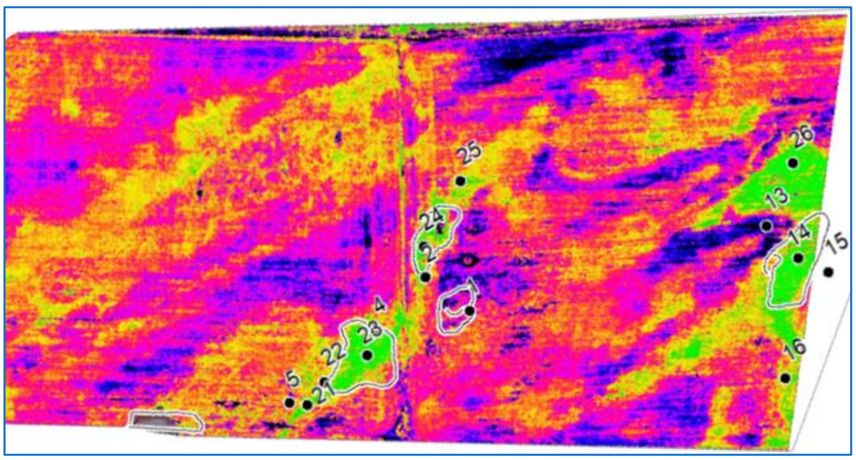
The Use of Normalised Difference Vegetation Index (NDVI) to Manage Seeps

Martins Report, Karoonda

Project SGR1-0338 for the South Australian Murray-Darling Basin Natural Resources Management Board



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1 Project Summary

The formation of seeps across Mallee landscapes has been a very fast growing phenomenon within the last 10 years, causing severe land degradation and loss of production for mallee farmers. The purpose of this project has been to provide an initial study into the potential use of Normalised Difference Vegetation Index (NDVI) to provide farmers with an early indication as to where seeps may be threatening to form within their paddocks. This may then allow them to apply practical and effective high water use strategies to both manage and ameliorate the problems before they get to the stage of causing irreparable damage.

This project, which has been administered through NR SAMBD in collaboration with the Karoonda Agricultural Bureau, was conducted within 2 farms, targeting 500ha of land that were believed to have areas in the very early states of seep development. These paddocks were scanned both mid-season and late season using UAV (drone) mounted NDVI cameras, as well as analysed using satellite NDVI imaging over the last 4 years. Areas showing potential seep activity were ground truthed both mid-season and post-harvest to test for evidence of excessive water accumulation within the top 1m of soil where possible.

The results from this project have revealed that NDVI imagery can be effectively used for the identification of potential seep areas within paddocks. The clearest indication were provided by late season UAV flights (mid-October in SA Mallee in 2017), at a time when the majority of the crop in the targeted paddocks had senesced, but the areas with excessive subsoil moisture continued to grow. While many of these areas showed obvious physical signs of excess water accumulation throughout the season, the NDVI imaging often revealed a much larger area that was under threat, which was subsequently verified by soil testing post-harvest.

There were some areas within the NDVI images produced that showed similar characteristics to the seep threatened areas, but appeared not to be under threat when physically inspected and monitored. This showed the importance of ground-truthing the images produced and taking into account other landscape issues, such as the proximity to deep sandy areas, in understanding and interpreting the information provided.

The use of early (pre 2015) satellite NDVI imagery was initially seen to be of poor resolution and unhelpful in identifying the formation of seep areas. However, more recent NDVI satellite imaging has proved to provide pictures that are reasonably comparable to the more defined UAV NDVI maps. While there can be problems with cloud cover compromising image production and quality, the fact that there are regular flights (fortnightly) and accessible via the internet, creates large advantages to its potential application. Images of the project paddocks taken slightly later, from mid-November 2017 satellite flight appeared to provide a strong identification of potential seep areas at some sites.

The NDVI images from both UAV and satellites also indicated areas of poor crop growth that may be leading to recharge, and could be targeted for strategic high water use management options.

While it is still unclear as to how accurate or how pre-emptive this technology could become, there are clear indications from this project that it should continue to be developed help give farmers the best information available as to where seeps may be developing, so they can commence early remedial work before severe land degradation occurs. Further development is required in the understanding of the data provided by the NDVI images, and the building of programs to accurately manage and interpret the images over time. If successful, this could provide a valuable tool for land managers, State bodies and organization to identify and strategically overcome this rapidly growing problem of Mallee seeps.

2 Introduction

Seeps are a recent and rapidly growing issue across the Mallee regions of SA and Victoria. Farmers are mainly reporting seeps in the mid-slopes or swales below deep sandy rises, generally when high rainfall leads to water draining through soil profiles until it strikes impervious clay layers beneath, creating a perched water table. As this recharge water builds up it can appear at the surface where the clay is close or at the lower lying areas of the catchment. Initially these areas of higher soil moisture can provide some productivity increases, but over time become saturated, weed infested, saline and scalded, eventually rendering them degraded and economically unviable.

Farmers need to find ways to identify areas where seeps are threatening to form before they get to the stage of causing irreparable land degradation, so that they can target practical high water use options to prevent the problems occurring. The use of NDVI images from both UAVs and satellites have shown potential for the early detection of areas within paddocks that are becoming saturated.

Photo 1. Mannum farmer Kevin Bond viewing developing seep area

3 Methods

Project managers met with Karoonda Agricultural Bureau members to discuss issues, possible courses of action and suitable sites that could be used for investigation. Paddocks were identified on the both the Martin's property at Karoonda and the Bond's property near Mannum, on paddocks where the farmers were concerned that new seeps could begin to form. Initial ground truthing showed deep sandy rises and areas potentially at risk in the vicinity of areas with recent seep formation.

In both August (mid growing season) and late October (as crop matured) these paddocks were scanned with a UAV mounted NDVI camera and the images analysed to identify areas with higher or longer crop growth patterns associated with a wetter soil profile. These areas were observed and analysed through the season and after harvest, including using a soil moisture probe to 1m depth to test for any underlying saturated soil layers. Areas of similar map NDVI colours were tested to see if there were consistent indicators of seep activity from the images gained, taken at different times. These areas were also compared against the existing available satellite NDVI images that are taken more regularly, but with lesser image quality than the UAV images, to assess whether this technology may also be useful for potential early seep identification.

While this report focuses on the results gained at the Martin property, the insights and outcomes from the project worked proved to be very consistent across both properties.

4 Results and Discussion

4.1 Martin Property, Karoonda

After surveying paddocks on the Martin property, there were four paddocks in two areas chosen that the farmers were concerned about potential seep formation. While there were many recently formed seep and scald areas that had developed on adjacent paddocks, these project paddocks were still being entirely cropped with both cereals and pulses, apart from 1 small seep on the edge of Paddock 3 and southern fence of Paddock 4 (see Figure 1).

Figure 1. Martin's property showing existing seeps and project NDVI scanning areas

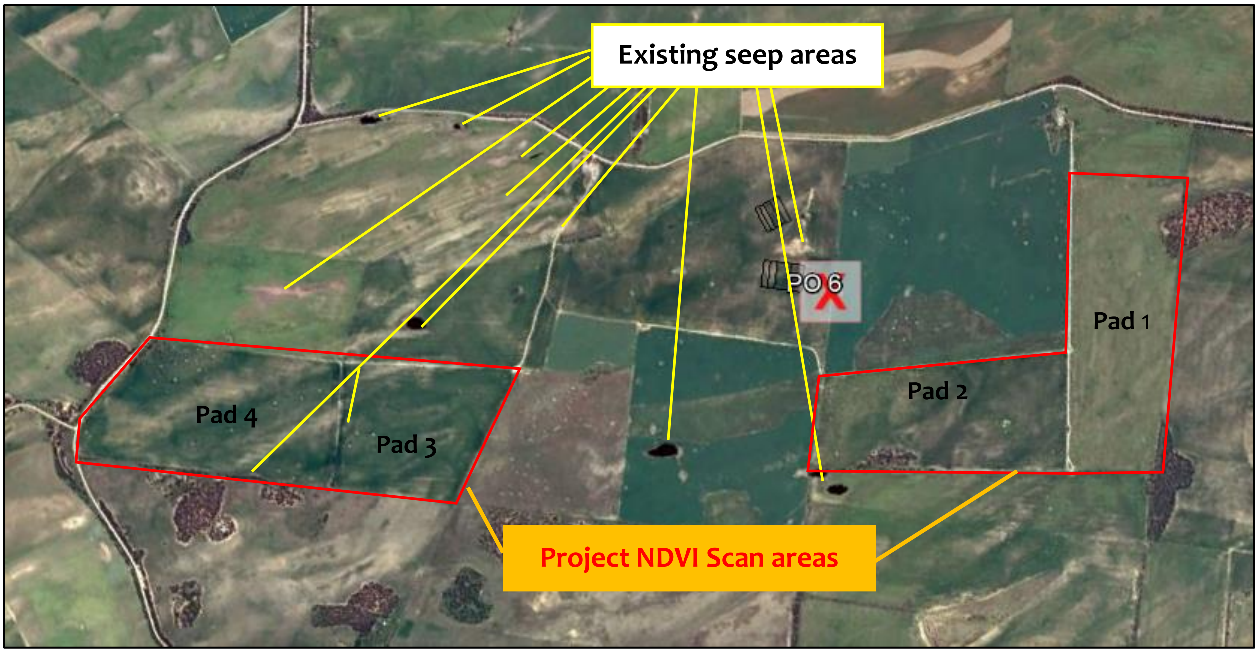


Photo 2 Tony & Simon Martin survey scalded seep affected land

An initial appraisal of the project paddocks in May 2017 showed areas of greener, thicker crop growth, higher ryegrass populations, and a few areas beginning to bare out, all surrounded by deep non-wetting sands. Some of these sites were found to have saturated soil layers within the top 1m. There were two small areas in Paddock 1 where the lentils were showing signs of yellowing, beneath which saturated soil was found.

4.2 Paddock Drone NDVI scans, photos and ground truthing

In August 2017 the initial Drone flights over the paddocks took place taking both aerial photos and NDVI pictures, in an attempt to ascertain whether potential seep areas could be accurately identified in this mid-season period. Areas of concern are characterized by subsoil waterlogging that may be expressed at the surface initially as better, thicker, greener crop growth, with possibly higher weed infestation, depending on the development stage of the seep. More mature seep areas may appear as poor, yellowing crop, bare scalds or surface water ponding.

Photos 3-6 reveal a number of factors that can influence crop growth within a paddock that may have little to do with potential seep activity, but could show similar map colours. Photo 3 reveals a stone heap area with no sown crop that may appear similar to the bare scalded area nearby. The greener area at the base of the sandy rise could be due to seep moisture or a more fertile soil type, or both.

Photo 3. Drone photo of Paddock 2 looking west, Aug 2017

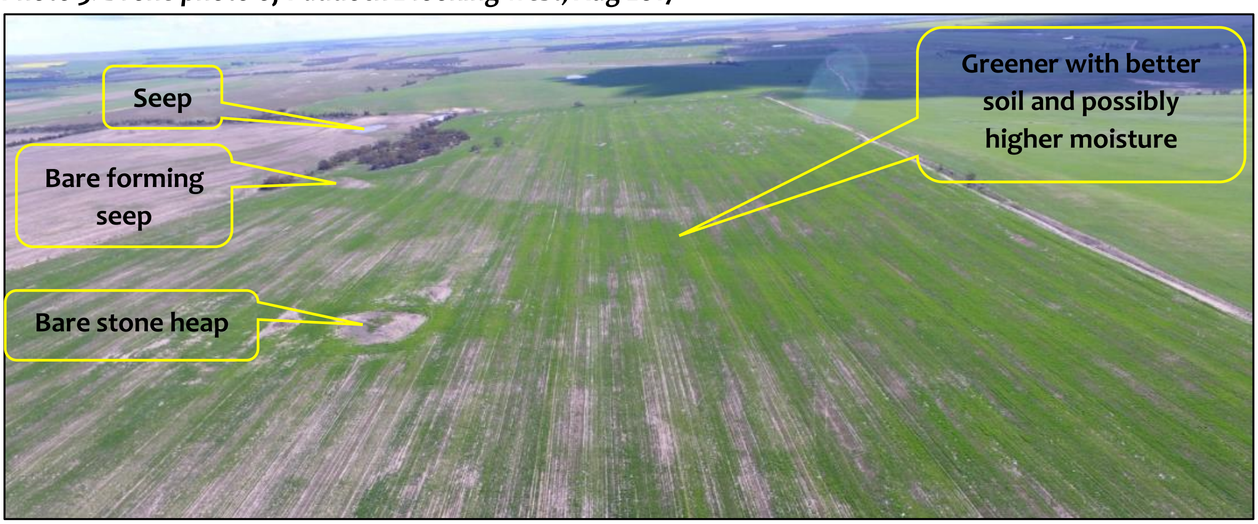


Photo 4 shows green paddock areas due to the double sowing and fertilizer of the headland, while photo 5 and 7 show barer paddock areas in the lupin crop caused by mouse and insect damage at crop establishment. There are many other factors that can clearly influence crop growth and colour, that may be totally unrelated to seep development, which emphasizes the importance of local knowledge and paddock monitoring to verify aerial or satellite images, when assessing the potential for seep related influences.

Photo 4. Drone photo of Paddock 2 looking southwest, Aug 2017

Photo 5. Drone photo of Paddock 1 looking northeast, Aug 2017

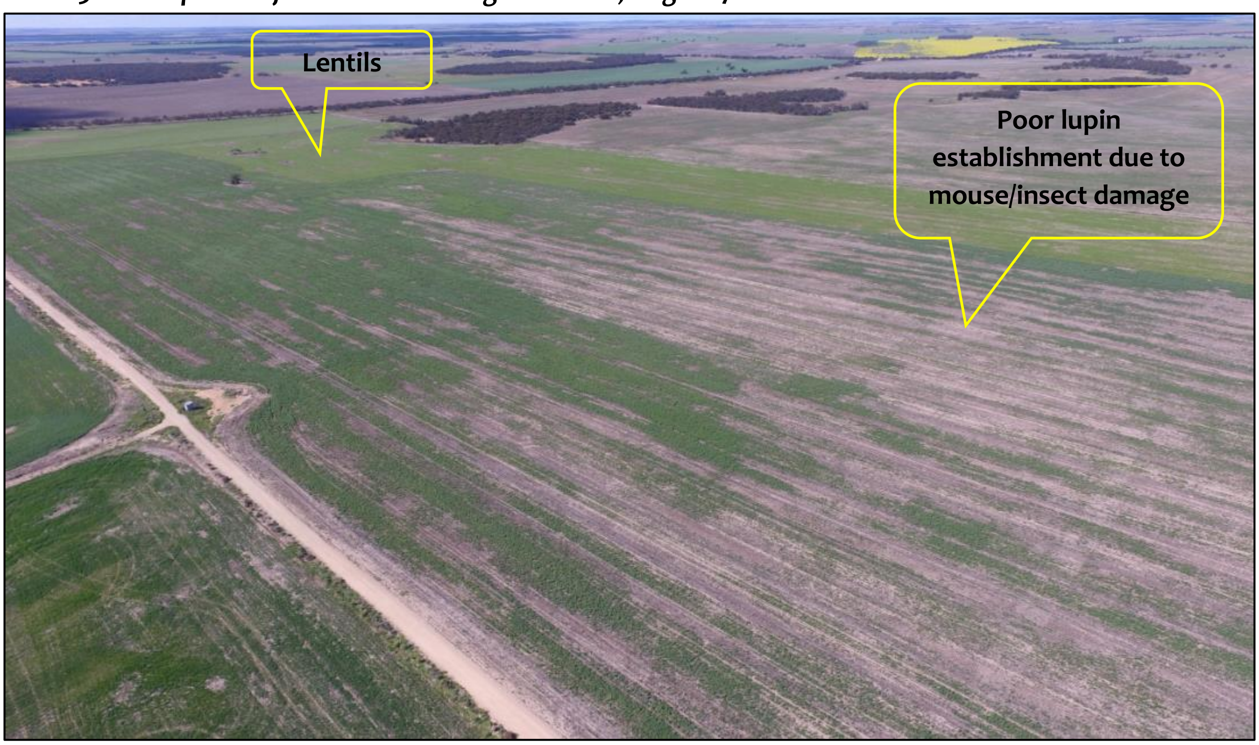
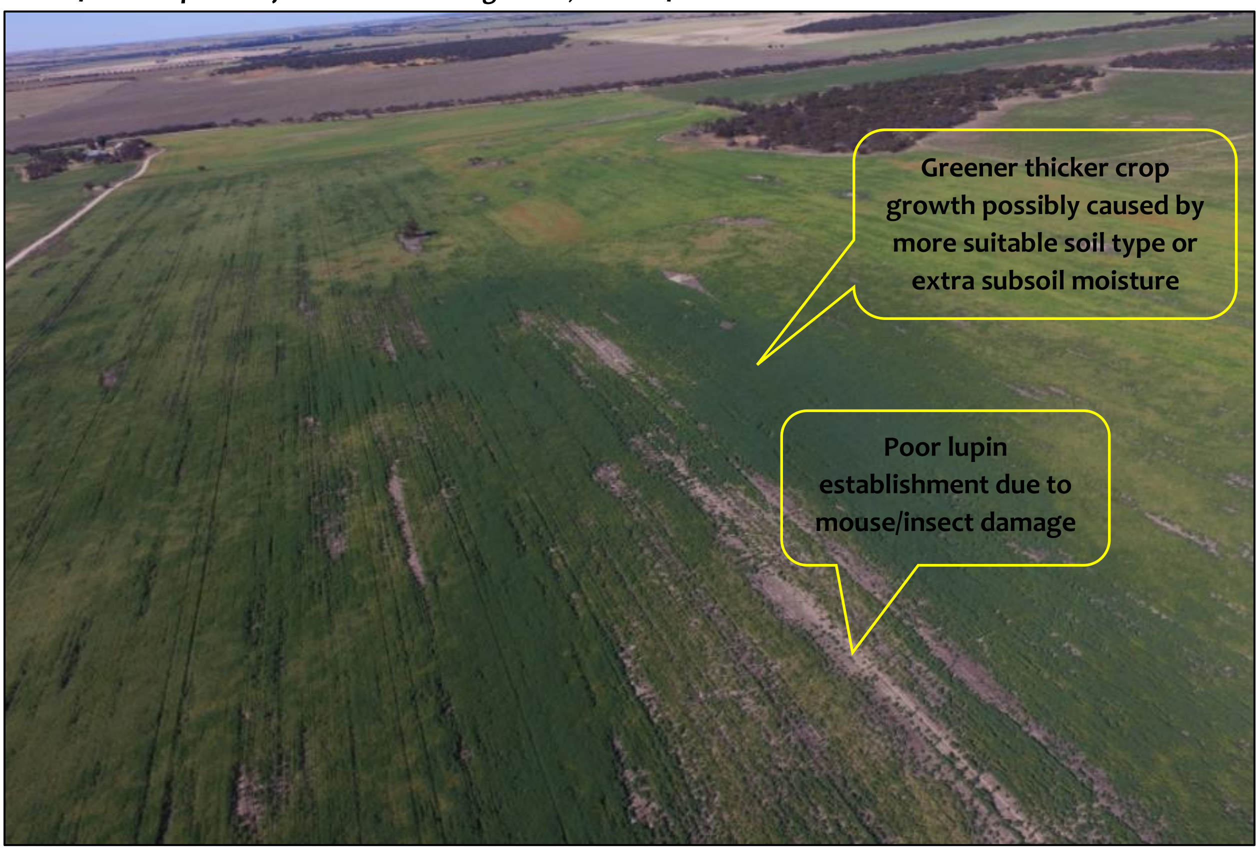


Photo 6. Drone photo of Paddock 4 looking northeast, Aug 2017

Photo 7. Drone photo of Paddock 1 looking north, Oct 2017



Paddock maps were produced from NDVI drone camera images as shown in Figures 2 and 3 from both the mid-season and late season flights undertaken. The numbered points show where post-harvest soil monitoring took place to identify areas that exhibited high levels of subsoil moisture within the crop rootzone, and were therefore considered highly prone to seep formation. Rainfall events (Karoonda Bureau of Meteorology) in the 3 months prior to the image being taken are also shown to help understand the possible influences of recent additional moisture that may affect crop growth. Results of this post-harvest soil assessment is shown in Table 1.

Figure 2 Early Drone Flight NDVI map of Martins Trial Paddocks 1 & 2

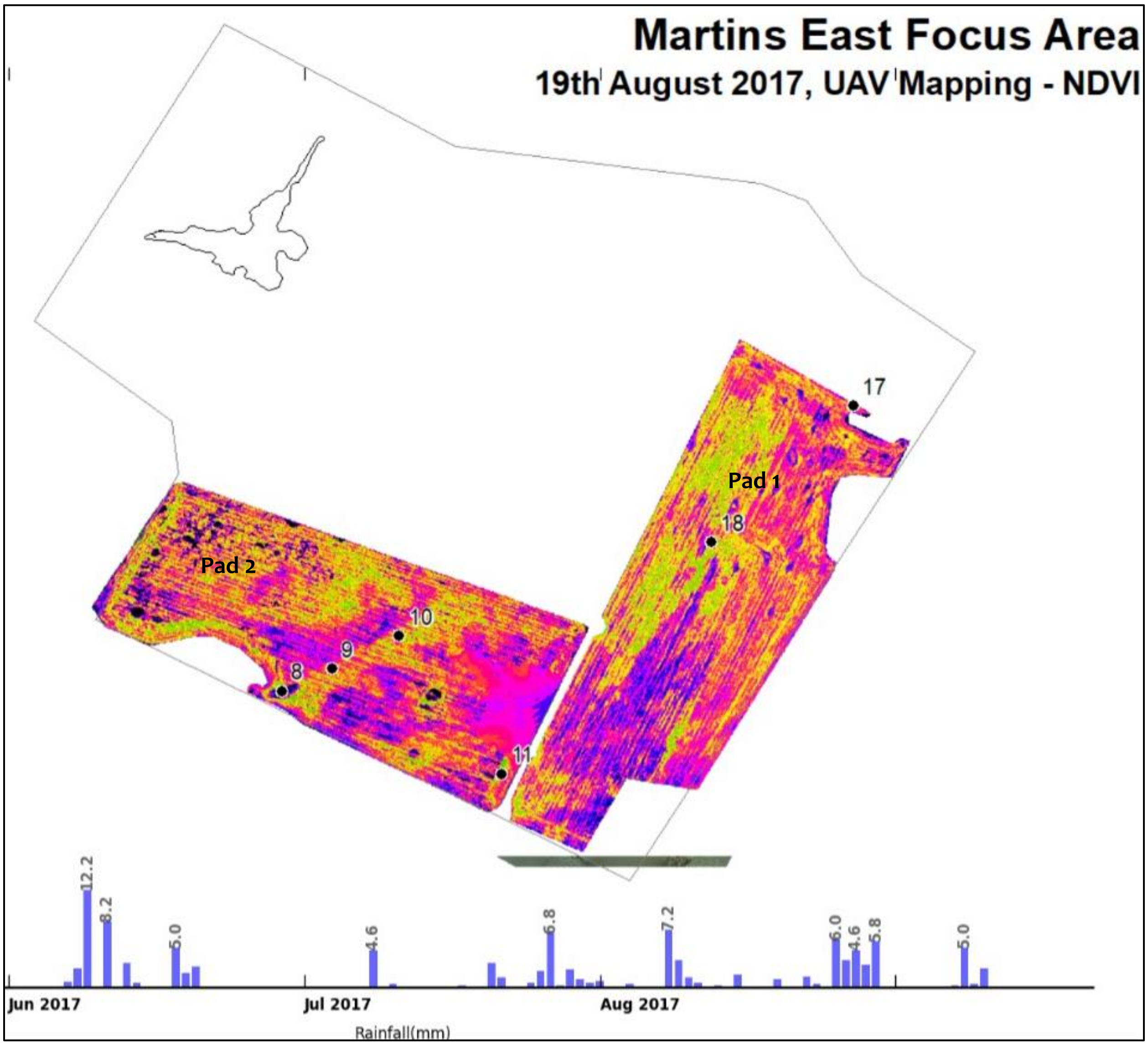
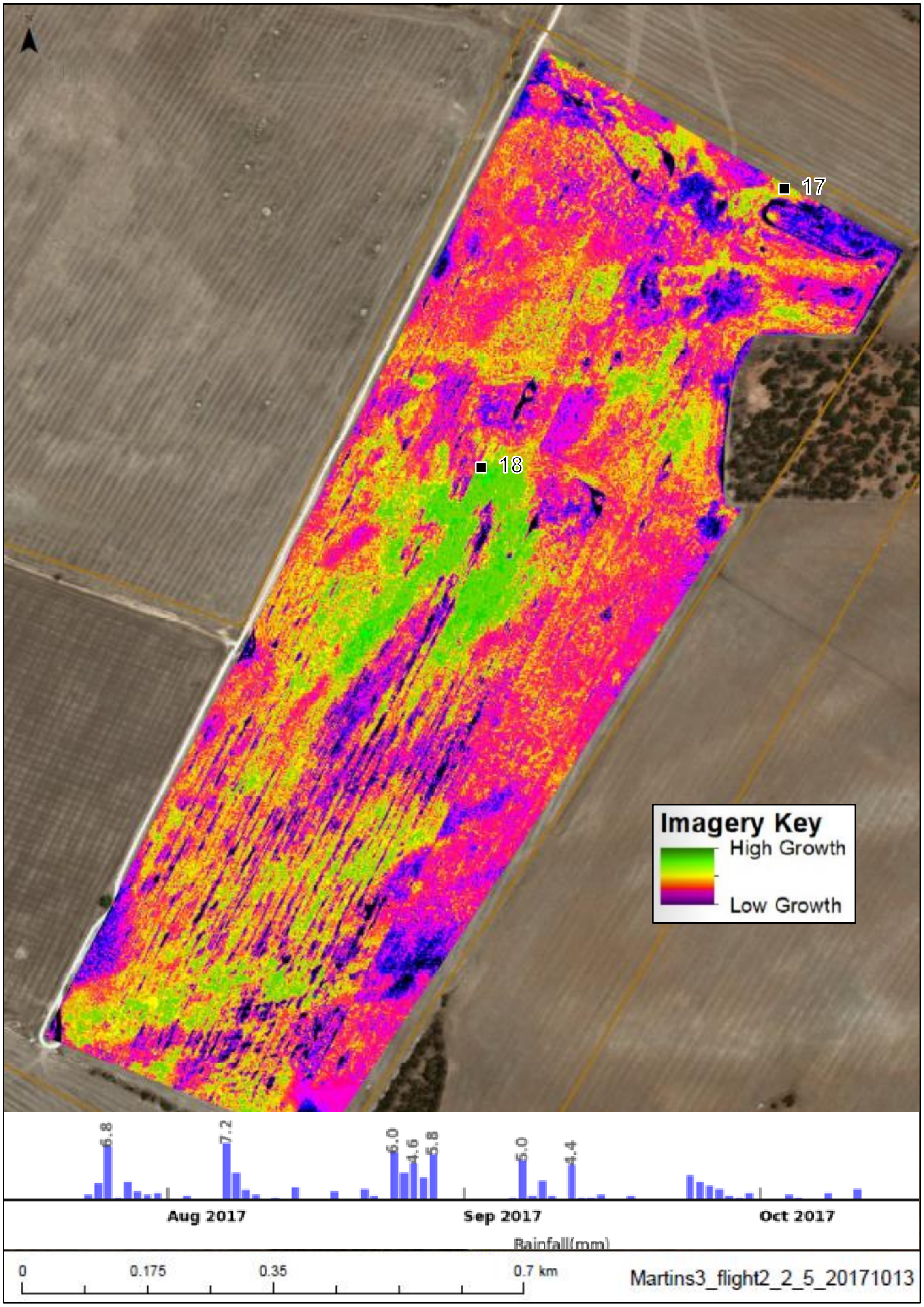


Figure 3. Late Drone Flight NDVI map of Martins Trial Paddocks 1, Oct 13th 2017



(NB. Technical difficulties meant the images late images for Paddock 2 were not obtained.)

Figure 4. Early Drone Flight NDVI map of Martins Trial Paddocks 3 & 4, August 19th, 2017

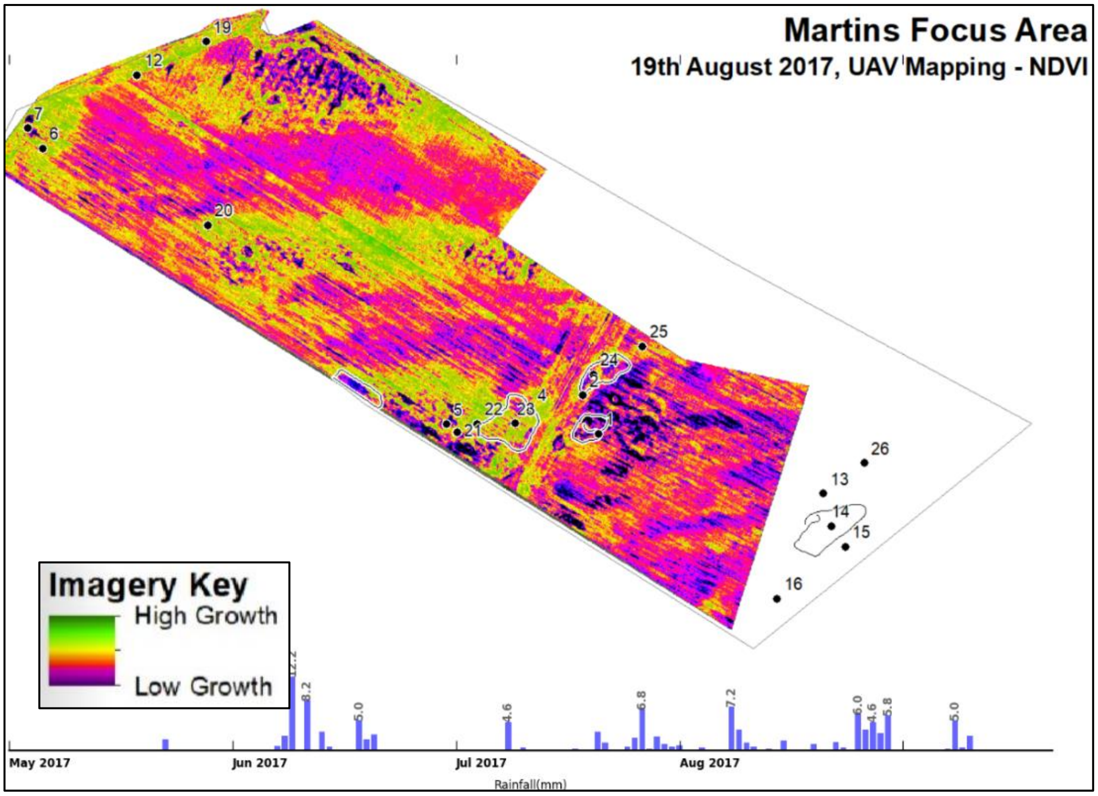
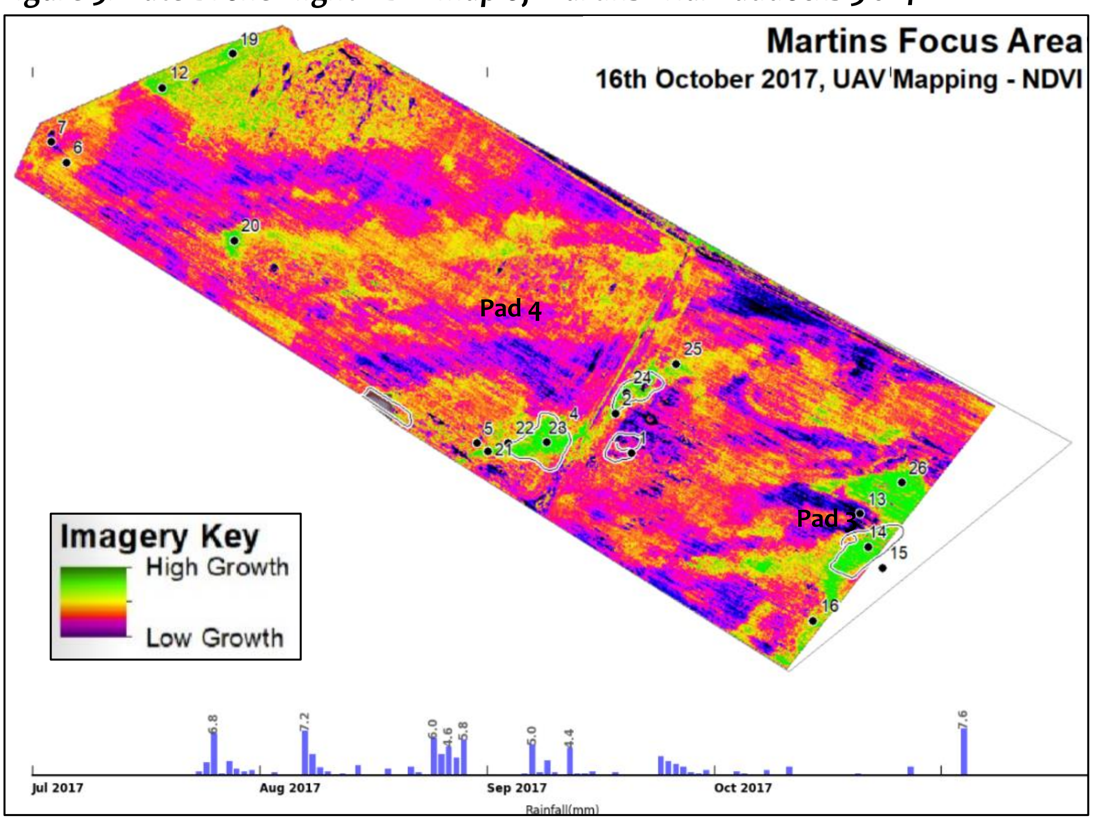


Figure 5. Late Drone Flight NDVI map of Martins Trial Paddocks 3 & 4



The following photos were taken at the time of ground truthing on Dec 5th 2017, and relate to the monitoring sites shown in Figures 2-5. Photos 8 & 9 as well as 12 & 13 show seep forming areas that were wet and ryegrass dominated mid-season, even though they were sown to crop. These sites started to become a concern to the farmer in 2016 as beginning to retain excess soil moisture. So while these specific areas have been identified as seep threatened without the use of NDVI imagery (even the satellite NDVI imagery may only indicate a slight possibility of a seep threat in 2015 - see Figure 8), the ground truthing of the wider areas (site 15, Photos 14 & 15) showed a clear saturated layer in the sand above the clay layer, in an area still growing good crop, but shown as threatened by NDVI images.

Photos 8 & 9: Site 23 Ground Truthing. Thick dominant ryegrass. Saturated Clay below 60cm

Photos 10 & 11 x: Site 13. Deep grey sand directly above seep forming area (blue circle)

Photos 12 & 13: Site 14 Wet during season, thick ryegrass, saturated clay below 70cm

Photos 14 & 15: Site 15 below site 14. Normal crop, no ryegrass but wet sand above clay at 40cm

Photos 10 & 11 (site 13) show the deep sandy soil above the seep forming areas, that are likely to be contributing excess water down the slope. Photo 16 shows a clear recent seep formation which has high moisture levels being retained through summer, as eveidenced by the specific patch green summer weed growth. While it is presently appearing in only the lower part of the swale, there are concerns that more land further up the swale may be at risk, despite the rootzone soils not appearng seep affected at present.

Photos 20 and 21, taken on the same monitoring day, show the real seep threats within the immediate landscape, as evidenced by the perched water tables both below and at the ground suface.

Photo 16: Newly forming seep area at site 8, evident by green summer weed growth

Photo 17: Newly forming seep area at site 8, looking north east towards sties 9 & 10.

Photo 18 & 19: This tall lupin crop at site 18, not currently under immediate seep threat.

Photo 20: Perched water table evident in neighboring paddock

Photo 21: Seeps forming and growing areas in neighboring paddock

Table 1. Ground Truthing of Martin Sites

Site	Martins Ground Truthing Site Monitoring	Basic Soil Texture (S-sand, LS-Loamy sand, SL-Sandy loam, SCL-Sandy clay loam, L-Loam, LC-Light Clay, Rk-Rock) Moisture Level (D-Dry, M-Moist, FC-Field Capacity, Sat-Saturated, Sl-Sloppy)									Current Seep Potential
	Soil Depth Analysis (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	
6	Midslope area, Not seep prone, Stone at 50cm	LS	SL	SCL	SCL	LC	Rk				No
		D	D	M	M	M					
7	Bottom of Slope. Stony loam over stone at 35cm	SL	SL	SCL	SCL	Rk					No
		D	M	M	FC						
8	Developing seep in swale	SL	SCL	LC	LC	LC	LC	LC	LC		Yes
		M	Sat	Sat	Sat	FC	FC	M	M		
9	Good ground cover above scald. Very damp below	SL	SL	SCL	SCL	SCL	LC	LC			Maybe
		M	M	M	FC	FC	FC	FC			
10	A bit wet on top of clay but no seep potential now	SL	SL	SCL	LC	LC	LC				No
		M	M	M	FC	FC	FC				
11	Top of hill, stony ground										No
12	Bottom of sandy rise	SL	L	SCL	SCL	Rk					No
		M	M	M	M						
13	Deep sand for at least 90cm.	S	S	LS	LS	LS	LS	LS	CS	CS	No
		D	D	M	M	M	M	M	M	M	
14	Ryegrass. Wet area through season. Saturated clay.	S	S	S	S	LC	LC	LC	C	C	Yes
		M	M	M	M	FC	FC	Sat	Sat	Sat	
15	Swale below, little ryegrass, moist sand over red clay.	LS	LS	LS	LS	LC	LC	LC	C		Yes
		D	M	M	FCS	M	M	M	M		
16	End of ryegrass area where bogged machinery mark	LS	SL	SCL	LC	LC	LC	LC			Yes
		M	FC	FC	FC	FC	FC	FC			
17	Nth end of lupins. Moist but no obvious see threat	SL	SL	SCL	SCL	LC	LC	LC	LC		No
		M	M	FC	FC	M	M	M	M		
18	Thick tall lupins. Not in obvious seep zone.	LS	LS	SCL	SCL	LC	LC	LC	LC		No
		D	M	M	FC	FC	M	M	M		
19	In swale, looks possible from the landscape	SL	L	SCL	SCL	LC	LC	Rk			No
		M	M	M	M	M	M				
20	Good crop at base of sand, no evidence of seep to 90cm	SL	L	L	SCL	SCL	LC	LC	LC	LC	No
		M	M	M	M	M	M	M	M	M	
21	Swale, leads towards seep. Possible danger area.	SL	SL	SCL	Rk						Maybe
		M	M	FC							
22	Mainly just moist. No clear threat.	SL	SL	SL	SCL	SCL	LC	LC	LC	LC	No
		M	M	M	M	M	M	M	FC	FC	
23	Ryegrass thick. Clay wet. Expect sloppy clay deeper.	SL	SL	SL	SL	SL	LC	LC	LC	LC	Yes
		M	M	M	FC	FC	Sat	Sat	Sat	Sat	
24	Beginning scald, very wet below 50cm	LS	LS	SL	SL	SL	LC	LC	LC	LC	Yes
		M	M	M	FC	Sat	Sat	Sat	Sat	Sat	
25	Green, but up slope. Damp clay. Not obvious seep.	SL	LS	LC	LC	LC	LC	LC			Maybe
		M	M	M	M	FC	FC	FC			
26	Lots of ryegrass. Obviously wet during season.	SL	SL	SL	L	SCL	LC	LC	LC	LC	Yes
		M	M	M	M	M	M	FC	Sat	Sat	

(NB: Soil textures were more visually derived rather than hand textured, as per basic monitoring required)

Table 1 reveals clearly developing seep areas at test sites 8, 14, 15, 16, 23, 24 and 26, with the possibility that sites 9, 21 and 25 might also be under threat. While the soil probe used was generally able to penetrate to the depths of the crops rootzones, there were some areas where it was impeded by stone, which may have had saturated areas below. There were others areas where a deep soil probe to 2-3m may have also provided important information about the catchments moisture dynamics. Sites 8, 14, 23 and 24 had all fitting within crop saturation zones or areas of infested ryegrass when paddocks were monitored mid-year, and therefore could have been identified without any aerial NDVI imagery.

However, what is critical is that the imagery has clearly identified the extent of areas under threat, which appears from the October scan, well after the main paddock had reached maturation (Figure 6), and confirmed which ground truthing to be clearly under threat. They exhibited saturated soil layers within the crop rootzone within a much larger area that was visibly recognizable form earlier visual ground monitoring. This is one clear advantage of applying this technology to better identify potential seep areas for targeted management for higher water use strategies, such as establishing lucerne strips on deep sands above threatened areas (as shown in blue in Figure 6), which is a strategy that has already been utilized elsewhere on the property (see Photo 22).

Figure 6 also shows some areas from the October scans that had similar colour readings to the clearly developing seep areas (sites 12, 19 and 20), but did not appear at immediate seep threat. While a deeper probe may have found moist soil, and there may be future seep development, at present they do not appear quite as distinct or have the same proximity to the deeper sands. Further monitoring and investigation of these sites may be useful to establish if in fact they represent the very early indications of seep areas.

Figure 6. Learnings from NDVI mapping and assessments of Paddocks 3 and 4

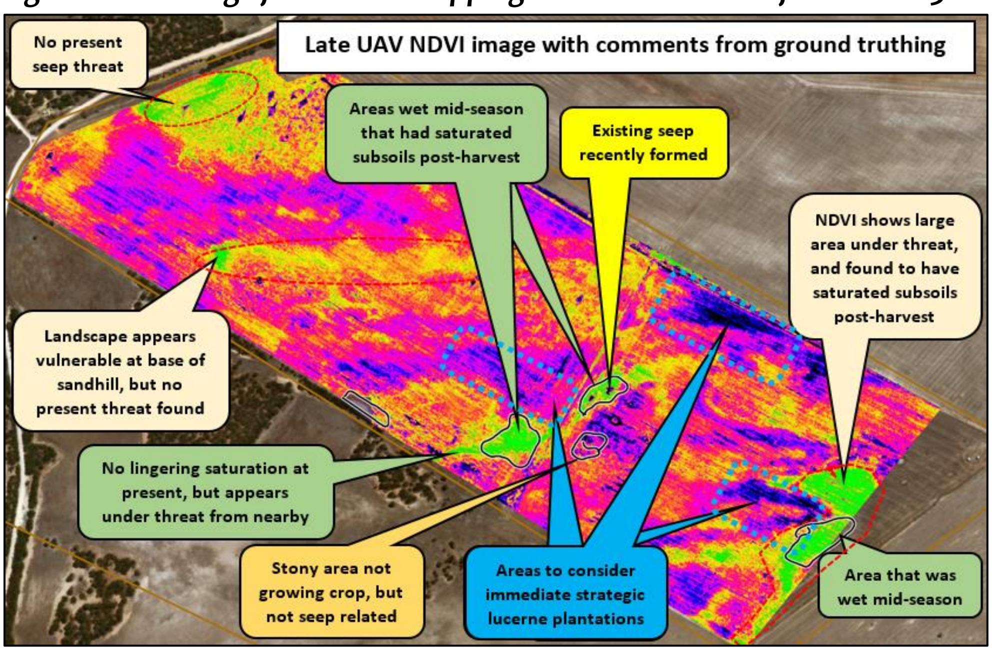
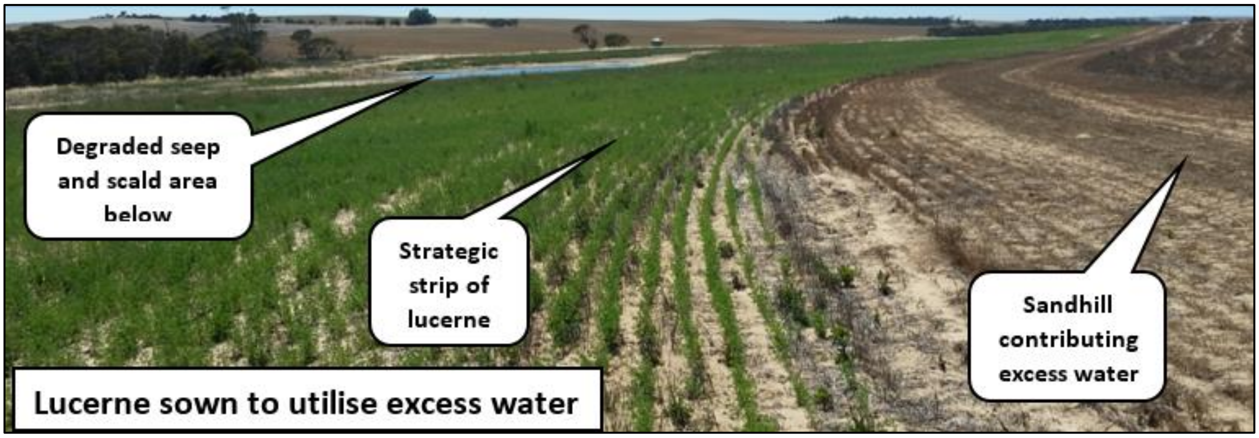


Photo 22. Recently established lucerne strip above existing seep to use up excess moisture



It would appear from this drone NDVI imagery provided, that the late season pictures are far more informative in identifying potential seep threatened zones, when the majority of the paddock has already dried off but the seep areas are staying green longer due to the excess moisture, rather than the mid-season drone flights.

The late flight information from Paddock 1 was difficult to interpret as much of the paddocks growth variation was due to unforeseen, unique agronomic factors such as mouse damage in the lupin crop, rather than potential soil seep issues (where patches of crop are thinner or establish later they can mature much later than the rest of the paddock). The paddock had not been reapt at the time of ground truthing, which made paddock access for ground truthing extremely limited. The green zone around site 18 did exhibit wet soil at depth, and so could be an area under threat to keep monitoring in the future, but did not appear to be obviously under immediate threat with its position in the landscape.

Unfortunately, due to technical issues with the drone apparatus, the October NDVI imaging for paddock 2 was not able to be obtained. Ground truthing did however reveal a developing seep at the base of a sandhill running through the paddock (site 8) which could potentially grow in a northeast direction towards site 9. This however was not shown as a clear potential threat from the midyear drone NDVI mapping flight.

4.3 Comparisons with satellite NDVI imagery

NDVI Satellite data was analyzed to assess whether this may be a practical, accurate and easily accessible tool for potential seep identification, and how well it aligns with the drone imagery and ground truthing undertaken in this project. The advantages of using the satellite imagery is that it is currently produced from fortnightly flights and is readily accessible through the internet.

Figures 7 and 8 show both Landsat 8 (pre 2015) and Sentinel 2 images of the project paddock sites at various times over the past 3 years, also showing ground truthing sites.

Figure 7. Progression of Satellite Images at Martins East area.

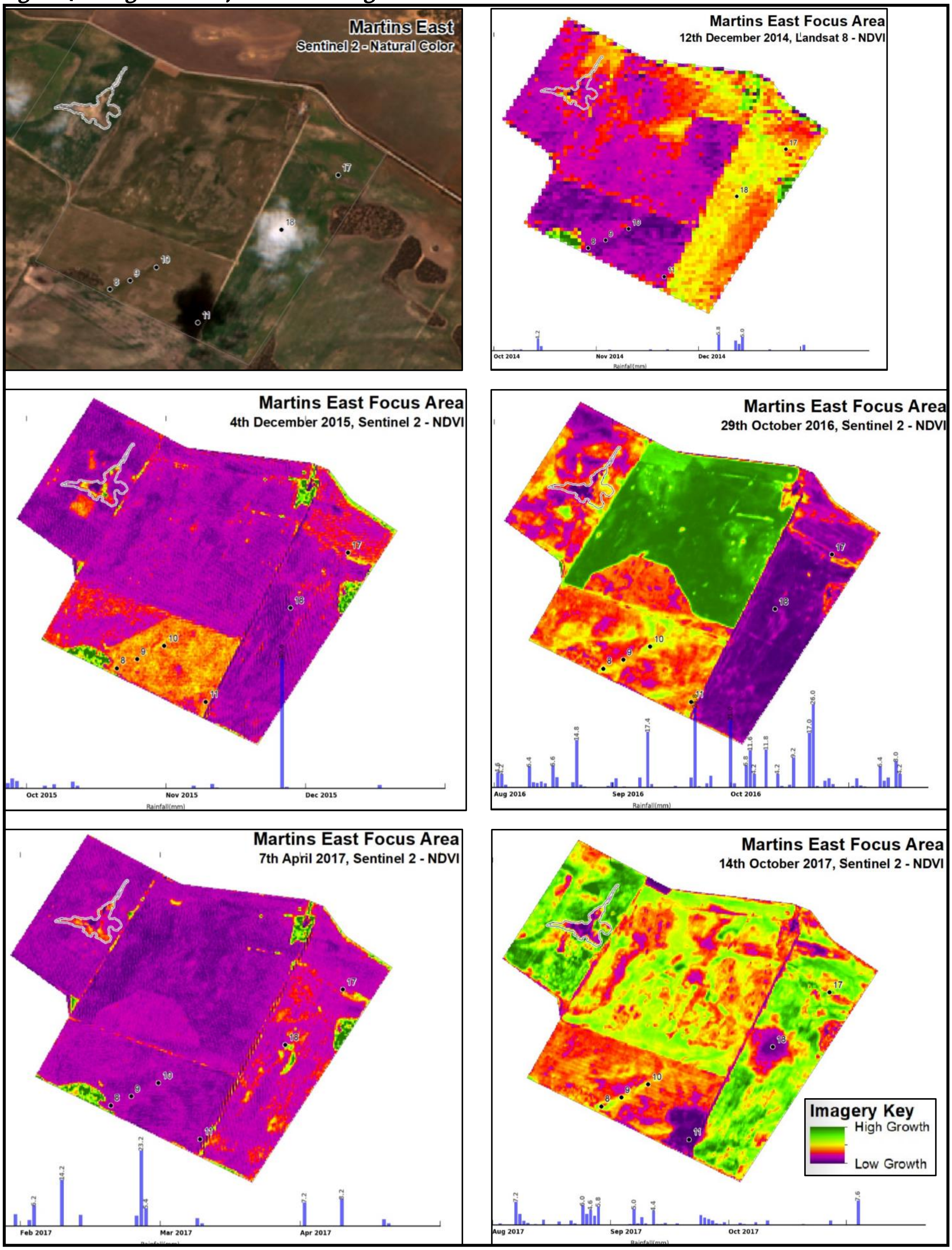
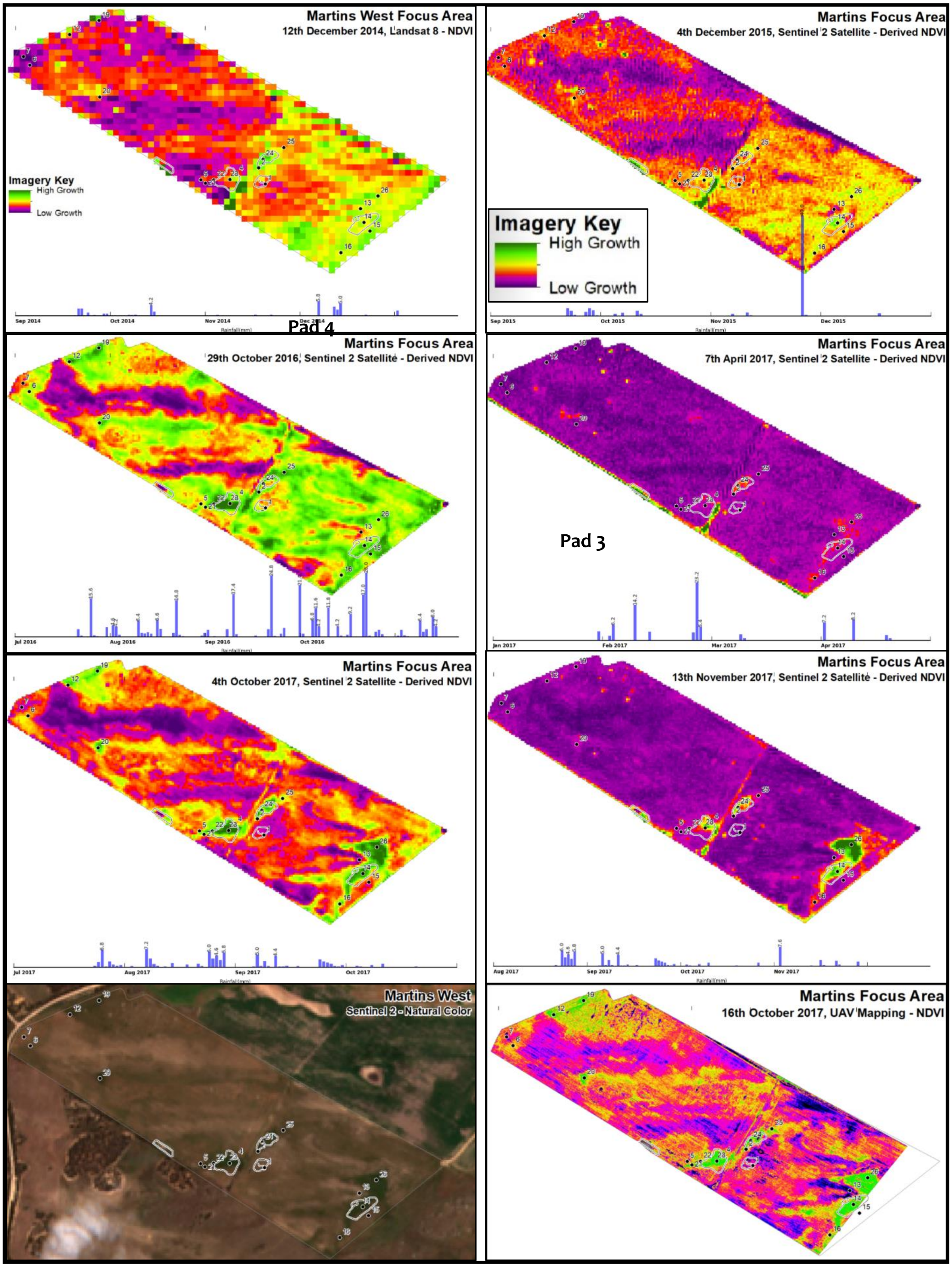


Figure 8. Progression of Satellite Images at Martins West area.



The series of satellite images shown in Figures 7 and 8 reveal a number of important factors:

1. The pixilation of the Landsat 8 images appear too broad to be able to draw meaningful paddock assessment and identification from. However, the Sentinel 2 images (which have been specially colour coded to match UAV images) are shown to be producing very comparable images to UAV images, with adequate detail to make reasonable paddock assessments and targeted management strategies. This suggests that more development work on the use of this technology based on seep formation since 2015 could be extremely beneficial.
2. The Satellite images from Nov 14th 2017 (Figure 8), one month later than the UAV images taken, appear to produce a more specific indication of the most threatening seep areas on Paddocks 3 and 4, suggesting that the optimal time for taking images may be slightly later than initially expected. More examination of this over multiple sites and seasons would help answer this question.
3. There are clear colour/paddock growth variations evident based on different crop types, sowing times and crop maturity. The green paddock in Figure 7, October 2016 represents a later maturing wheat paddock that benefited by late seasonal rainfall, in stark contrast to the earlier maturing crops in surrounding paddocks. Any programming to analyze and interpret large scale satellite data would need to address these issues.
4. The issue of cloud cover can distort ground images that could lead to false interpretation of reading, as evident in Figure 9. Site 18 was shown to be an area of high growth with subsoil moisture, but is shown in the NDVI image to have no growth due to the patchy cloud cover. It can also make many of the satellite flights images unusable for entire regions. As shown in Figure 10, this project was unable to utilize any images from 3 flights around Sept 2017 due to excessive cloud cover.

Figure 9. Cloud cover issues affecting image accuracy and interpretation.

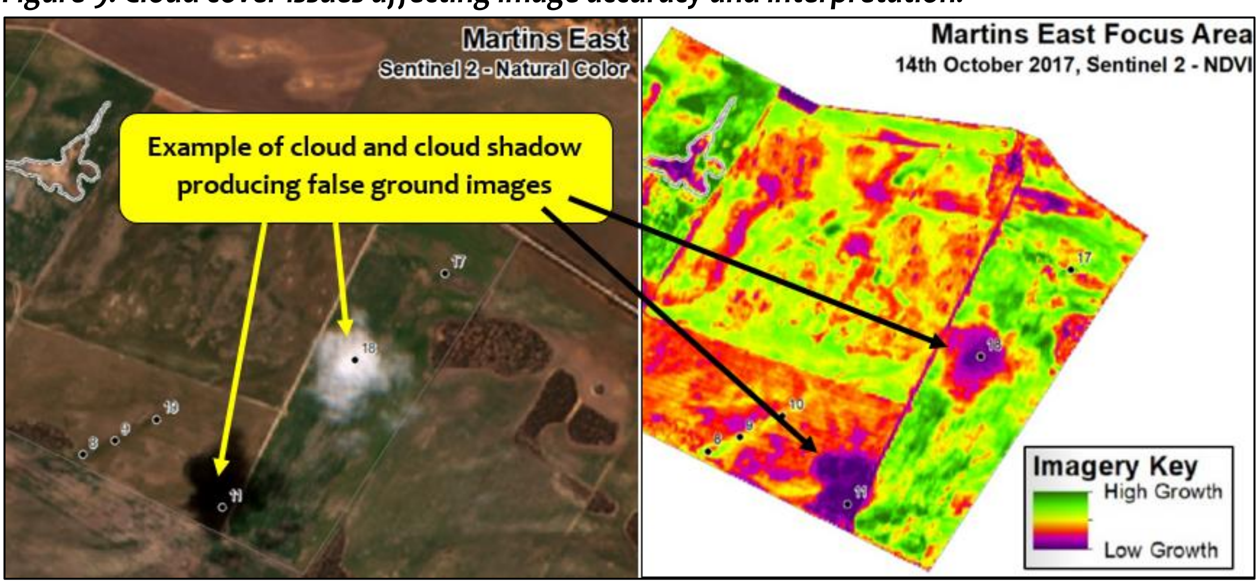
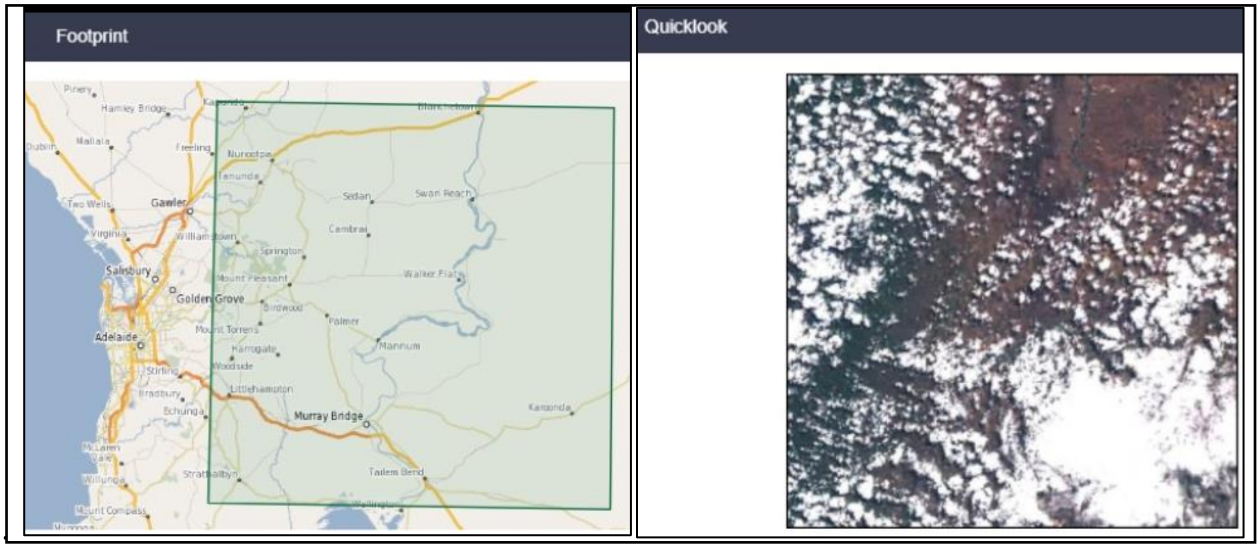


Figure 10. Sentinel 2 Satellite image in Sept 2017 showing problems with cloud cover.



5 The potential for further development of using NDVI technology for early detection of seeps

This project has uncovered strong potential for the use of NDVI technologies, both UAV and Satellite based, to give early indication as to the risk of future seep formation within landscapes. However, this was a relatively small project, with limited resources, conducted over 2 properties in one monitoring season. The areas that could greatly benefit from further development include:

5.1 The development of effective analysis methods.

Current analysis of NDVI images consists of visual assessment of potential sites, which does not scale to assessments of the wider landscape. There is a need to develop tools which can be used for early detection and remediation, more efficient methods are needed. More in-depth analysis of recent NDVI satellite imagery over areas that have formed seeps in the last 3 years should provide important guidelines as to the most critical times to view images for potential seep identification. This will need to account for seasonal variations, crop and pasture types, as well as variations in soil types and landscapes. This may provide guidance to the targeting of UAV operations as well as the potential for relying on satellite imagery.

5.2 Future seep identification form NDVI imaging should be based around a learning model of analysis:

Look at existing sites to determine:

- Spectral (image) characteristics
- Size and shape of emerging problem areas
- Any other common characteristics such as timing colour changes in paddock growth patterns, site proximity to poorer growing sandy areas

Use this information from known sites as training data for a model which scans satellite imagery and other data sources to find potential new sites.

Filter out sites which are not of interest, but which may have similar characteristics:

- Irrigation areas
- Areas close to the river corridor
- Urban areas
- Higher rainfall zones

Work with landholders identified through Mallee Seeps Survey to cross check and ground truth program findings. Mark sites which do not have problems as false positives and add this as data to the model. Rerun model and repeat the process with new data gathered. (This type of training model is more likely to be successful if using an existing model that has already been developed with similar landscape training data.)

5.3 The scale of use of predictive seep technologies:

While it is possible that methodologies using NDVI mapping with UAVs or Satellites may be developed for farmers to use for their own properties, it may also be possible for such technologies to be developed for regional scanning of large satellite data sets, whereby organizations or State bodies could assist in the identification of potential seeps sites, and then help in the facilitation of remediation and ongoing management of these issues with landholders across districts.

5.4 Additional datasets that may provide useful information on seeps:

Elevation / Lidar data:

- Seeps are often found low and midslope areas in the landscape, but the local topography is more important than the mean distance above sea level.
- Looking at current sites of interest may unearth some rules based on elevation which can be used in the search for other potential problem areas.
- This area is unlikely to be frequently imaged with high resolution lidar, but where it is available it would be a valuable source of information.
- For paddocks which are cultivated using precision farming equipment, high resolution elevation could be derived from seeding or harvest data for the paddocks concerned.