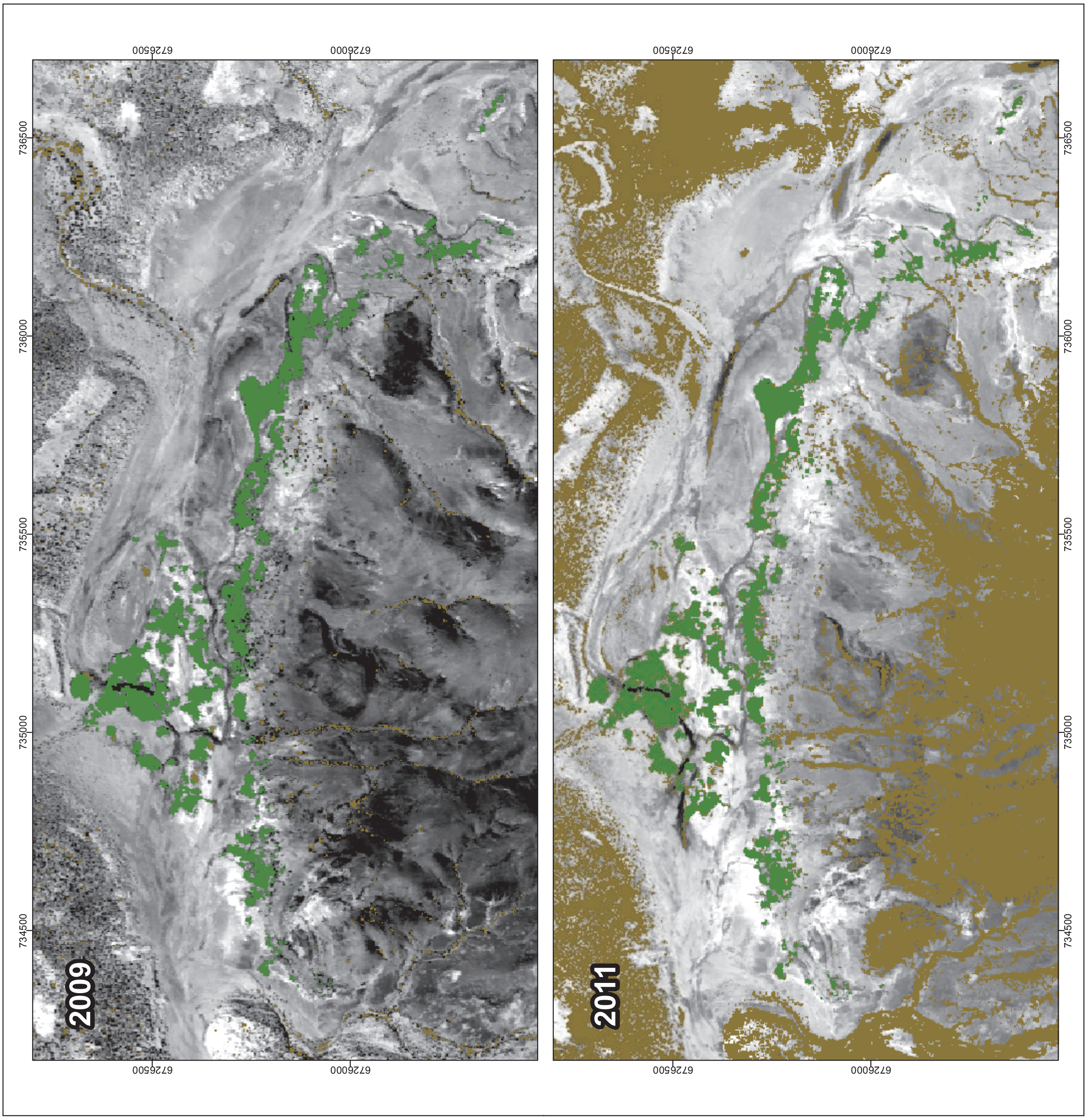
0 100 200 300

Metres

N

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 4.9: Comparison of distribution of vegetation, Hermit Hill Spring Group, from NDVI analysis of HyMap airborne hyperspectral imagery (March 2009 and April 2011)



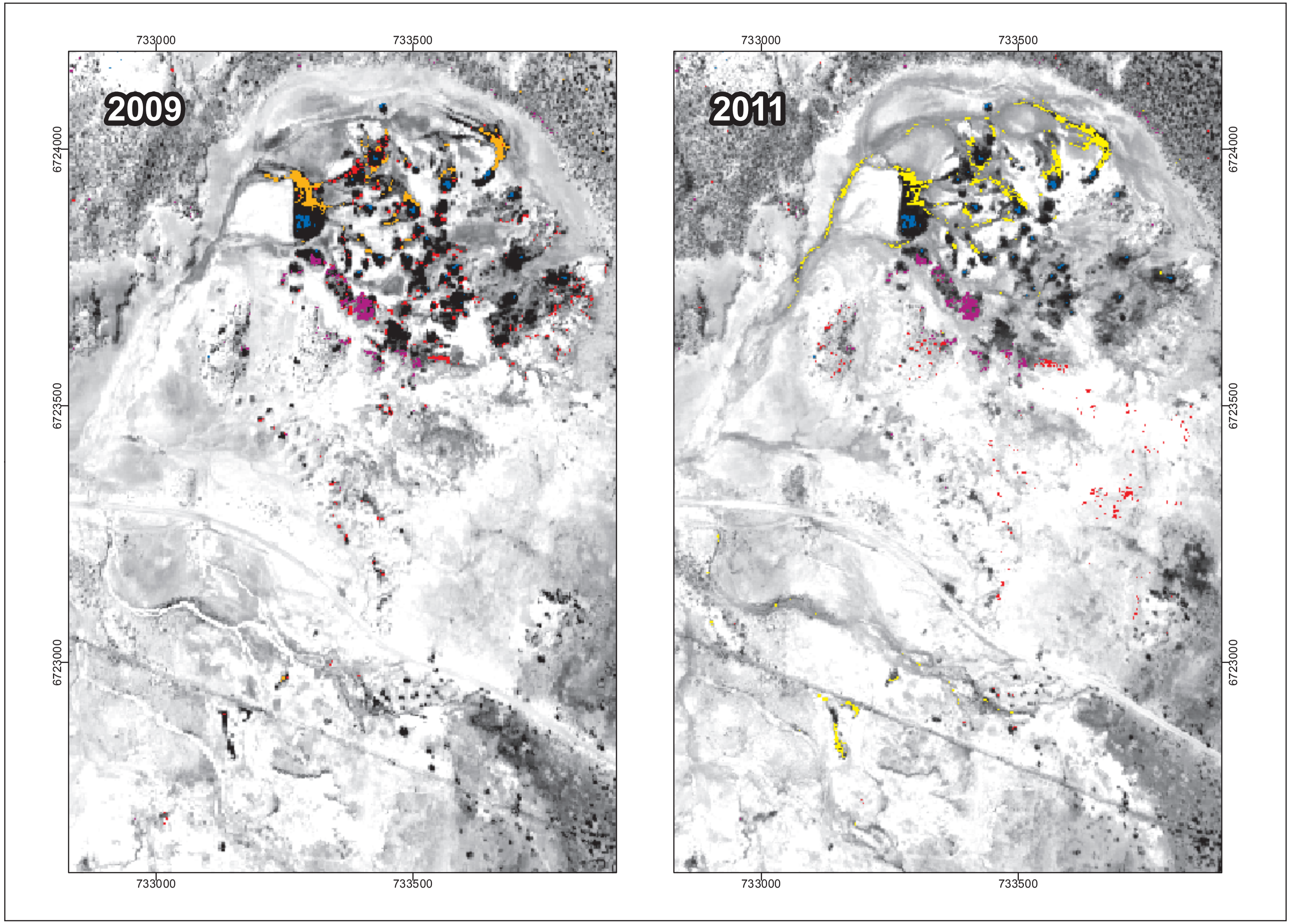


Figure 4.10: Comparison of wetland species distribution at West Finniss Spring Group, from mixture-tuned matched filter analysis of HyMap airborne hyperspectral imagery (March 2009 and April 2011)

The differences in species composition of the *Cyperus laevigatus* classes in 2009 and 2011 are due to the use of pure pixels for the hyperspectral image analysis derived from the field sampling plots containing these differing vegetation compositions.

Vegetation

- *Frankenia*
- *Phragmites*
- *Sporobolus virginicus*
- *Cyperus laevigatus and Fimbristylis*
- *Cyperus laevigatus and Baumea juncea*

0 100 200 300
Metres
N

Background image: HyMap, 665.7nm, 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

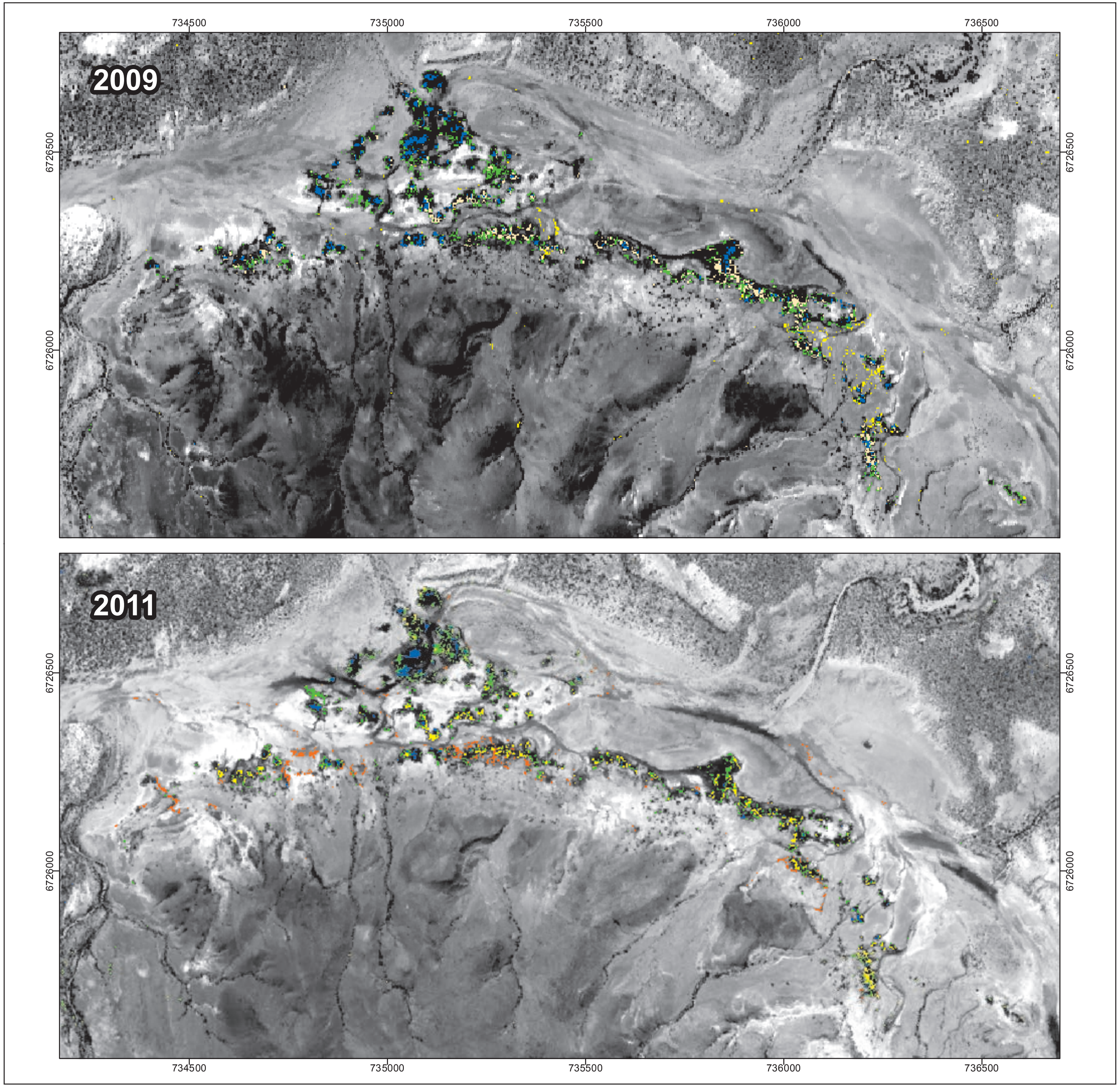


Figure 4.11: Comparison of distribution of wetland vegetation species, Hermit Hill Spring Group, from mixture-tuned matched filtering analysis of HyMap airborne hyperspectral imagery (March 2009 and April 2011)

The differences in species composition of the *Gahnia trifida* classes in 2009 and 2011 are due to the use of pure pixels for the hyperspectral image analysis derived from the field sampling plots containing these differing vegetation compositions.

Vegetation

- *Phragmites australis*
- *Gahnia trifida*
- *Cyperus laevigatus*
- *Baumea juncea*
- *Gahnia trifida and Fimbristylis*

0 100 200 300

Metres

N

Background image: HyMap, 665.7nm, March 2009 andApril 2011 respectively.
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

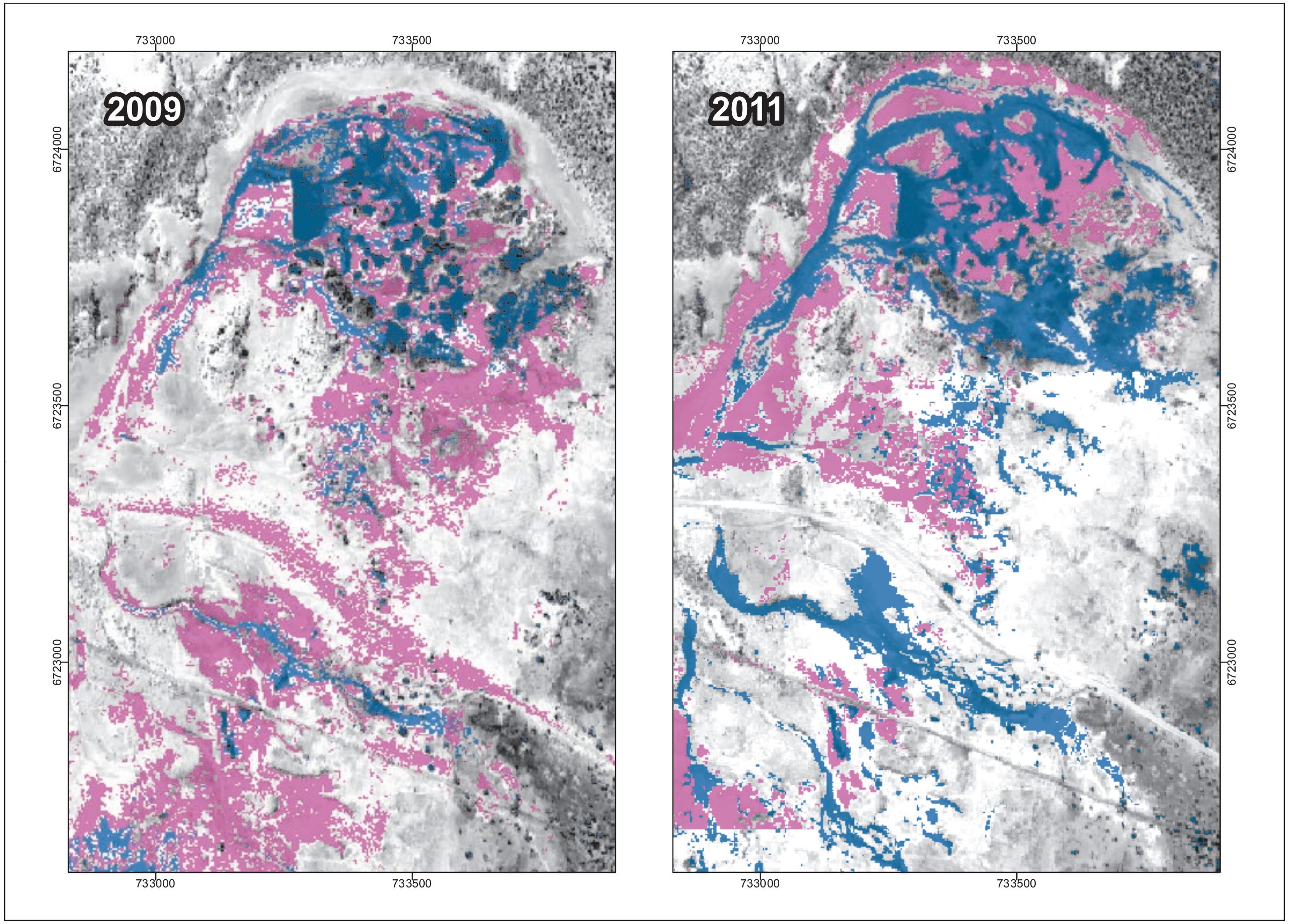


Figure 4.12: Comparison of wetted areas and diffuse discharge, West Finniss Spring Group, from NDSMI and spectral angle mapping analysis of HyMap airborne hyperspectral imagery (March 2009 and April 2011)

Background image: HyMap, 665.7nm, 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

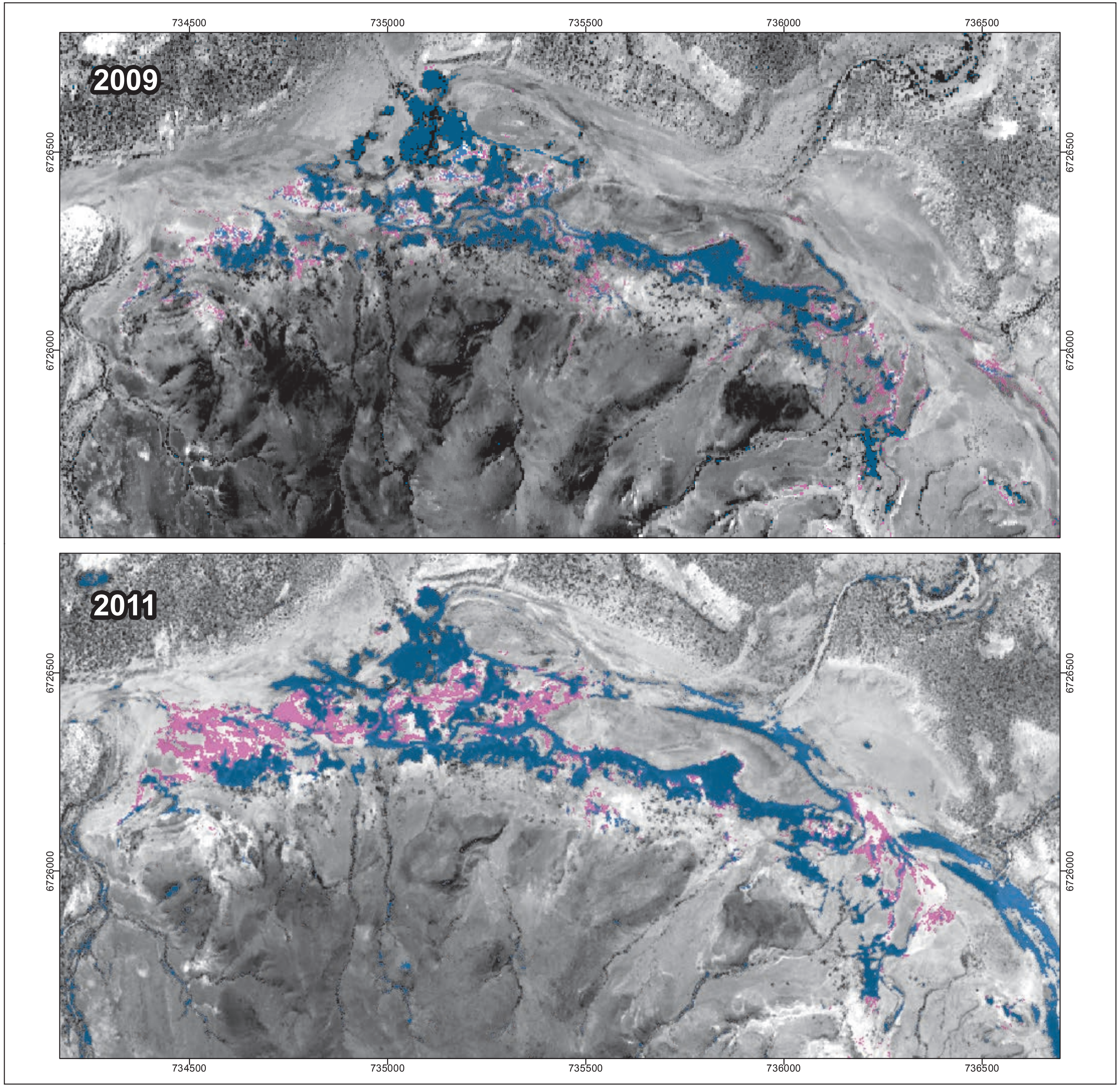


Figure 4.13: Comparison of wetted areas and diffuse discharge, Hermit Hill Spring Group, from NDSMI analysis of HyMap airborne hyperspectral imagery (March 2009 and April 2011)

Soil Moisture
Diffuse Discharge
Near Surface Moisture

0 100 200 300
Metres
N

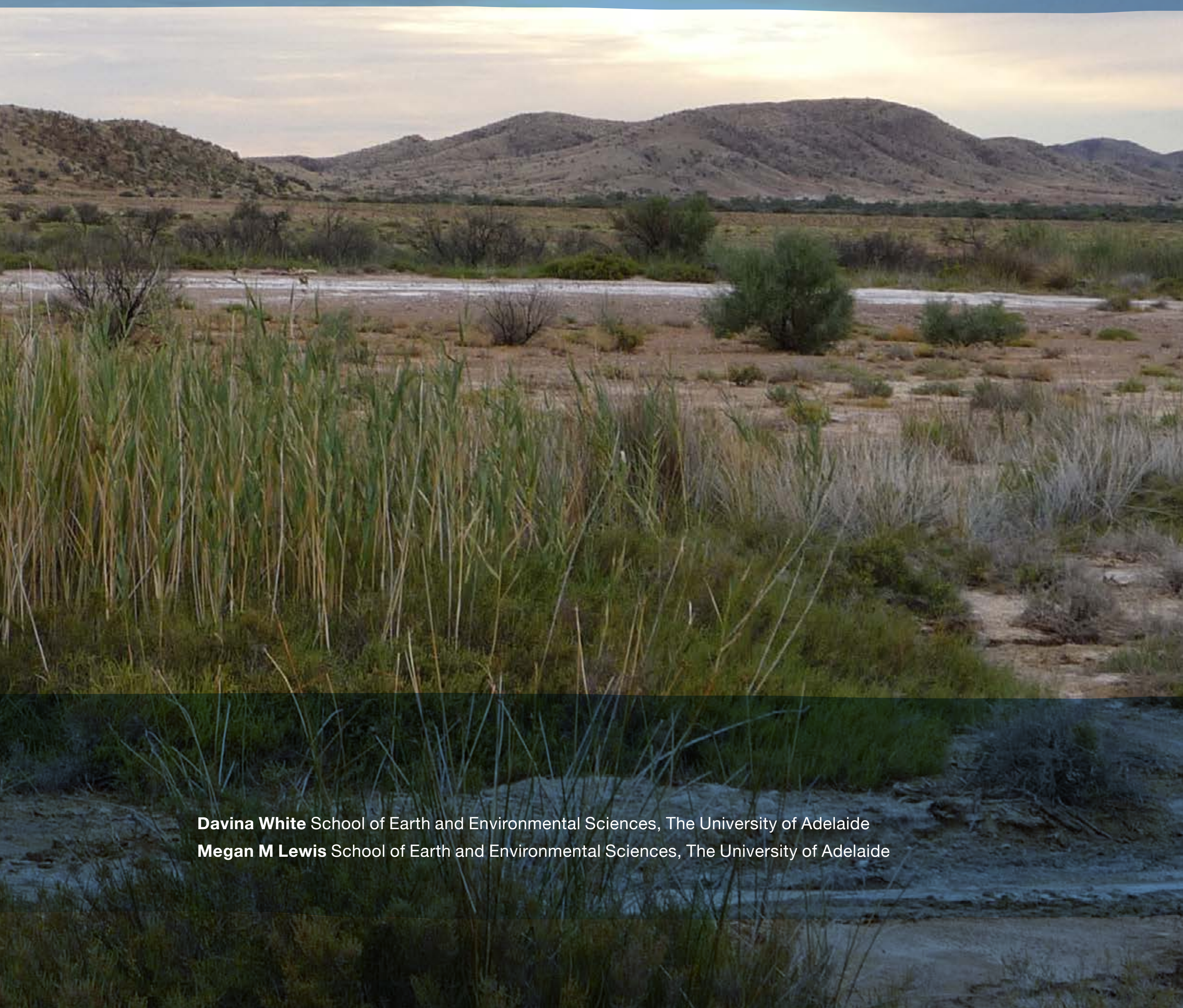
Background image: HyMap, 665.7nm, March 2009 and April 2011 respectively.
Produced by The University of Adelaide, School of Earth & Environmental Sciences
Map Projection: UTM Transverse Mercator
Map Datum: Geocentric Datum of Australia 1994
Date: January 2012

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

5

Associating wetland extent and spring flow rates



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5. Associating wetland extent and spring flow rates

5.1. Introduction

Establishing a relationship between individual spring wetland extent and groundwater flow rates provides a potential technique for monitoring changes in spring flows associated with changes in aquifer pressure. Williams and Holmes (1978), using small-scale black-and-white aerial photography and manual planimeter measurements, proposed that the flow rate from springs at Dalhousie Springs Complex was directly proportional to the area of wetland vegetation supported. This general relationship has been widely assumed for wetlands fed by springs in the Great Artesian Basin (GAB) but has not been tested or confirmed more widely.

This study developed new methods using digital image-based mapping to objectively quantify wetland areas associated with specific springs and, using new measurements of flow, tested relationships between flow and wetland area in a diverse range of spring settings. The studies focused on selected springs at Dalhousie and Mt Denison spring complexes. The Dalhousie component of this study has been published by White and Lewis (2011).

5.2. Methods

The Normalised Difference Vegetation Index (NDVI) was applied to very high spatial resolution satellite imagery (QuickBird and WorldView-2) to identify actively growing vegetation in the study regions. Calibration relationships were developed between NDVI and field measures of plant cover obtained from field sample plots recorded near the time of image capture (Appendix 2). From these relationships, NDVI thresholds were defined which discriminated wetland vegetation from dryland communities. The area of vegetation associated with specific springs was delineated from this wetland using on-screen heads-up digitising and through interpretation of flow paths in relation to surveyed locations of spring vents.

Measurements of outflow from specific springs were recorded as close as possible to the times of image acquisition. For Freeling Springs, these field measurements were made in May 2011 at previously unmonitored springs. For Dalhousie Springs, historic weir flow gauge data from monitored springs were used together with salt dilution gauge measurements made at additional springs in July 2009.

These methods provided data on spring flow and corresponding wetland area for seven springs in the Dalhousie Spring Complex and 21 springs in the Freeling Spring Group, Mt Denison Complex. For each of the groups of springs separate regression relationships were developed between spring flow (L/sec) and wetland area (ha). For Freeling Spring Group, this relationship relates to flow and wetland area development under the prevailing environmental conditions at the time. For Dalhousie Spring Complex, variability in this relationship was examined by use of wetland area and flow measurements for three periods between 2006 and 2010.

Fuller details of imagery and methods are provided in Appendix 2.

Photograph on facing page: Megan M Lewis

5.3. Relationships between spring flow rates and wetland areas

There is a strong positive linear relationship between spring flow rate and wetland area for the 21 springs measured at Freeling Spring Group, with 88% of the variation in spring wetland area being explained by the groundwater flow at the individual spring level. Spring wetland area (ha) is approximately twice the spring flow (L/sec) (Figure 5.1).

The spring flows measured at Freeling Springs had a narrow range; at most individual spring flows were less than 0.5 L/sec, with the maximum flow recorded at 2.09 L/sec. By contrast, the Dalhousie Spring Complex flows are two orders of magnitude greater, ranging from 0.7 to 1427 L/sec. However, at this larger scale, there is also a strong positive linear relationship between spring wetland area and flow rate ($R^2 = 0.99$, $p<0.001$; Figure 5.2). For the Dalhousie Spring Complex wetland area (ha) is approximately 1.3 times the flow rate (L/sec), (i.e. the slope of the regression is 1.3 (Figure 5.2)).

Although contrasting spring environments and different methods of flow measurement may account for differences in these relationships, it is likely that they are influenced by the prevailing climatic conditions. The relationship between wetland area and spring flow at Freeling Spring Group is based on measurements in May 2011, when preceding high rainfalls contributed to growth and expansion of the wetlands, as documented in Section 4.4. In contrast, the relationship for Dalhousie Spring Complex is based on wetland area and flow measurements made at three different periods: December 2006, May 2009 and May/June 2010. In May 2009, wetlands at Dalhousie Spring Complex were reduced in area following several dry years, while their expansion in 2009 and 2010 has been documented in Section 4.4. This allows an estimate of the range of variation in the wetland area/flow relationship that encompasses natural spring variability. The highest flows and most extensive wetlands at Dalhousie Spring Complex were recorded in May/June 2010, also following a period of high rainfall and under these conditions the wetland area/flow relationship is closer to that calculated for the Freeling Springs.

5.4. Conclusions and implications

The relationship between spring wetland area and flow rates at the Dalhousie Springs Complex agrees with that developed previously by Williams and Holmes (1978) using precise, manual measurements of wetlands and flow. Here, the natural range of variation in that relationship under different climatic conditions at the Dalhousie Springs Complex is demonstrated. The generality of these findings is extended by establishment of a similar relationship at Mt Denison Complex, with quite different geomorphic and hydrologic contexts and a much smaller range of spring flows.

These relationships are very significant, as they confirm widely-held assumptions and the underlying premise—that wetland area is an indicator of spring flow. Measurements of wetland area for individual springs can provide a surrogate for in-situ flow records that are often difficult to obtain and maintain over time. Remote sensing techniques, developed and demonstrated in this study, provide an objective, repeatable and cost-effective means of estimating and monitoring changes in spring flow.

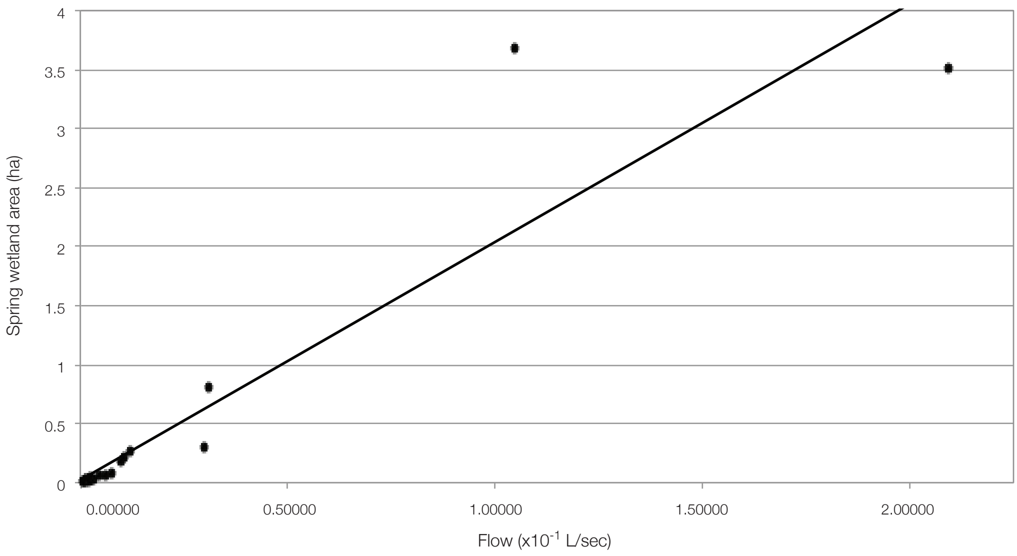

Figure 5.1: Relationship between wetland area and spring flow rate at 21 springs, Freeling Springs, Mt Denison Spring Complex

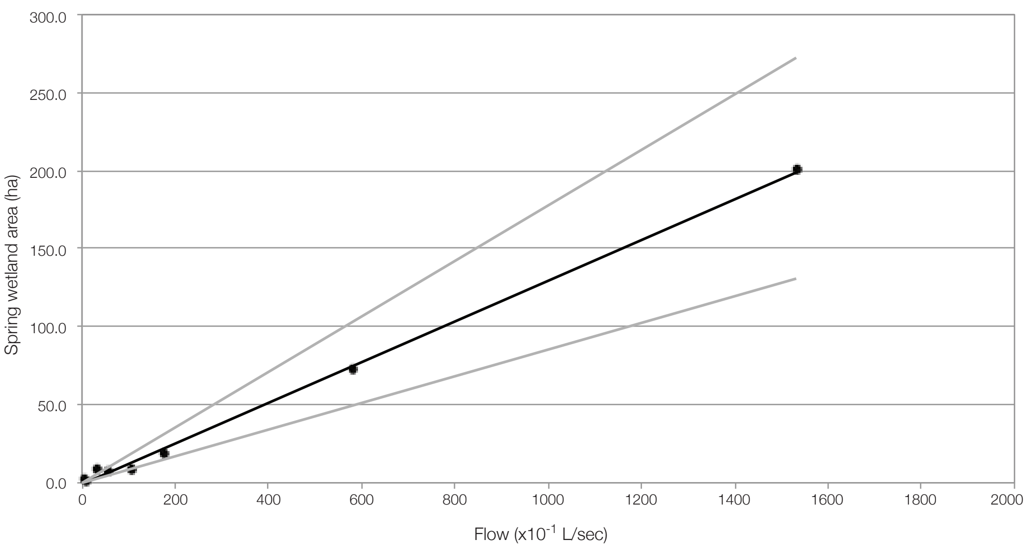

Figure 5.2: Relationship between wetland area and spring flow rate at eight springs, Dalhousie Spring Complex