Delineating tile drain networks using infrared imagery from drones -Final report

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Exec Summary

Previous research performed in the United States showed it was possible to detect the location of subsurface field drains using Near InfraRed photography. The aim of this project was to use existing camera technology with UAVs (drones) to determine if tile drains could be located within field systems. The effect of soil moisture and surface drying on reflectance was determined in a controlled experiment with five levels of moisture. This showed the best moisture levels for widest reflectance differential was between five and fifteen percent moisture by volume, and also confirmed the expected effect on surface drying on reflectance levels. These results indicated that detection of soil moisture patterns required a very narrow set of conditions.
A tool was developed to plot the reflectance of the surface across a field, and hence apply metrics to the detection process, as well as better detect the centre of the drain.
Flight trials were carried out over two properties which contained known field drains, and three types of cameras were used to survey the areas, in both the Near InfraRed and Red Green Blue visible spectrum. In one site, several drains were detected, but in the case of the other site, no drains were evident in any spectral band, despite having similar weather patterns. As we know the drains were flowing at that time, the lack of detection can probably be attributed to different soil types, but this is unproven. Trials within the project timescale in the Environment Southland regional territory were hampered by the lack of farms identified with suitable fields, lack of rain or unsuitable post rain weather.
Weather conditions played an important controlling factor in this project; it largely determined the success of detecting subsurface field drains and the infrequent occurrence of ideal conditions is mentioned in previous research. The ideal conditions require a large amount of rain, and then overcast skies, little wind and high pressure to reduce surface evaporation. In addition, the fields should have bare earth showing, and be devoid of clay type soils to help ensure good drainage.

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1 Introduction

The distribution of tile drain networks is a critical knowledge gap in Southland and other parts of New Zealand with extensive artificial drainage networks. Evaluating whether tile drains are a major contributor to water quality problems is currently almost impossible, because water quality patterns cannot be related to corresponding patterns in tile drain distributions or density. Similarly, it is hoped to relate the quality of water in tile drains to their respective catchments, but this is another difficult task without an accurate map of the tile drain network. Environment Southland considers that a better understanding of tile drains is a high priority, and needs advice on how best to collect this information. The use of unmanned drones could provide a very low cost and effective method of producing maps of tile drain networks.

The purpose will be to capture infrared imagery via drones 2-3 days following heavy rain and produce maps of the tile drain networks using patterns in soil moisture.

This project is effectively a proof of concept into the use of drone derived infrared imagery for mapping artificial drainage networks. Specifically, the aim is to produce maps that the science team will use to structure water quality investigations into the effects of varying land use practices on tile drain water quality. This will be a key step into a greater understanding of water quality issues in Southland, and enable a more effective response to setting limits as part of the response to the National Policy Statement for Freshwater Management.

2 Existing research

Several papers have been published in this subject, much of the work was first carried out by Verma A.K. et al in 1996 (1) and later by Naz B.S. et al in 2008 (2). In these studies “colour infrared” (CIR) photographs were used, which we believe to be scanned versions of film photographs.

Much of the work was carried out in the Midwest regions of the USA, where the tile drain systems are much more extensive than in New Zealand. The picture in Figure 1 shows a sample of their work, where each drain has many branches, indicating very large field sizes.

This early work concentrated on automatic detection techniques, using edge detection algorithms to distinguish linear features. If successful, these could eventually lead to the production of shape files representing the centre line of the drains, and could be directly imported into a GIS tool.

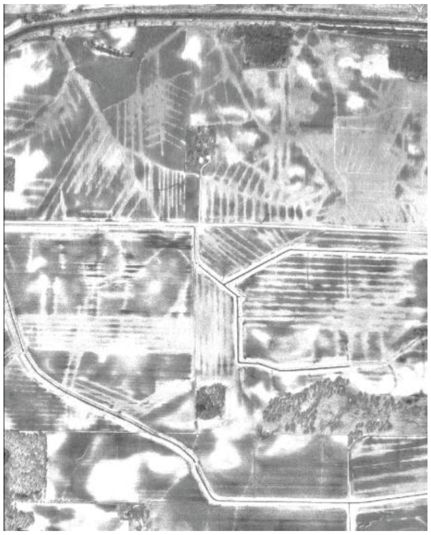


Figure 1. An example of aerial image showing the installed tile lines in agricultural fields. The tile lines appear brighter on the image than surrounding areas.

3 UAV aircraft types and selection of suitable airframes for this payload and task.

There are currently two categories of Unmanned Aerial Vehicle (UAV) or “Drone”, rotary wing and fixed wing.
The rotary wing aircraft, like a helicopter, is very manoeuvrable and capable of landing and taking off vertically. This is an advantage when operating around trees, buildings and power lines. However, the total mass of the payload and aircraft is carried by the trust of the motors, so the operational endurance is limited by the payload weight.

Alternatively, a fixed wing aircraft is much more efficient and as the total mass is lifted by forces on the wings, can stay airborne for greater than 20 times a rotary wing equivalent, so would therefore be the choice when areas greater than 5 hectares are to be surveyed. However, this type of aircraft would require a larger take-off and landing space.

As this project was a proof of concept, the area of survey for each field was limited to restrict the data set size to manageable quantities. This allowed the use of a rotary wing aircraft and freedom to operate in a wider choice of fields, trees and vegetation, with a subsequent improvement in safety.

The specifications of the UAV used in this project are shown below.

- Manufacturer Steadidrone
- Model QU4D
- Type quad rotor airframe
- Autopilot Arducopter APM2.
- Operational endurance approx. 15 minutes, dependant on payload mass.
- Max payload 500grms
- Cameras as specified by mission.

Figure 2 SERC QU4D multirotor UAV.

4 Selection of suitable cameras.

The previous research in this subject (Ref 1) used “Colour Near Infrared” images, which guided this project into using Near Infrared (NIR) cameras, as well as multispectral cameras and “visible light” Red Green Blue (RGB) cameras.
In other studies of soil moisture remote sensing, such as Ref 5, a wide multispectral or hyper spectral camera has been used, with specific inter-spectral relationships giving estimates on wide area soil moisture content. However, these types are cameras are usually large and carried by satellites where the resolution would not be fine enough to detect individual tile drains. Some smaller hyper spectral cameras can be carried by full size aircraft, and even large UAVs, but have a very high cost and therefore could not be included in this study.

4.1 Choice of cameras for small UAVs.

A small low cost UAV has a limited payload weight, there has to be some compromise with camera performance. Smaller, lighter cameras have smaller lenses which will have lower light input than larger cameras, needing longer exposures and hence slower ground speeds. However, the most recent “sports” cameras have excellent performance, and with lens distortion correction software, acceptable results can be achieved.
The spatial resolution to detect tile drainage patterns would need to be better than 1 metre for good results; all the cameras used in this project have resolution better than 50mm.

4.2 Cameras used in this study.

A. For the RGB (visible light) spectrum we used a GoPro Hero Black sports camera, configured in the 12mpx single shot time lapse mode. Due to the wide angle nature of this lens, all images needed to be passed through a distortion correction process. At a height above ground of 120m the spatial resolution of this camera is approximately 25mm, with a single image size of 0.76 Hectares.

B. For the multispectral images we used a Tetracam ADC lite (Figure 4) with C mount variable aperture lens. This had a spectral response of approx. 850nm Near InfraRed (NIR), 600nm (red). At a height above ground of 120m the spatial resolution of this camera is 48mm per pixel, with a single image size of 0.73 Hectares.
C. As an alternative to the Tetracam, a ContourGPS sports camera (Figure 3) was converted to the Near Infrared spectral band (900nm wavelength) by removing the internal Near InfraRed (NIR) blocking filter and adding a NIR band pass filter to the lens front. Due to the wide angle nature of this lens, all images needed to be passed through a distortion correction process. At a height above ground of 120m the spatial resolution of this camera is 26mm per pixel, with a single image size of 0.3 Hectares. Specifications can be found in Ref (6).

Figure 3 Contour camera, modified for NIR images

Figure 4 Tetracam ADC lite multispectral camera

5 Flight guidance system.

5.1 Regulations

Currently the CAA legislation controlling the use of UAVs is lagging behind the capability of the technology. The current rules are based on recreational flying of radio controlled model aircraft, and do not permit operations where the aircraft is beyond the visual range of the pilot on the ground, with the height not to exceed 120m above ground. Additional restrictions apply when in the vicinity of controlled airspace or within 4km of airfields, and no night flying is permitted. In special one off circumstances these restrictions can be exceeded by application to the CAA for exemption.
This research centre is actively working with the Civil Aviation Authority to introduce new rules allowing more flexibility in the use of professional UAVs, whilst ensuring the same safety standards that are experienced in the current aviation community.

5.2 Flight planning and guidance systems

The most common method to control a UAV is to use a waypoint driven guidance system. This requires the pilot to determine the path of the UAV when in flight, by placing waypoints on a map, as shown in Figure 5 below. Each waypoint sets a position and height above ground. Point 13 is a placeholder waypoint with an instruction to auto land at the home position. Intermediate waypoints such as 2, 5, 8 and 11 are inserted to maintain height above ground when the tracks between waypoints are over 300m. The small white circle around each waypoint sets the capture radius, in this case 5m that must be entered by the UAV before continuing the flight.

The distance between tracks, and hence the side overlap of images, is dependent on the field of view of the cameras. If the cameras are not gyro stabilised the roll angle due to turbulence will also determine the track widths, which is a very difficult parameter to predict, and is currently a judgement of the planning pilot.

Similarly, the overlap of images along the flight track is determined by the frequency of image capture if still pictures are being taken. This is not normally a problem and good overlap can be ensured by increasing the picture rate.

As can be appreciated, a good map of the area is essential before flight planning takes place, and this can sometime be an issue when arriving at a site with no internet capability, and no prior knowledge of the area.

This particular example, setup for the Eiffelton field, is a flight of over 2km which would have a flight time of 12 minutes. Adding some safety margin for take-off and landing, this would be the maximum time/distance this type of aircraft could fly, although a small increase could be achieved by increasing the ground speed, with subsequent risk in blurred images.

Figure 5 Mission Planner map showing flight guidance waypoints

6 Image stitching software for NIR and RGB images.

If the area to be surveyed is larger than one image of the camera, then some form of stitching process will need to be carried out. This project used two different tools to do this. For fast processing and "quick look" results the Microsoft "Image Composition Editor" tool was used, and in some cases gives adequate results for publishing. For more professional results, the Agisoft Photoscan tool was used. This builds a 3D reconstruction of the survey area and then lays the images over the elevation model thus

created. An ortho rectified mosaic can then be exported. This tool also has the ability to directly georeference images from GPS measurements on the UAV, but accuracy will be poor if the image centre is not directly below the aircraft. For this reason, Ground Control Points (GCP) can be employed to georeference images and hence fix the resulting mosaic to earth surface coordinates.
Other tools can be employed for this task, such as PIX4UAV http://pix4d.com/products/ as well as AreoHawk http://areo.co.nz/areohawk/

6.1 Georeferencing

Although the images collected in this project were not geo-referenced, it would be a simple matter of surveying the field corners, or some other identifiable feature, and incorporate these GCP into the mosaic image stitching tool to georeference the output. Alternatively, a GIS tool like ARC MAP can be used to ortho-rectify the mosaic.
From these results, measurements in the GIS tool could be made to locate the drains to within a very high accuracy, dependant on the original survey points and image resolution. Further improvements in accuracy could be achieved with the use of the Transect pixel value tool developed in this project (Section 9).

7 Preliminary work

7.1 Controlled soil moisture reflectance trials

This project relied on the ability to detect patterns in soil moisture around subsurface drains. Therefore, to assess the changes in reflectance qualities of soil with various moisture levels, trials were set up using samples of soil with specific water content. The effect of evaporative drying of the soil on reflectance was also measured.

7.1.1 Objective

To determine the reflectance of soil surface with various moisture levels, in various spectral bands.

7.1.2 Materials

80 litres of screened soil (light clay loam), five 10 litre plastic containers with top diameter 29cm.
Cameras - Tetracam ADC lite, GoPro Hero Black, ContourNIR.

Material preparation – The complete stock of soil was laid in a thin layer across a concrete plateau to dry in the sun. The soil was deemed to be dry when the particles, including their insides, turned a very light grey colour. Five 10 litre samples were created from the soil stock. Each sample was laid out over the concrete and had a specific water volume evenly added to the soil. The sample was then quickly placed in a 10 litre plastic bucket and an air tight seal applied.

The samples were given the following moisture by volume 0%, 5%, 10%, 15%, 20%
At approximately 25% the average soil is deemed to be at “field capacity”, which is the maximum water volume that can be held by freely drained soil. This is different to “saturation” where no further water can be absorbed into un-drained soil, and would be signified by long duration laying water. Ref (4).

7.1.3 Trial 1. Reflectance of different soil moistures.

7.1.3.1 Method

The containers were grouped together and photographed with all cameras in turn, in both direct sunlight and diffused light. The resulting images were converted to Greyscale, then had the pixels of the each soil surface sampled to a median level.

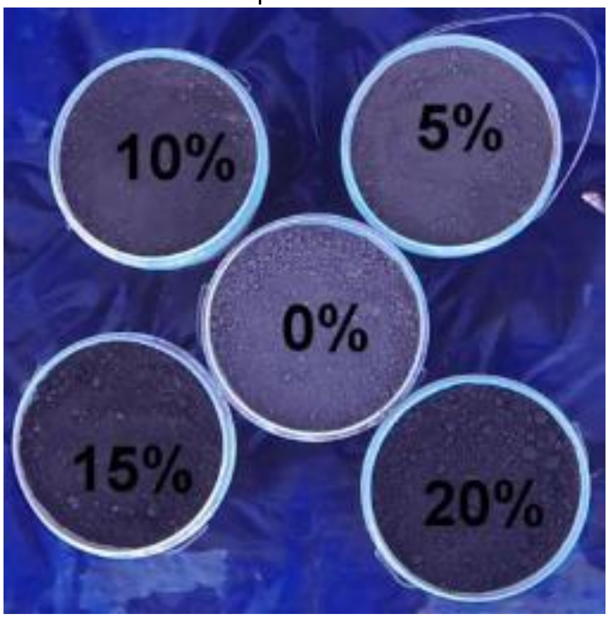


Figure 6 General arrangement of containers with different soil moistures

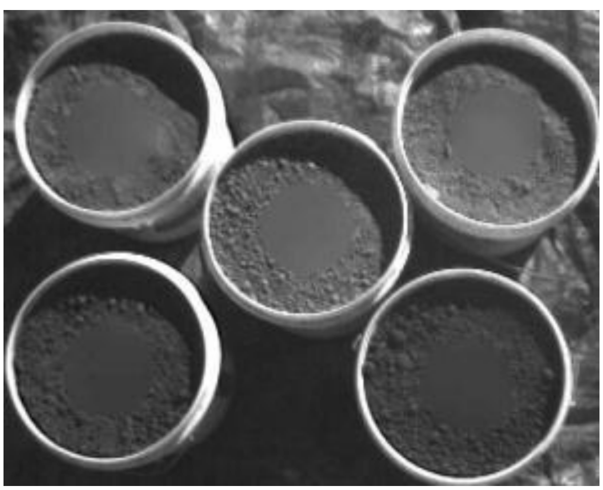
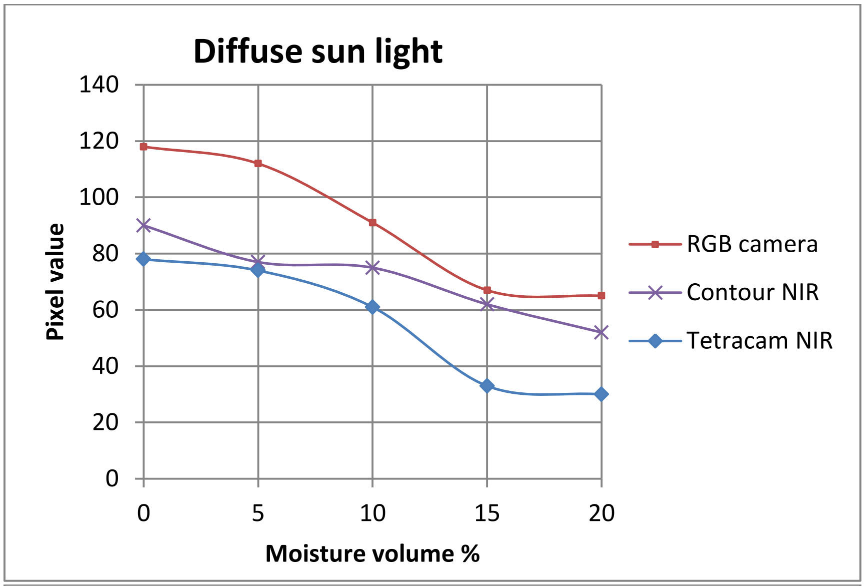
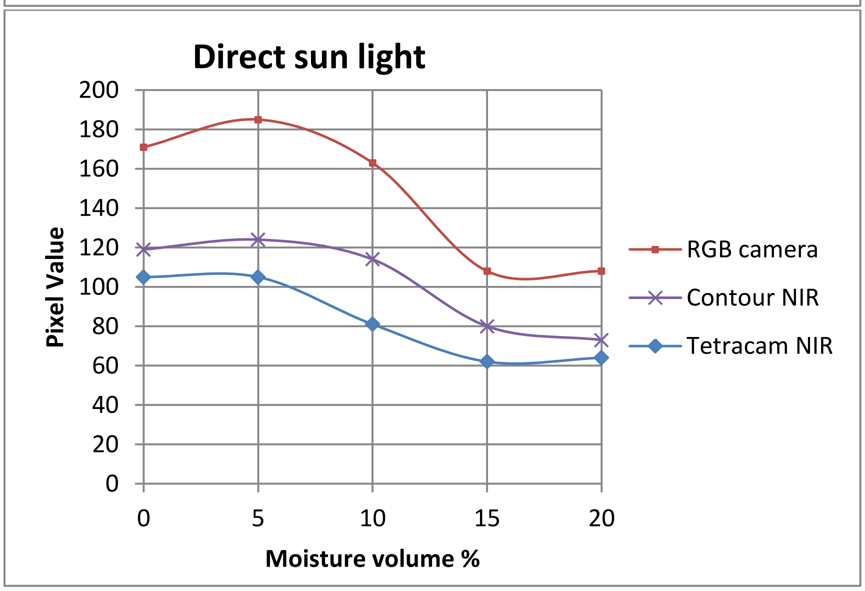


Figure 7. Typical image showing the conversion to greyscale and sample spots converted to median intensity.

7.1.3.2 Results





7.1.3.3 Discussion

As can be seen in the graphs above, the major reflectance differential at the sampled wavelengths appears to be between 5% and 15% moisture volume, with little differential at the dry and wet ends of the scale. In this trial the RGB camera (total luminance) gave a better signature for soil moisture than the Near Infrared cameras. Some unexplained effects are evident, such as the higher reflectance of 5% compared to dry soil, although there has to be more variations in all the direct sun measurements due to shadowing from larger soil particles when the sun is not overhead.

In both direct and diffuse sun light, the RGB camera would appear to give marginally better reflectance differential.

These results would suggest there is a critical soil moisture level that is required to give the best conditions for moisture patterns to be visible. This condition will occur at some time after the field has receded from “field capacity”, and this time delay will be dependent on the soil types. Clay soils will drain more slowly than lighter soils.

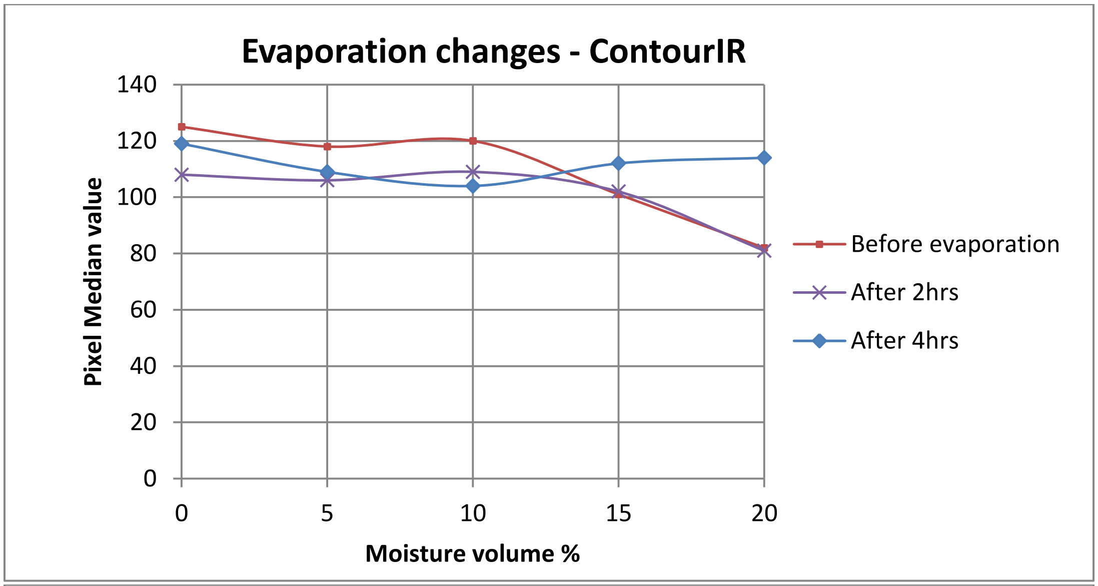
7.1.4 Trial 2. Effect of surface evaporation.

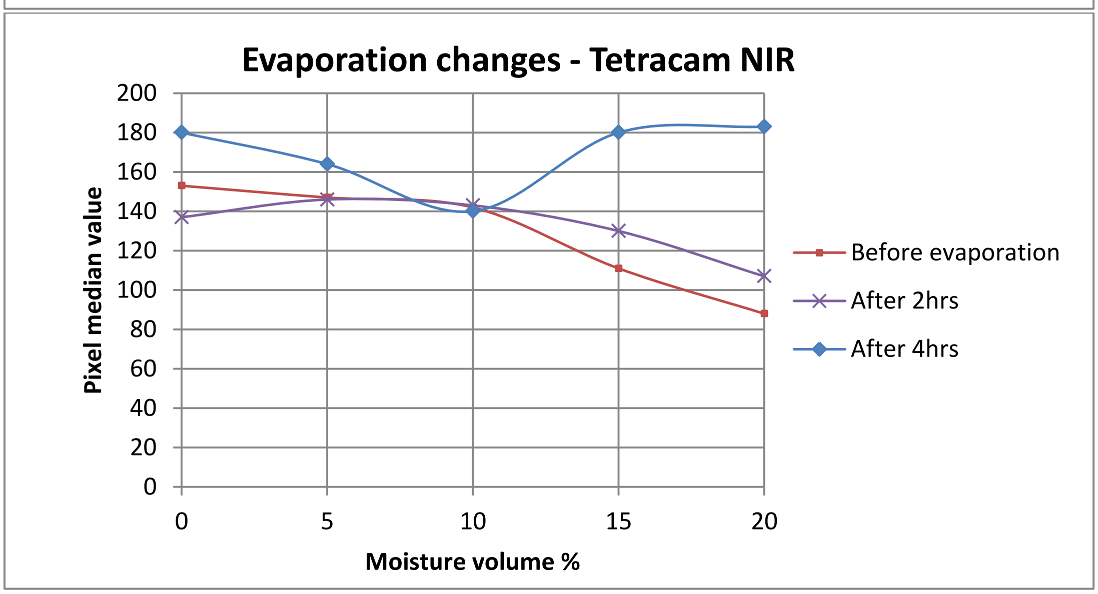
The objective was to measure the reflectance changes as the soil top surface dries with direct sunlight.

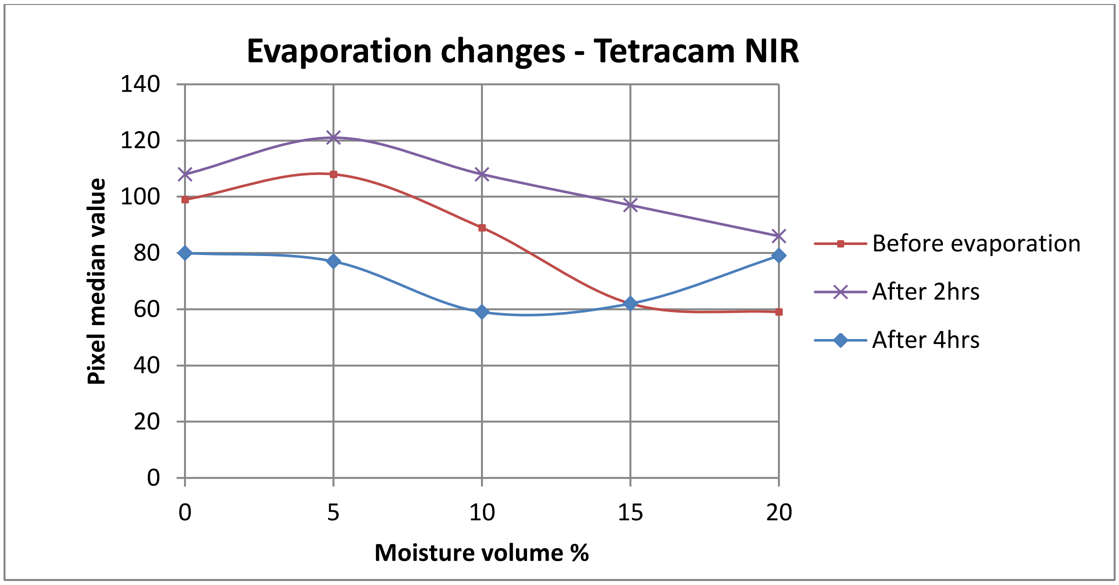
7.1.4.1 Method

The buckets were grouped together in direct sunlight and photographed with all cameras in turn, then left to dry. This image capture was repeated at two hour intervals.

7.1.4.2 Results







7.1.4.3 Discussion

We would normally expect the surface of the moist soils to become gradually dry, and to approach the same reflectance as the dry sample. Undoubtedly this would have occurred if the experiment had continued for longer than 4 hours, but unfortunately the direct sunlight was lost at that time. However, a common effect was seen after four hours; the 20% moisture soil appeared to become as light as the dry soil, whereas the 5, 10 and 15% soils still appeared to be slightly darker. The explanation for this is unknown, but one hypothesis may be the large particle size of the more moist soil sample causes shadows at low sun angles, creating an overall darkening of the image. This effect could also skew the results in the field, and emphasises the effect of sun angle.

8 Airborne trials

Trials were carried out in two locations with working distance of University of Canterbury. The land owners permitted the work to be carried out, but no results of this project were shared with them. Previous studies in this subject (ref 2) recommended at least 25mm of rain in the preceding 2 days, although in personal communication with one author, this was changed to preceding 2 hours.
As the following data shows, the total rainfall in the preceding 7 days was approximately equal in all trials, but the number of dry days after rain is different.

8.1 Akaunui Farm, Eiffelton

Figure 8 General Google Earth view of the Akaunui paddock in Eiffelton. Red lines indicated drain routes estimated by the land owner.

Akaunui Farm is a mixed cropping farm, mainly growing feed for the dairy industry and also having large fields dedicated to the production of grass seed.

Landcare information (ref 11) shows Soil type is Wate shallow Silt, Poorly drained.

8.1.1 Eiffelton 7th March 2014

Rainfall in preceding 7 days = 29.2mm
Preceding sun days = 2
State of tile drains – not flowing
Field state – bare soil, stubble residue

Figure 9 Eiffelton 7th March, Field state, showing stubble residue

8.1.1.1 Results

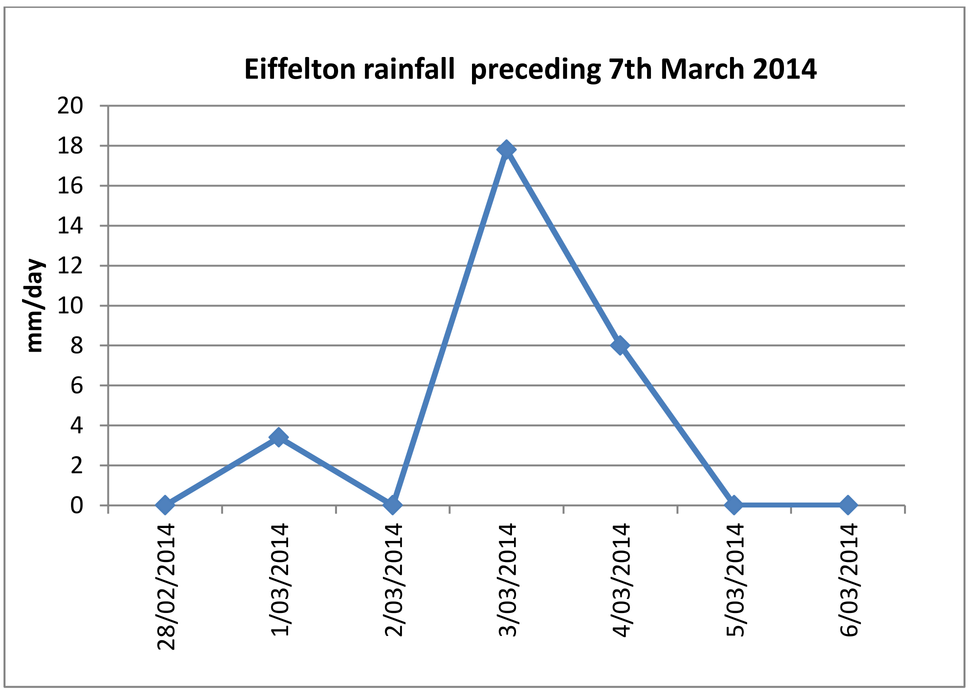


Figure 10 Eiffelton rainfall preceding 7th March 2014 (NIWA Cliflo data : ref 12)

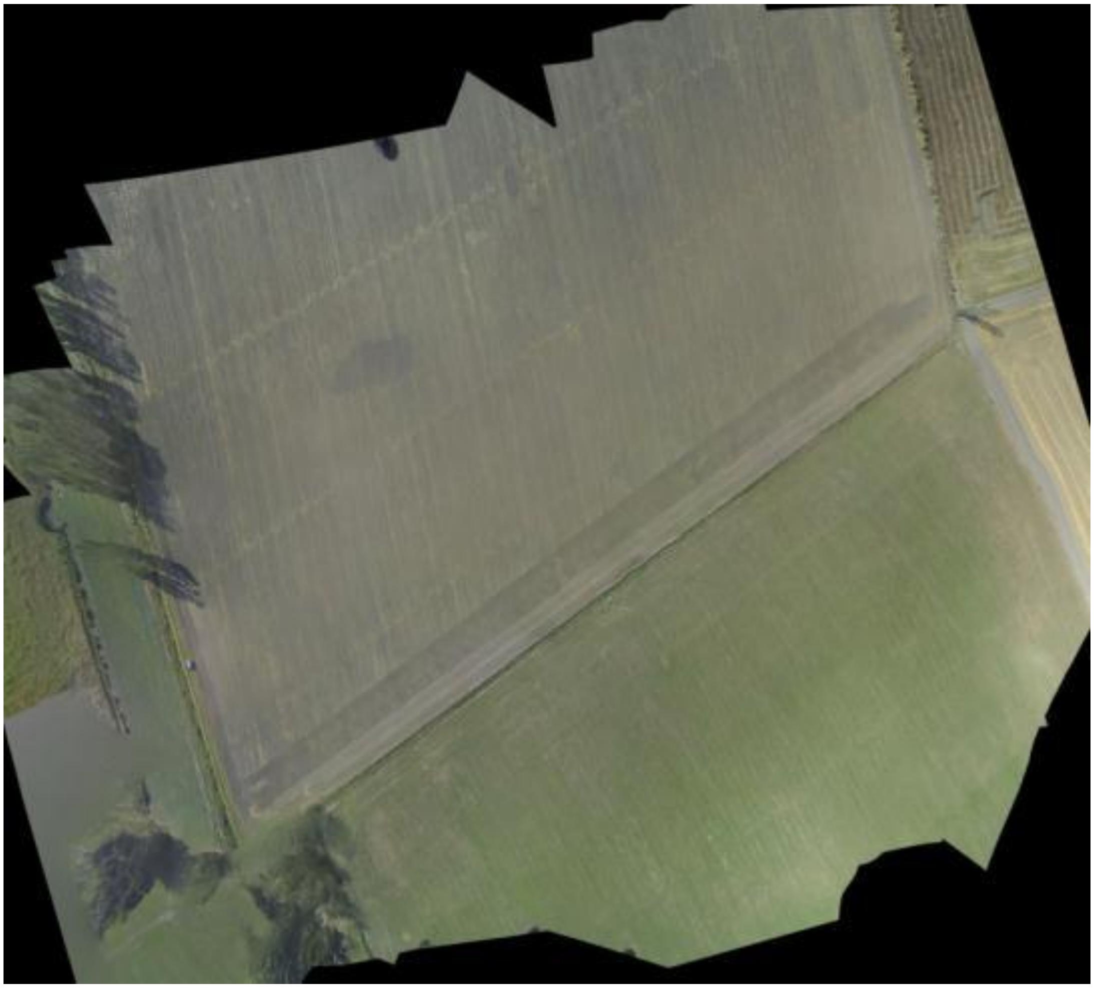


Figure 11 7th March Eiffelton. South West corner. RGB image.

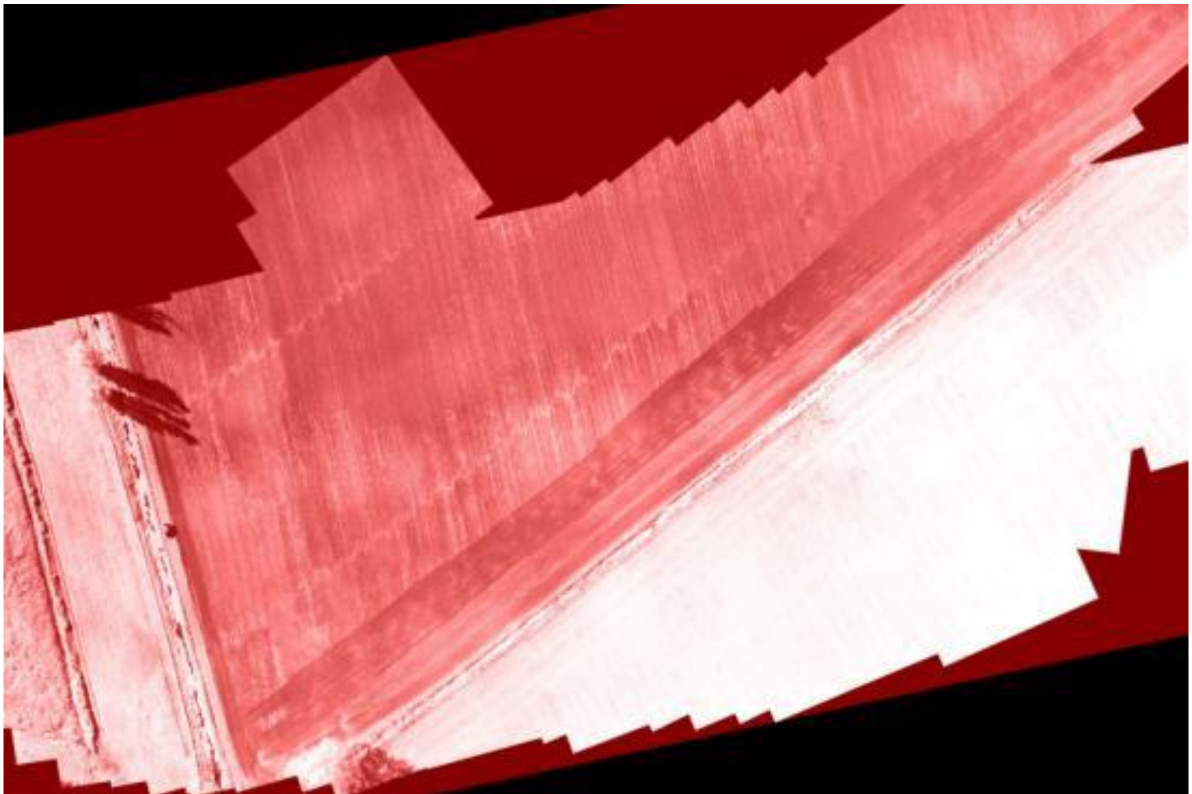


Figure 12 7th March Eiffelton. South West corner. Near InfraRed image from Tetracam camera.

8.1.1.2 Discussion

The subsurface tile drain is not evident in either the RGB or NIR image, although there is some evidence of the old stream bed cutting across the field corner. The soil had been subjected to direct sunlight since the last rain stopped; hence the top surface was dry, with scattered stubble residue.

Some moist areas can be seen in the RGB image, these have been identified as sub surface irrigation points.

The NIR images were limited in area as the high wind weather conditions on the day did not permit long flights.

8.1.2 Eiffelton 2nd May 2014

Rainfall in preceding 7 days = 37.6mm
Previous sun (days) = 1
State of tile drains –flowing
Field state – Early growth of grass.

Figure 13 Eiffelton 2nd May , condition of field state.

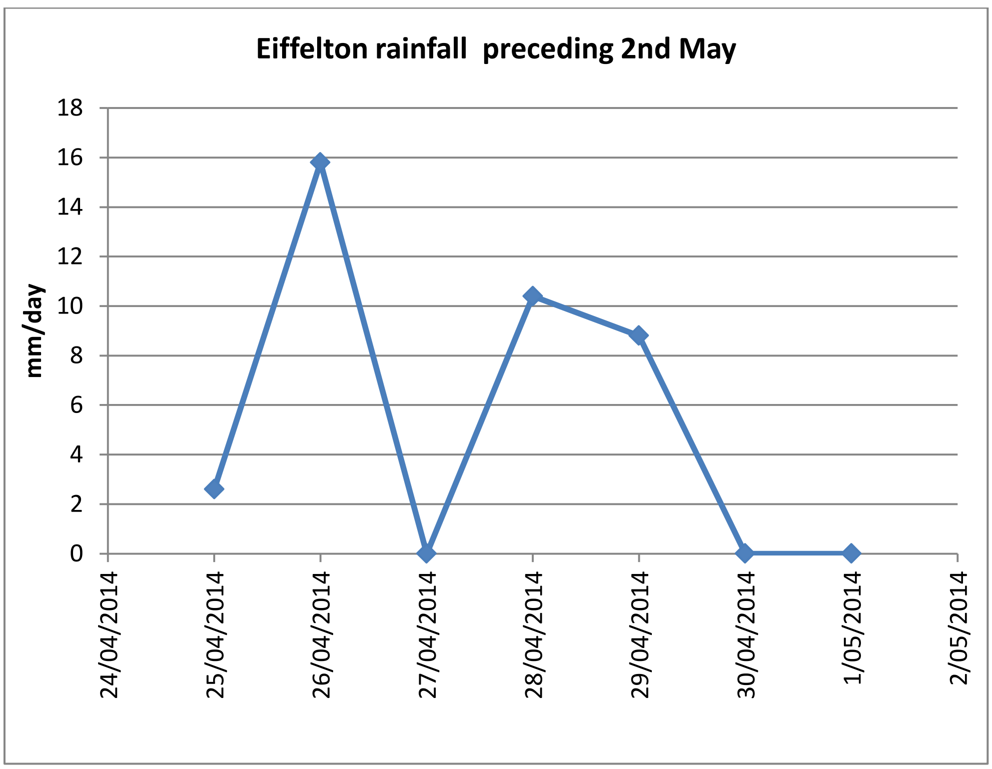


Figure 14 Eiffelton rainfall preceding 2nd May (NIWA Cliflo data : ref 12)

8.1.2.1 Results

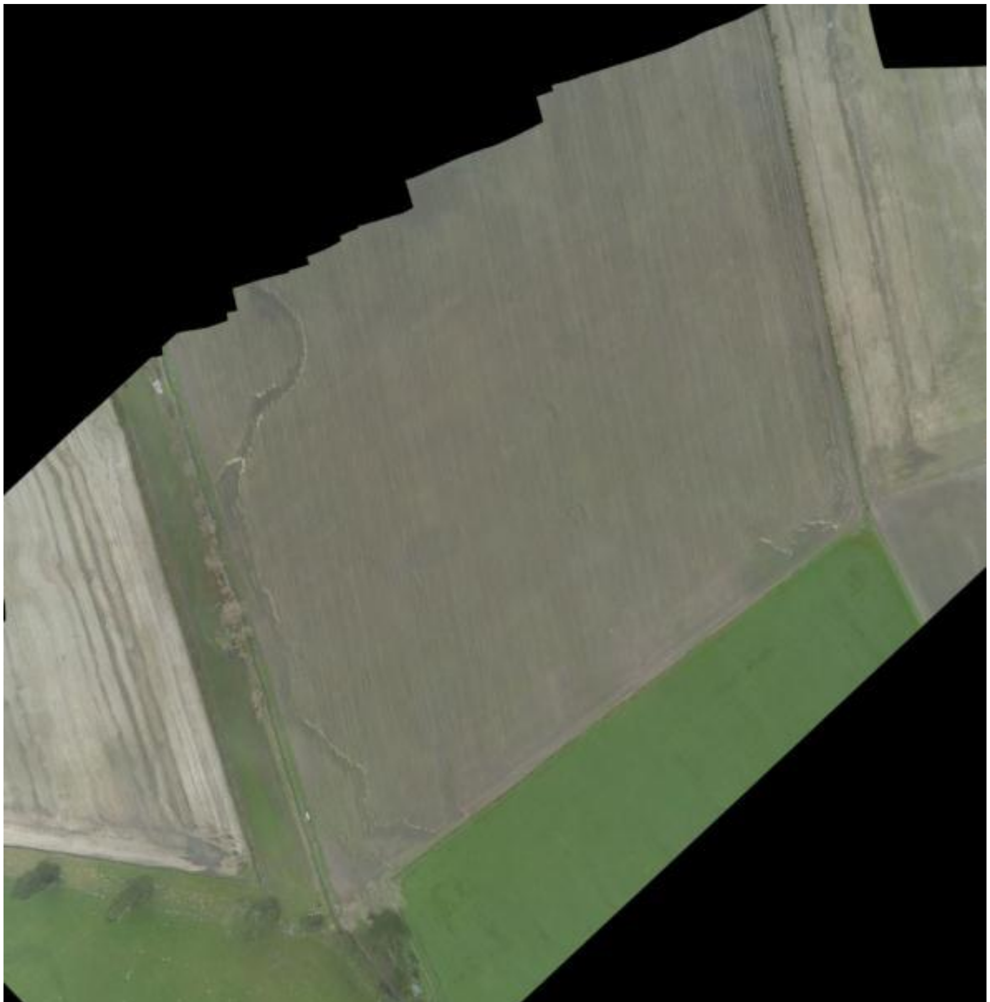


Figure 15 2nd May Eiffelton. South West corner. RGB image.

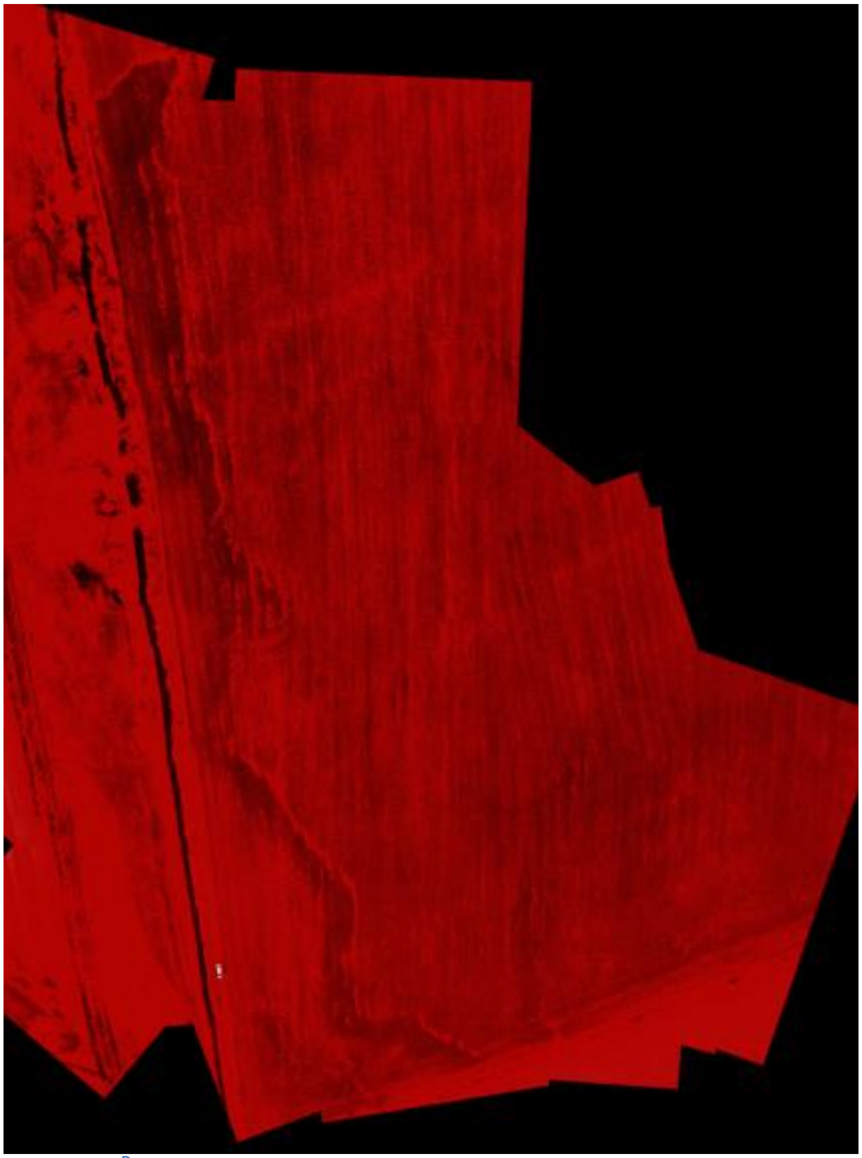


Figure 16 2^{nD} May Eiffelton. South West corner. Near Infrared mosaic ContourNIR camera

8.1.2.2 Discussion

Despite the NIR images being enhanced by extended differential magnitude, neither the RGB nor Near Infrared images show signs of soil moisture patterns due to subsurface drains. The route of the old stream is more evident in these images. Some striations of moisture are evident in the NIR images, maybe due to the cultivator leaving patterns in the soil surface, or variations in the early grass growth.

8.2 Waipuna Farm, Irwell

Southern Seed Technology Ltd is an Agribusiness servicing the needs of national and international plant breeders, seed producers and seed marketers.

Landcare information (ref 11) shows Soil type is Sali deep Silt/Clay, poorly drained.

Figure 17 General Google Earth view of the paddock in Irwell. Red lines indicated drain routes estimated by owner.

8.2.1 Irwell 19th March 2014

Rainfall in preceding 7 days = 38.2mm
Previous sun (days) = 1
State of tile drains – not flowing
Field state – bare soil.

Figure 18 Condition of field 19th/20th March. Irwell.

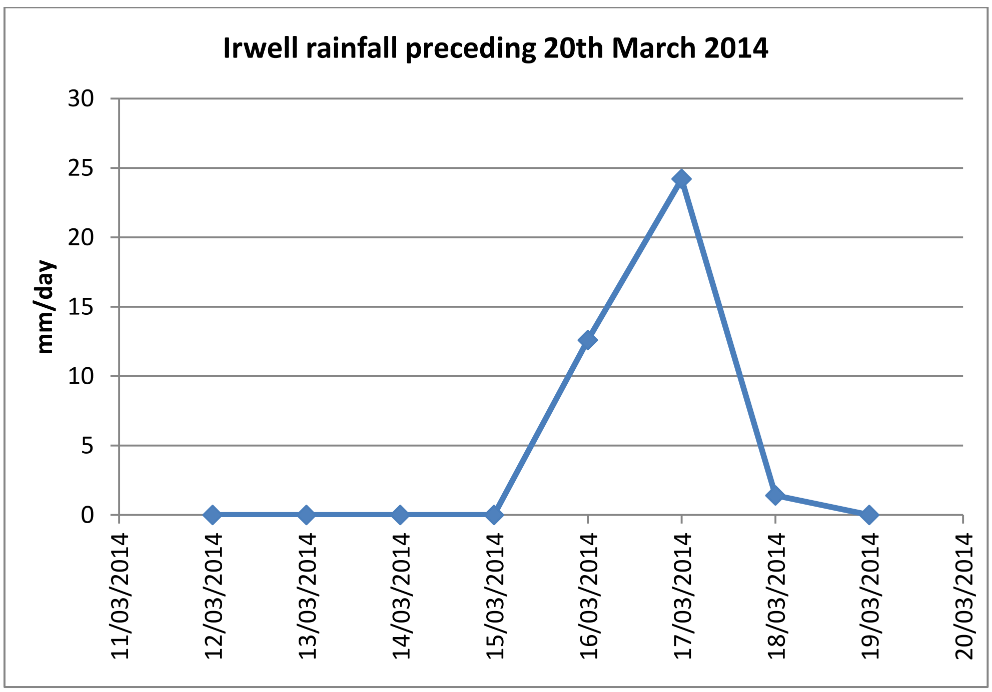


Figure 19 Irwell rainfall preceding 20th March 2014 (NIWA Cliflo data : ref 12)

8.2.1.1 Results

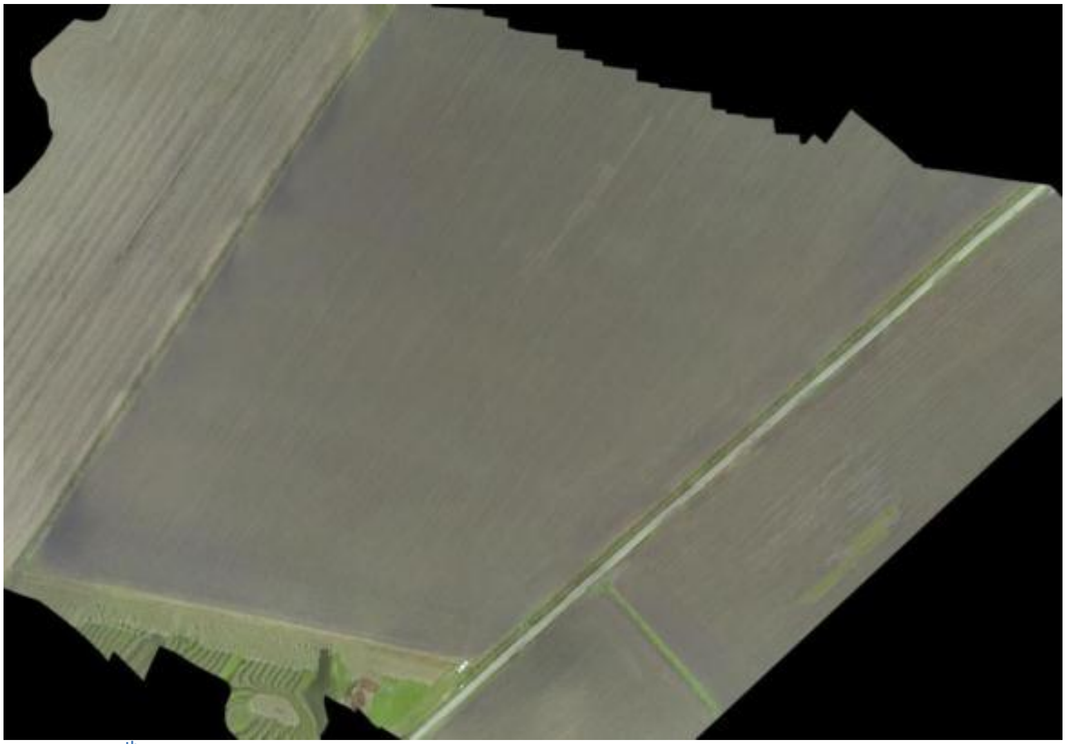


Figure 20 19th March Irwell. RGB image.

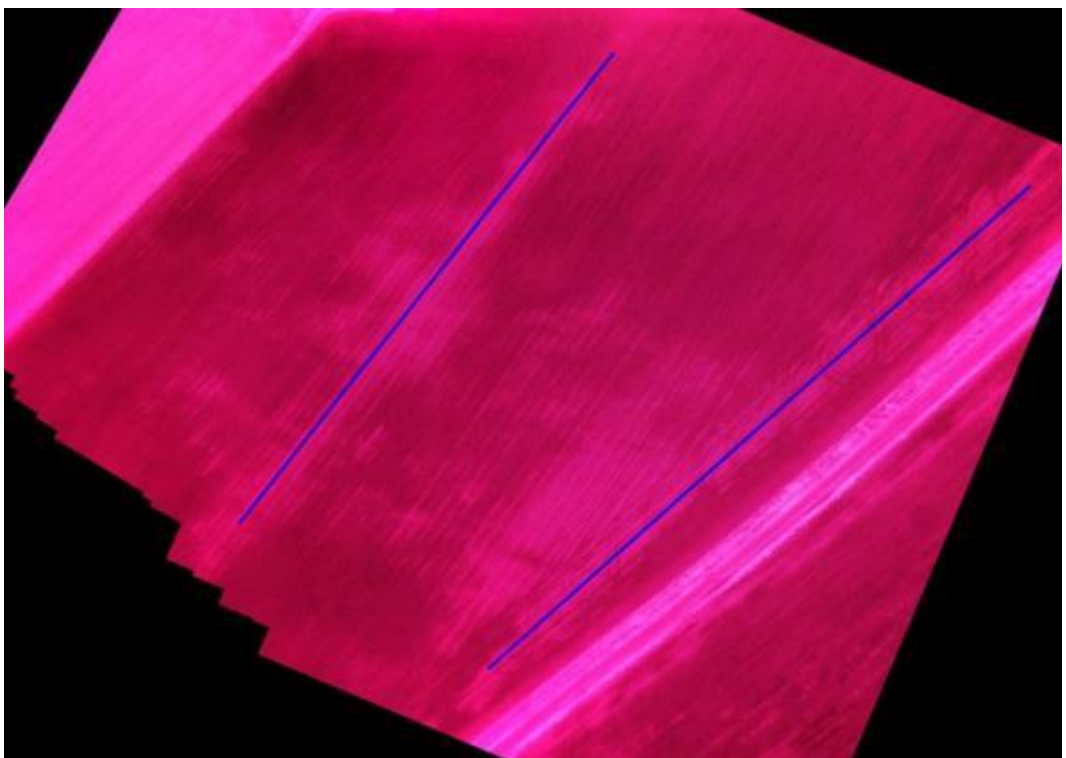


Figure 21 19th March Irwell. Near Infrared mosaic image ContourNIR camera.

8.2.1.2 Discussion
See Irwell 20th March, below.

8.2.2 Irwell 20th March 2014
Rainfall in preceding 7 days = 38.2mm
Previous sun (days) = 2
State of tile drains – slightly flowing
Field state – bare soil.

8.2.2.1 Results

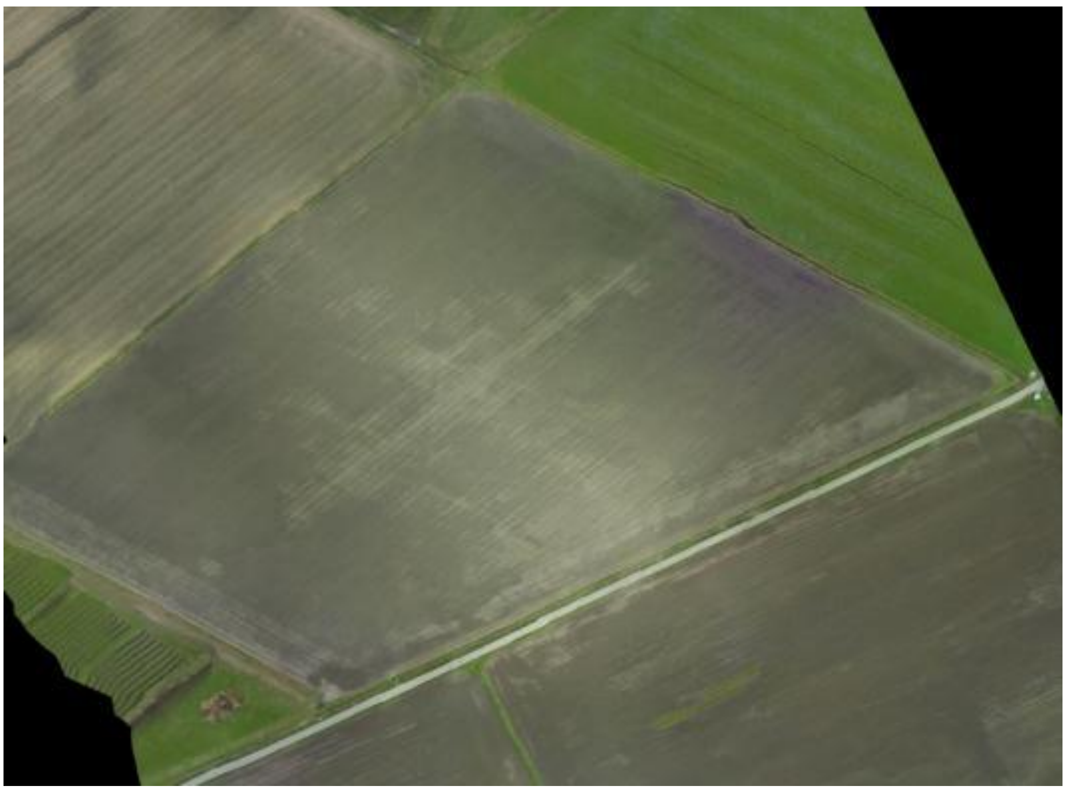


Figure 22 20th March Irwell. RGB image

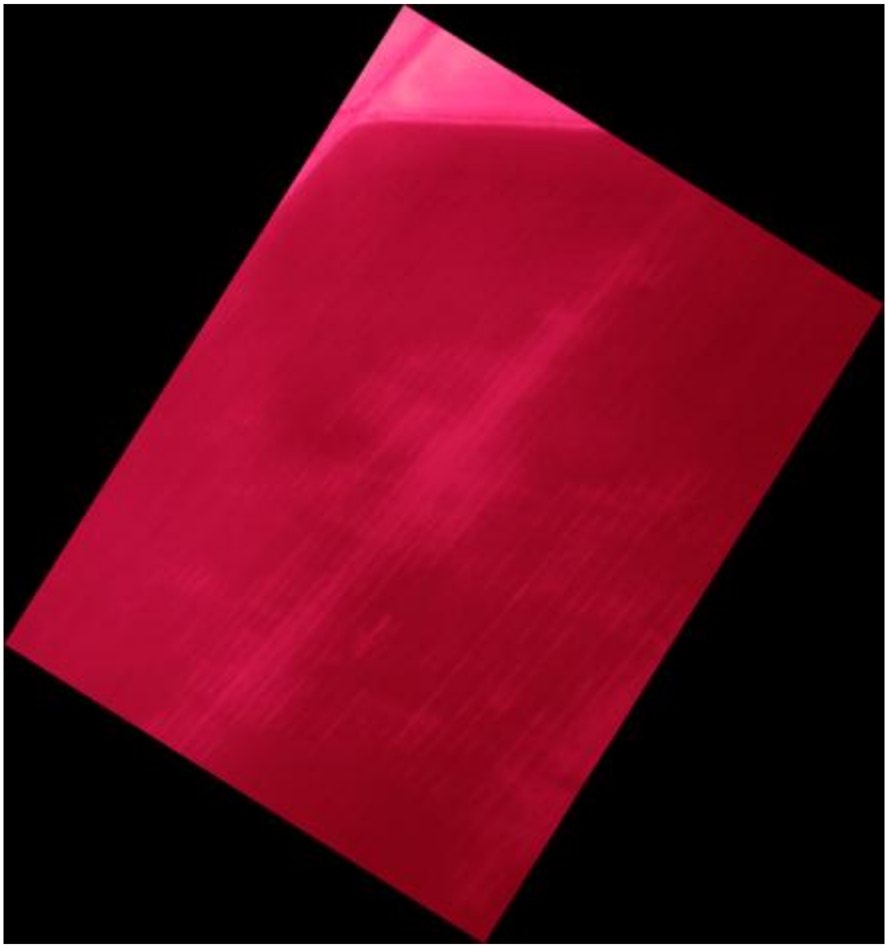


Figure 23 20th March Irwell. ContourNIR camera. Near Infrared

8.2.2.2 Discussion on 19/20th March results

The drains were not flowing on these days, and there had been direct sunlight in the days following the rain, therefore the RGB image shows no sign of soil moisture patterns except for a very narrow light line in the top centre. However, there is some evidence of the two subsurface drains in in the NIR image, as shown by the blue lines in Figure 21.

The two RGB images from consecutive days are of interest. On the 19th the soil moisture patterns showed very little evidence of subsurface drains. However, one day later the drainage had revealed defined patterns showing the central drain, side drain, as well as an additional drain route along the south west edge, although this would not be a natural route for a subsurface drain (transverse to the landfall) and may be natural soil runoff into the open drain along that edge.

The Near Infrared images show drainage patterns on both days, and this is the only example where NIR has an advantage over RGB in all the samples taken in this project

On all images showing drainage patterns, there are some evidence lateral drains coming off the central route, which were not known by the land owner.

Note: A camera fault during flight of the ContourNIR limited the images from that instrument to just one picture. Figure 20.

8.2.3 Irwell 1st May 2014

Rainfall in preceding 7 days = 37mm
Previous sun (days) = 0
State of tile drains –flowing
Field state – early growth of grass. Laying surface water.

Figure 24 Condition of field 1st May. Irwell.

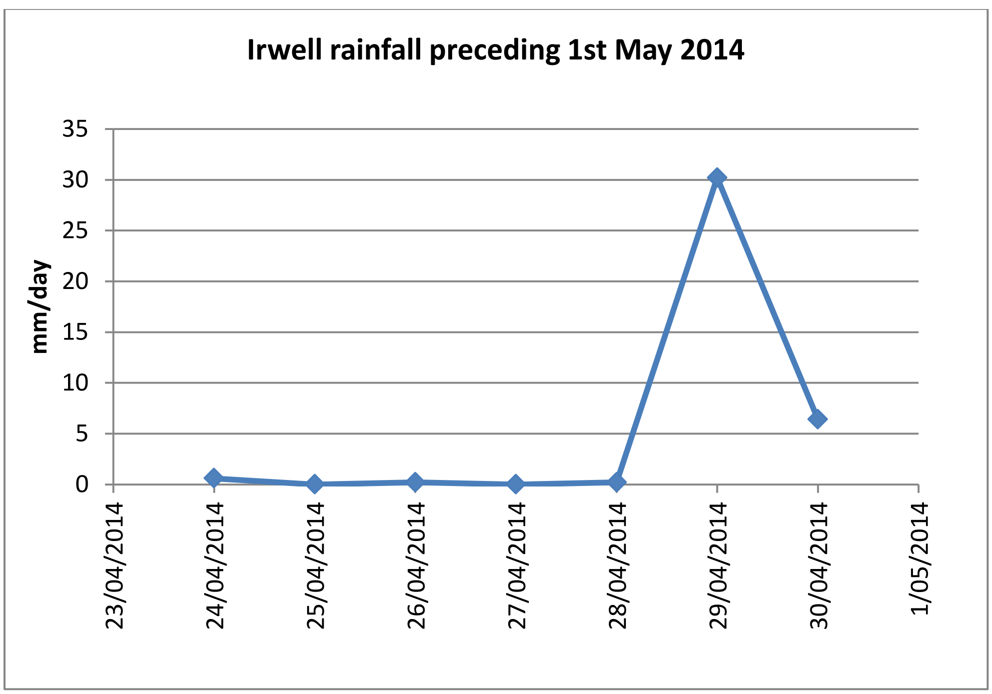


Figure 25 Irwell rainfall preceding 1st May 2014 (NIWA Cliflo data : ref 12)

8.2.3.1 Results

Figure 26 1st May, Irwell. RGB mosaic with colour and contrast enhanced. Distortion at top right is due to inadequate flight coverage in that area.

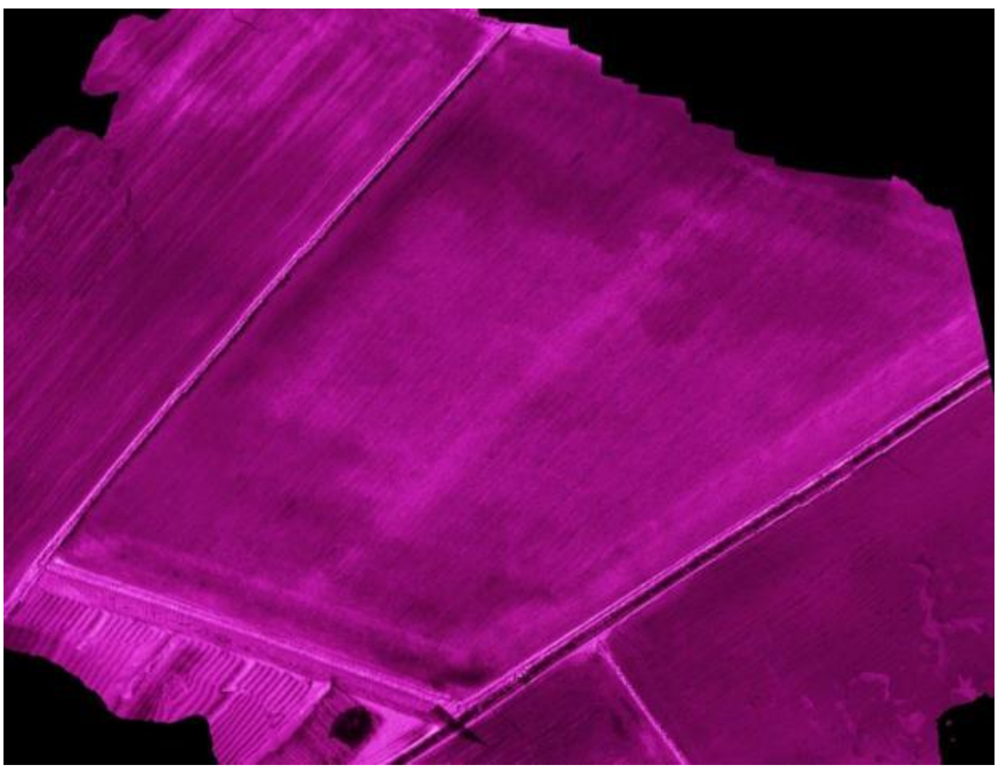


Figure 27 1st May Eiffelton. Near Infrared mosaic image ContourNIR camera

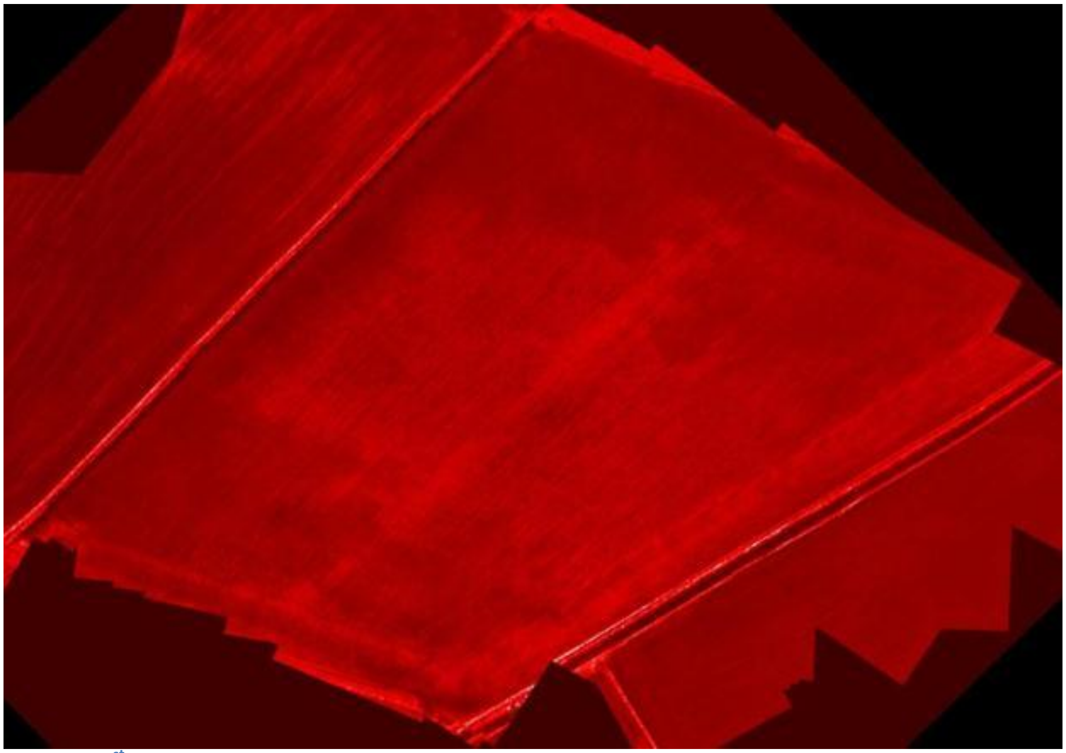


Figure 28 1st May, Irwell. Near Infrared mosaic image Tetracam camera.

8.2.3.2 Discussions

On this day the field condition was very different to the last samples on 19th and 20th March. The young grass was creating a light vegetation cover and the soil was close to a saturated state, with areas of laying surface water.

The RGB images show the thin covering of vegetation as bright green areas, and the light grey areas are probably laying water or saturated soil. Therefore the green areas represent areas where the grass is growing better due to less water, and this may be an indication of the better drainage in those areas. This aligns with the estimated route of the subsurface drains.

Like the RGB, both NIR images are dominated by the effect of vegetation, as reflectance is very high from healthy leafs. The central and south east side drains are evident, and the south west lateral drain is more pronounced. Again, the central area has a rectangular area of better drainage, which maybe evidence of lateral branches to the central drain. These are also evident in the RGB images from 20th March.

8.3 Flight trials at other sites

It was the original intention of this project to perform flight trials in the regional area of the commissioning body Environment Southland. Searches were made by Environment Southland staff members to find suitable farms for these trials, and on 24th March 2014 Andrew Wilkinson of Dacre offered his fields for trails. However, this site was not suitable due to unsuitable weather conditions and the presence of grass on the fields at the time.

Again, on 23rd April 2014, Doug Lindsay of Waihopai Pastoral offered his fields for trials. This was a 256ha dairy farm. However, despite having fields with field drains, much of the land was under deep grass or crop cover, and would therefore not be a good trials site.

A further site was found by the author on 9th May 2014, this being Neil Gardyne of Otama, but by this stage in the project, time and travel resources had been exhausted. There was a possibility the author would visit this site in early June for other reasons, and so take opportunity to collect data whilst there at no cost to the project. However the weather conditions have not been favourable for soil moisture flight surveys to occur.

9 Pixel intensity analysis on a transect line.

A software application was created by SERC to analyse the intensity of pixels along a straight line (transect) across a field. This tool can be used to

1. Pick out dry paths representing drain routes
2. Look at general trends across a field
3. Show distances from features like field edges.

The tool accepts an image of the survey area, and the transect is manually added to the image area of interest. The tool then creates a spreadsheet style file of the pixel values along the transect, which can then be plotted or used for further analysis.

9.1 Transect analysis - Irwell 19th March 2014

The following transect analysis was performed on the image from the Contour NIR camera, with separate traces for Red, Green and Blue.

The tile drain lines can be seen at pixels 201 and 442, with the field edge at 26 and the road starting at 483. For the central drain, the relative contrasts are calculated:

1) The Red channel shows of peak of 41 above the adjacent field intensity
2) The Blue channel shows of peak of 51 above the adjacent field intensity
3) The Blue channel shows of peak of 15 above the adjacent field intensity

It is interesting to note the Blue channel shows the most contrast, yet this channel should be blocked by the NIR filter in the lens. This warrants further investigation outside of this project's scope.

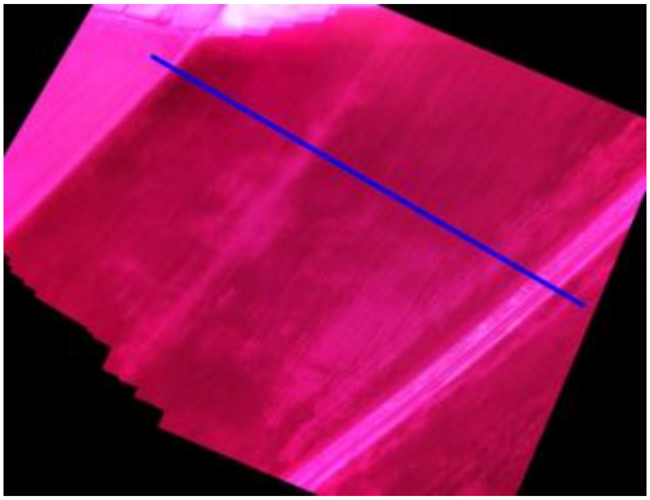


Figure 29 Irwell 19th March 2014 ContourNIR with transect line

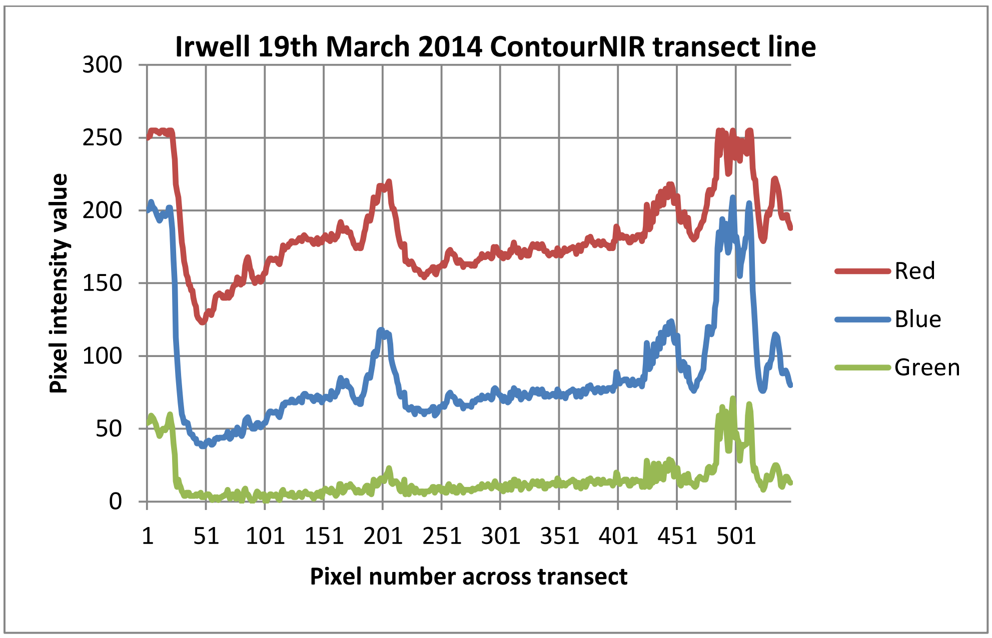


Figure 30 Irwell 19th March 2014 ContourNIR - Pixel intensity values across the transect line

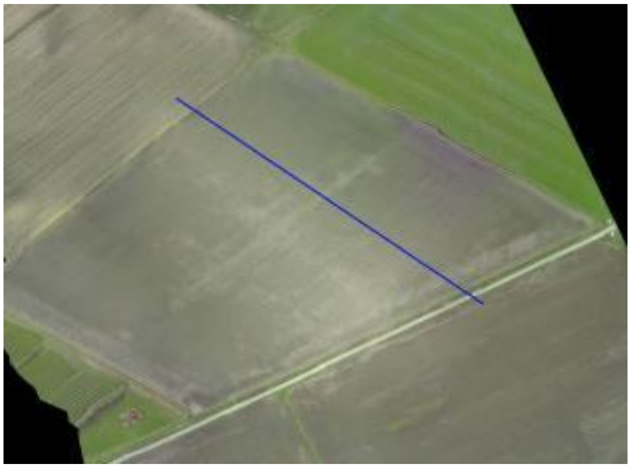


Figure 31 Irwell 19th March 2014 GoPro RGB with transect line

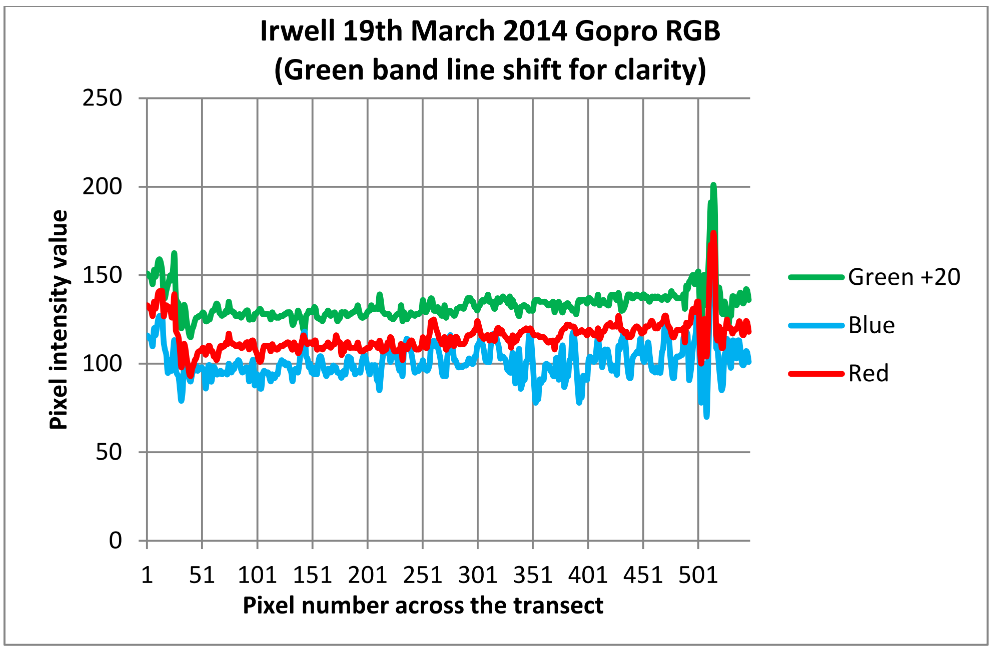


Figure 32 Irwell 19th March 2014 GoPro RGB - Pixel intensity values across the transect line

9.2 Discussion on transect pixel values

With this method, the centre line of the drain route can be identified in the Near Infrared image (Figure 30) within a few pixels, as opposed to viewing a survey image for light/dark areas. With the transect line at 280m in length, and 547 pixels, the resolution is 280m/547px=0.51m/pixel, giving the central drain position as 201-26*0.51 =89m from the field edge. It is of significant interest that the blue spectrum band shows the drain route with more contrast than the red or green, as this spectral band should be blocked out in this camera. Investigation of this effect will take place outside the scope of this project. For comparison, the RGB visible spectrum image from the same flight (Figure 32) shows almost no evidence of the drain route at pixel number 201 with this method, with no particular spectral band being an advantage despite being visible to the viewer.

10 Conclusions

10.1 Controlled moisture tests

These showed the level of light reflectance from particular soil moistures, in both visible and near Infrared spectrums, with the result that very little difference is detected between these bands. The best moisture levels for widest reflectance differential were between five and fifteen percent moisture by volume.

The trials also showed the effect of surface drying due to direct sunlight, with the result that the soils of different moisture become the same reflectance, thus reducing the difference in reflectance in all spectral bands. The soil with the most moisture appears to dry more quickly than medium moisture, an unexplained effect that will be investigated outside the scope of this project.

These results indicated that detection of soil moisture patterns requires a very explicit set of soil moisture conditions.

For drainage detection it is very difficult to predict the best post rainfall delay using these controlled soil moisture measurements (Section 7.1) as the soil moisture is dependent on so many other different conditions, like soil type, wind, sun etc. However, we can predict the best conditions are around the medium moisture levels, such as found at Irwell on 19th March.

10.2 Use of UAVs for this purpose

The application of unmanned aerial vehicles in this application may have an advantage of full size manned aircraft for the following reasons:

1. The survey can be performed at a lower cost (but see section on Selection of aircraft type)
2. The survey could be flown at very short notice, to catch the ideal conditions for detecting soil moisture patterns.
3. The survey can be performed in areas that could be too dangerous for full size aircraft, such as around trees, valleys and buildings.

It is important to point out; these trials required fast response timing of the flights to catch the ideal weather and soil conditions, and as such, suited the use of small UAVs that require minimal setup and preparation.

However, a manned aircraft would have the ability to carry more capable instruments, perhaps hyper-spectral cameras that could provide further spectral information for research.

In the near future there will probably be "medium" size UAVs which can both carry large payloads and operate in areas where manned aircraft are not capable.

10.3 Airborne trials- Field survey results

In general, the ContourNIR camera gave better NIR results than the Tetracam, as the images from the latter were difficult to mosaic into one survey area. This was probably due to the low contrast nature of the images, and the small view angle giving many images of field surface soil with few features to match picture edges.

On both survey dates, the Eiffelton site showed no sign of the subsurface drainage known to the land owner, and when comparing Eiffelton with Irwell, as the dates and previous rainfall were similar, this difference may be due to the types of soil, or the effectiveness of the existing drains.

However, the Irwell site does show some evidence of drainage. On the 19th/20th March there was evidence in the NIR images on both days, but in the RGB image only on the second day. This indicates there needs to be a time delay after rain for the drainage to establish. On the 1st May the drainage was evident in both RGB and NIR, but this result may have been due to differences in vegetation cover, as the crop will have grown better in well drained areas.
In general, the results obtained in this project have identified the route of subsurface drains, but only when particular conditions are met.
The following table summarises the drain detection results:

Date	Site	Previous 7 days rain (mm)	Previous sun (days)	Surface condition	Drain detected (NIR)	Drain detected (RGB)
7/03/2014	Eiffelton	29.2	2	Bare/stubble	No	No
19/03/2014	Irwell	38.2	1	Bare	Yes	No
20/03/2014	Irwell	38.2	2	Bare	Yes	Yes
1/05/2014	Irwell	37.0	0	Sparse early grass	Yes	No
2/05/2014	Eiffelton	37.6	1	Sparse early grass	No	No

Table 1 Table summary of drain detection results

The transect line analysis method gives a better way to identify the centre line of the drain route, but the application software should be adapted to work in conjunction with GIS tools for distance measurements. Some tools, like ENVI can already perform this task to some degree: Ref (10).

From the work carried out in this project, we can conclude the successful use of aerial survey imaging to determine the position of subsurface tile drains requires the following criteria to be met.

1. Substantial rainfall in the preceding two days. The amount depends on the existing soil moisture loading and the nature of the soil with regard to water dispersal.
2. The tile drains must be flowing. This ensures the water is draining, which should then show as variations in soil moisture.
3. A soil type that drains well, such as sandy loam or silt loam.
4. Minimal crops growing. Preferably bare soil showing.
5. Minimal residue from previous crops.
6. Minimal sunshine since the last rainfall, to minimise surface evaporation.
7. Relatively high atmospheric pressure, to minimise surface evaporation.
8. Relatively calm winds, to minimise surface evaporation.
9. Minimal cumulus clouds. This reduces the risk of cloud shadows which appear as variations in soil reflectivity.

As stated in the academic paper (ref 1), these particular weather conditions occur only two or three times a year with weather dominated by a large continental mass such as North America. In the New Zealand oceanic climate, it is rare to have no sunshine after heavy rain.

10.4 Other soil moisture measurement methods

There are other methods of detecting soil moisture, and are mentioned here for completeness. However the instruments needed for these methods were beyond the scope of this project.

1. Multispectral NIR/Red/FIR comparing Short wave Infrared (NIR), visible (Red) and Long wave Infrared (FIR). See ref (5). Currently instruments suitable for small to medium UAVs are very expensive (>US$50k).
2. Cosmic Ray absorption method. Ref (8). This is unlikely to give good resolution with instruments currently suitable for a small UAV.
3. Passive microwave method Ref (9). Unlikely to give good resolution with current instruments suitable for a UAV.

11 Future work.

The exact combination of time, climate conditions and soil types should be investigated further as this may yield a combination that would allow a high degree success in detecting tile drains. This study showed there were very few instances where NIR had any advantage over RGB images, but a hyperspectral camera, which would allow surface temperature (FIR) to be added to the data, may be able to detect soil moisture patterns when other methods fail.

12 References

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