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Agriculture Irrigation in the Canterbury Plains - New Zealand: Assessment from Landsat Imagery Remote Sensing

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Abstract

The Canterbury Plains have gone through significant agricultural changes since the 1970's. Being situated along the drought prone east coast of the South Island of New Zealand and over permeable postglacial washover deposits and braided river coarse gravels, freshwater management is of prime importance. Agricultural changes have resulted in substantial increases in the amount of irrigated land across the Canterbury Plains, which have in turn led to significant management issues in relation to the availability, distribution and monitoring of freshwater resources. Therefore, it appears essential to develop an understanding of the water usage and resource at the plain-scale. The most appropriate approach at this scale is certainly satellite remote sensing. The availability of Landsat data dating back to 1973 has provided an opportunity to assess the capability of using the normalised difference vegetation index to identify irrigation areas. Through identifying the key long term changes and short term changes in rainfall and groundwater, an understanding of the variations that occur in NDVI was established. The initial assessment of the capability of using NDVI to map irrigation provided positive results for mapping the entire Canterbury Plains. The three tested dates found irrigation estimates for the Canterbury Plains to have results that fit in with the growth of irrigation in the Canterbury Region. February 5th, 2004 recorded 199,682 hectares, February 16th, 2008 recorded 263,697 hectares and December 26th, 2010 recorded 297,251 hectares. However upon closer investigation, it was found that errors were likely occurring on a local scale. In order to improve the accuracy of using NDVI to map irrigation, field investigations at the incorrectly identified sites and fine tuning the defined threshold of NDVI values are required.

The present work was completed as part of a 400 level dissertation by Matt Harrison under the supervision of Dr. Christopher Gomez in y. 2013.

Introduction

The Canterbury Plains are one of the most important agricultural areas of New Zealand. The aquifer system of the Canterbury Plains is essential to maintaining the agricultural productivity of the land (Environment Canterbury [ECan], 2011a). The past 40 years have seen the Canterbury Plains go through a phase of change from mostly extensive sheep farming to intensive dairy farming (Smith and Montgomery, 2004). This change has led to increased pressure on the freshwater resources of Canterbury due to the higher water demand associated with dairy farming. The successful management of the freshwater resources of Canterbury is paramount to the future success of Canterbury as a leading agricultural producer in New Zealand. Remote sensing techniques provide very useful tools for rural management. This report will assess the potential of the normalised difference vegetation index (NDVI) to map irrigation. Remote sensing can play an integral role in understanding how agriculture has changed over the years and help to provide guidance for future agricultural development.

Canterbury Plains

Canterbury is home to the largest area of plains in New Zealand being around 180km long with varying widths stretching from the foothills of the Southern Alps to the coast. The Canterbury Plains have very little topographical variation with a gradual increase in elevation from the coast up to the foothills as well as slight depressions along the path of the rivers as shown in figure 1B. This extensive area of relatively flat land was formed from the deposition of the many glacially fed river fans that emerge from the Southern Alps. Geologically, the Canterbury Plains are comprised from primarily gravel dominated alluvial deposits along with many additional deposits of loess as shown in figure 1A (LRIS Portal, n.d.). Over time varying stages of glaciation and sedimentation have created many different layers of geological formations, some of which are more permeable than others. The more permeable layers hold the various aquifers of the Canterbury Plains. The depths required for a well to reach these aquifers vary from a few metres at the coast, to up to 150 metres near some areas at the foothills of the Southern Alps (Lough & Williams, 2009). While relatively dry and prone to droughts, the Canterbury Plains are well known for its agricultural production (Wilson, 2012). This is largely due to irrigation from river uptakes and diversions, and groundwater extractions which boost agricultural capacity during the hotter, drier periods of the year.

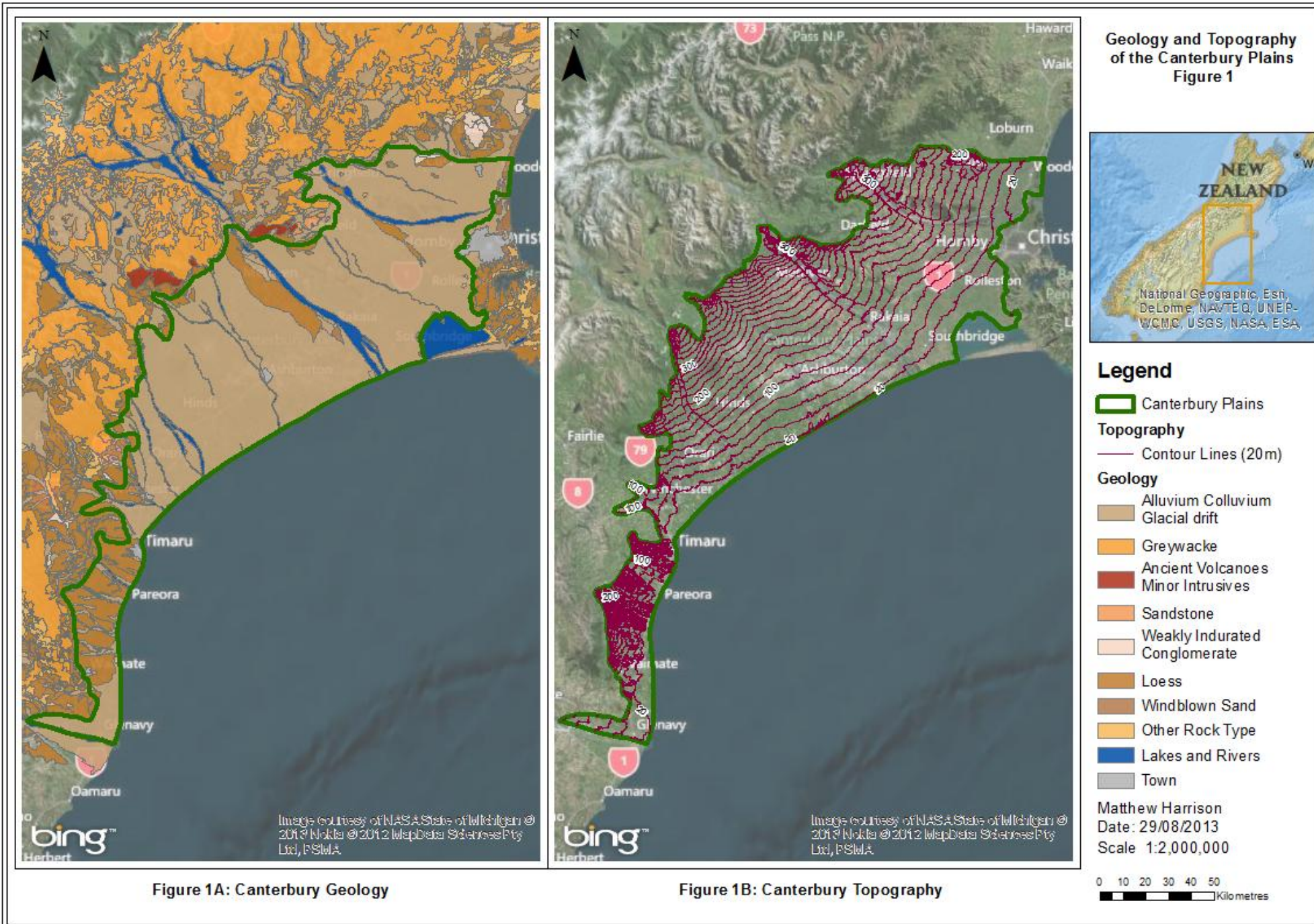


Figure 1A: Canterbury Geology

Figure 1B: Canterbury Topography

Figure 1A and 1B: Geological map and topographical map of the Canterbury Plains (data obtained from LRIS Portal)

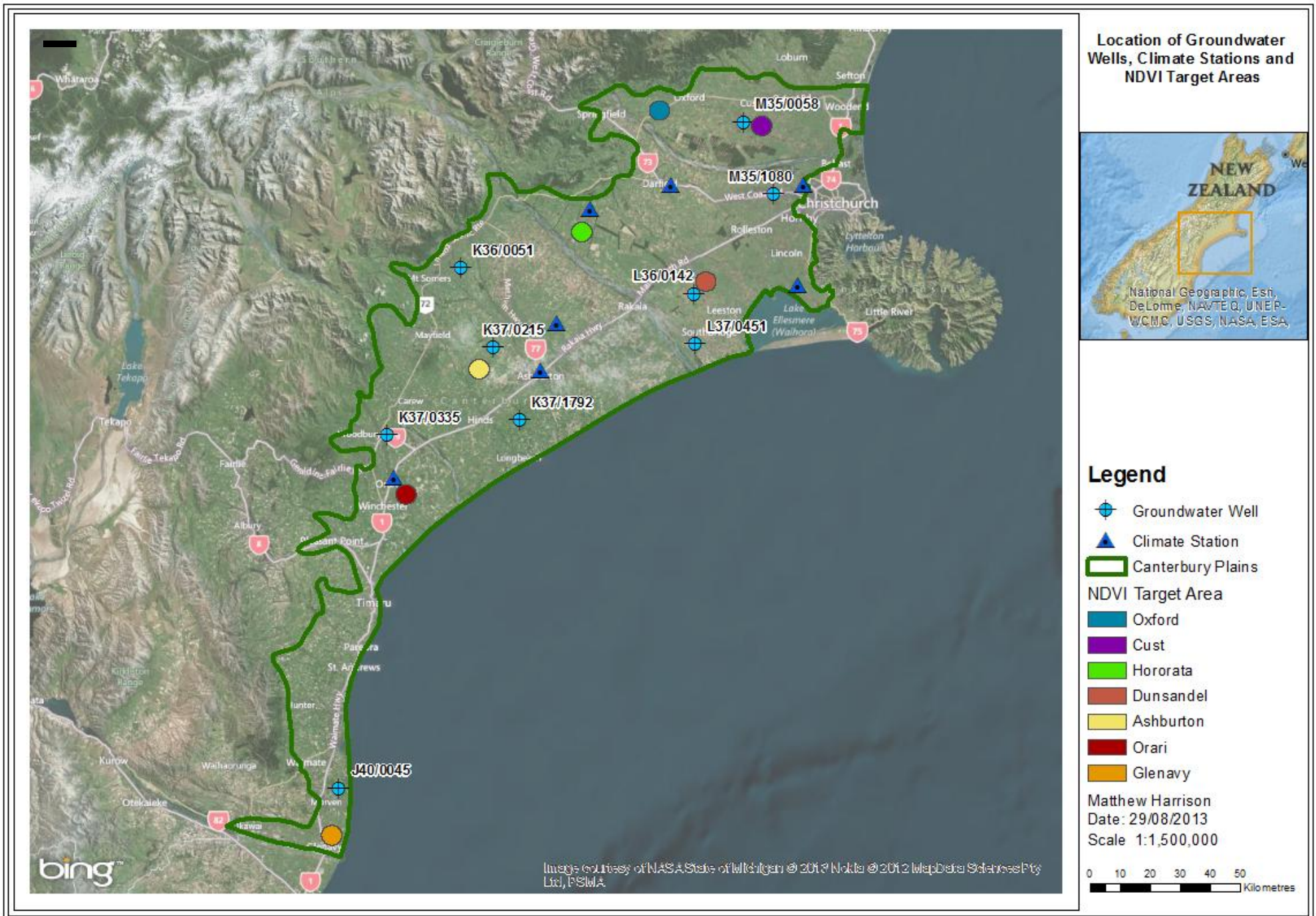


Figure 2: Regional map of Canterbury Plains highlighting target areas, groundwater wells and climate stations.

Study Area

The study area has been limited to the Ashley River to the north, the Waitaki River to the south, the foothills of the Southern Alps to the west and the Pacific coast to the east. In addition, the area of Christchurch and Banks Peninsula were excluded from the study area, as they both present a very different physiography that does not interest this study. The borders of the foothills and Banks Peninsula were defined using Landcare Research's 25m digital elevation slope model (LRIS Portal, n.d.). The area of Christchurch was also excluded to the extent of Halswell, Hornby, Christchurch Airport, Belfast and Kaiapoi. Christchurch is a large urban area with a population of nearly 400,000 people. The focus of this study is towards the rural environment; therefore Christchurch was removed from study. Within the study area, seven target areas were located specifically to build a representative example of the Canterbury Plains. The overall extent of the study area along with the seven target areas can be seen in figure 2.

Climate

The Canterbury Plains are relatively dry and susceptible to prolonged periods of drought. Typical summers have low rainfall coinciding with increased sunshine and temperature. Winter conditions lead to increased rainfall and decreased temperatures and sunshine as shown in figure 3 over the page. The increased temperatures and sunshine hours in summer can lead to increased water stress through evapotranspiration. The climate of the Canterbury Plains area is largely determined by the surrounding topography. Being in the rain shadow of the Southern Alps, rainfall from the west falls before reaching the plains due to the topography of the Southern Alps through orographic rainfall. Expected climate change scenarios are likely to bring about increased severity, length and number of droughts (Ministry for the Environment [MfE], n.d.; Parkyn & Wilcock, 2004). The change in climate will impact Canterbury water supply through decreased rainfall, increased evapotranspiration and decreased natural water storage due to glacial retreat and higher snow lines (Srinivasan, Schmidt, Poyck and Hreinsson, 2011). Srinivasan, Schmidt, Poyck and Hreinsson suggest that by 2040, there could be a 5% increase in the average number of days each year where water supply falls short of demand and by 2090 this could reach up to 17%. In order to better comprehend the situation for Canterbury agriculture, a stronger understanding of agricultural water use over the past four decades will be very useful. Sufficient management processes and policies need to be properly implemented to ensure sustainable and proficient use of Canterbury's water sources. Exploring the potential of remote sensing can aid in building management techniques through a better understanding of the changes occurring over time and by providing a tool that can quickly analyse current conditions.

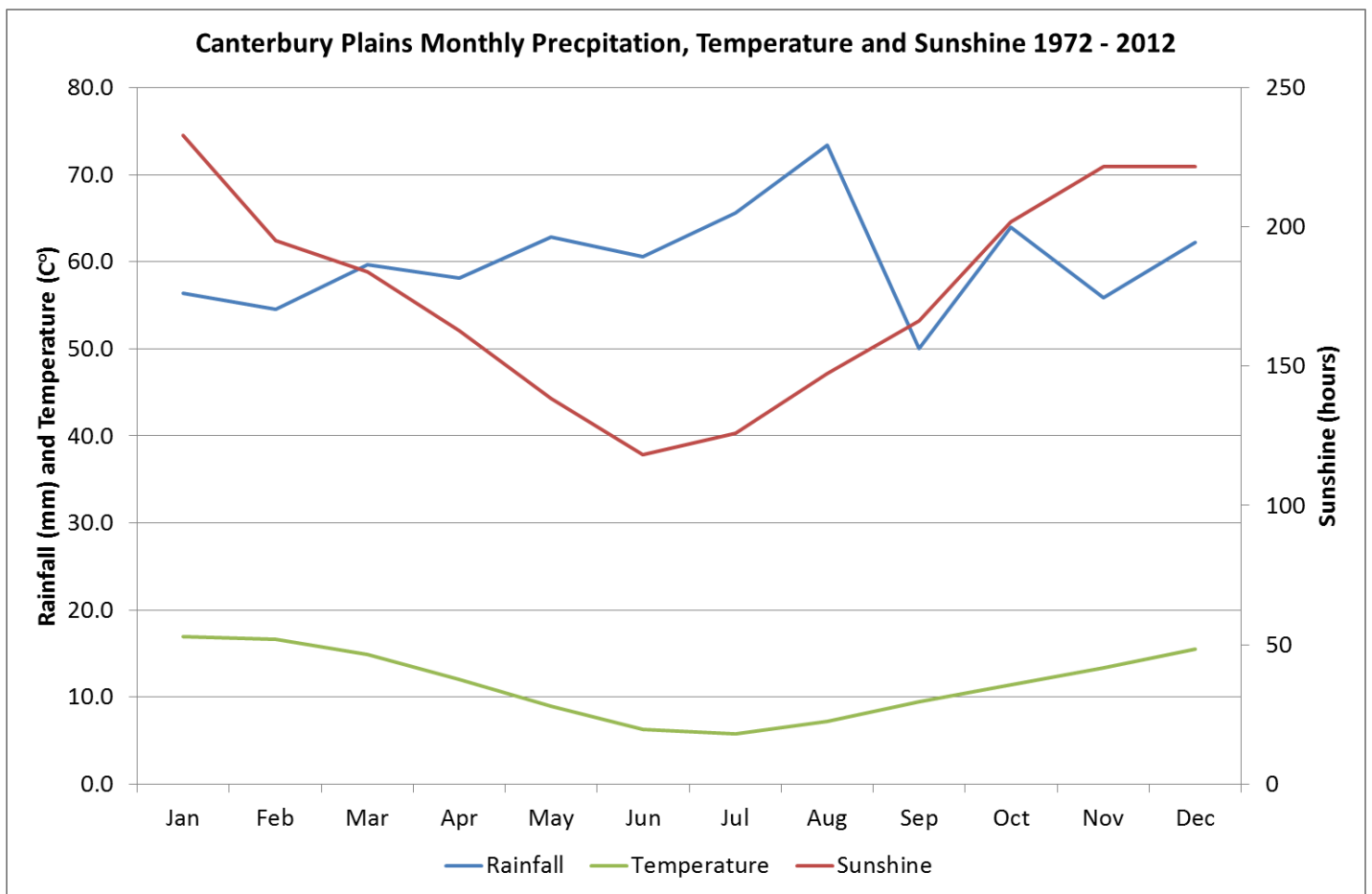


Figure 3. Canterbury Plains monthly average in precipitation, temperature and sunshine 1972 – 2012 (Adapted from Cliflo Database, n.d.)

Groundwater

While surface water extractions from rivers, lakes and irrigation channels are very important for irrigation in Canterbury, there is an increasing reliance on groundwater sources for irrigation. Recently annual groundwater use began exceeding annual surface water uptakes (ECan, 2011a). Groundwater is often the primary source for public, industry and agricultural use in the Canterbury area. It is used to help supplement agricultural productivity when rainwater is not sufficient and surface water is inaccessible. Historically Cantabrians have taken advantage of the complex aquifer systems of Canterbury since the mid 1800’s (Brown, 2002). However, many areas of Canterbury are already over allocated for groundwater use, with some areas such as the Rakaia-Selwyn zone at 145% of the allocation limit. These allocation limits are set using a combination of techniques that relate to average rainfalls, land-surface recharge and area specific hydrological knowledge in order to maintain sustainable groundwater levels (ECAN, 2011c). While these allocations are not always used to the maximum allowable uptake, there is an alarming potential for groundwater to be overexploited in Canterbury which suggests a need to further management techniques.

Agriculture

Agricultural production in Canterbury provides a significant input to the national economy and will gain increasing importance as dairy numbers continue to grow. The spatial extension of agriculture in Canterbury (table 1) covers an area of 2,519,110 hectares, 444,777 hectares of this is equipped for irrigation (Bascand, 2012). Due to a focus towards livestock farming, agricultural land in Canterbury is concentrated towards grazing and grasslands which take up over 80 per cent of the total land. Traditionally stock type in Canterbury has been dominated by sheep; however, recent trends show Canterbury is undertaking the fastest change nationally towards dairy (Bascand, 2012). In 1999, the number of sheep in Canterbury were just below 10 million, while dairy cattle numbered as little as 275,000 (Tinkler and Golby, 1999), since then, sheep numbers have nearly halved to 5,348,010 and dairy cattle have increased nearly fivefold to 1,200,293 (Statistics New Zealand, 2012). This follows similar national trends where the number of Sheep dropped from a peak of just over 70 million in the early 1980's to being as low as 32 million by 2010 (FAOSTAT, 2012), while dairy farming over this same period has seen numbers double from 3 million to 6 million in 2011.

Tab. 1 Canterbury agricultural land use (hectares). (Statistics New Zealand, 2012).

Tussock and danthonia used for grazing (whether oversown or not)	Grassland	Grain, seed and fodder crop land, and land prepared for these crops	Horticultural land and land prepared for horticulture	Plantations of exotic trees intended for harvest	Mature native bush	Native scrub and regenerating native bush	Other land	Total land
1,125,500	1,136,615	240,656	16,339	92,215	50,369	72,086	65,512	2,801,462

Agriculture in New Zealand has been largely influenced by changes in governmental policy towards subsidies during the 1980's. In November 1984, changes in government budget, led to nearly 30 agricultural production subsidies being removed. This was a huge change as previously up to 40% of beef and sheep farm income was provided by the government through various subsidies (Smith and Montgomery, 2004). This removed the governmental influence and provided incentive for farmers to choose the type of farming which they believed would bring in the best returns. This led to large changes in the New Zealand farming industry; particularly important was the switch from largely extensive sheep and beef based farming to more profitable and intensive dairy farming.

Dairy farming requires much higher levels of water input when compared to other farming types. Stewart and Rout (2007) recommend a range of 95 – 140 litres of water per day for drinking water and dairy shed operations. This water requirement excludes the additional water required to maintain pasture growth to meet feed requirements. Comparatively, according to ECan (2011b) recommendations, sheep farming only requires three litres per head per day. This highlights the increased stress Canterbury's water resources are going through. Canterbury accounted for nearly 60% of the national increase in irrigable land from the year 2007 – 2012 and this has been largely attributed to the increase in dairy farming (Bascand, 2012). The changes in agriculture in Canterbury are and will continue to cause strain on freshwater resources.

There is a long history of surface water diversions across the Canterbury Plains. As early as 1896, the Waimakariri was diverted for irrigation purposes (Waimakariri Irrigation Limited, n.d.). The Rangitata Diversion race, the Lower Waitaki Scheme and the Greenstreet (Mid Canterbury) surface water diversions were all created between the 1940s and 1970s. In 1987 the Eiffelton Community Irrigation scheme was completed in the Mid Canterbury area. In addition to this, there is currently many new surface water diversions being proposed or under construction across the Canterbury Plains (Irrigation New Zealand, n.d.). Surface water diversions are important to take note of as they will impact the natural seasonal variations of vegetative health. Monitoring the changes in irrigation across the Canterbury Plains is very important in managing Canterbury freshwater resources. Differences in irrigated and non-irrigated agriculture are likely to be evident in satellite imagery, making it a useful management tool.

Management – Environment Canterbury and the Resource Management Act

The allocation of water for irrigation purposes in Canterbury is primarily the responsibility of Environment Canterbury, however is largely influenced by the Resource Management Act (RMA). ECan's "Canterbury Water Management Strategy", states that "Environment Canterbury is responsible for managing the region's water resource, including the flows and levels in any water body; control of taking, use, damming and diversion of water; the allocation of water and the control of discharges" (ECan, 2009). While maintaining this responsibility, ECan also has to uphold its role as a part of the RMA to monitor, report on and provide research in regards to the state of its freshwater resources. ECan is responsible for the allocation of freshwater resources for agricultural irrigation purposes across Canterbury. However, a large portion of the Canterbury Plains is already over allocated for groundwater take consents as shown in figure 4. This shows that many areas require strong monitoring to understand exactly how much of the allocation is being used. Currently there is a variety of methods used to measure how much of an allocation will be used. One method commonly used is the 150 day method (Aitchison-Earl, Scott & Sanders, 2004). This method is based on the assumption that irrigation users will use up 60% of their allocation over a 150 day period. As this is an assumption, there is a high potential for actual use to be greatly underestimated.

The Selwyn River is in an over allocated area and is particularly vulnerable due to its heavy reliance on groundwater recharge to maintain its flow. In particularly dry periods, well over half the length of the river can remain completely dry (Kelly, Davey & James, 2006). The purpose of the RMA is "to promote the sustainable management of natural and physical resources" (New Zealand Government, 1991). Appropriate management of the groundwater resources in Canterbury is therefore very important in order to meet the requirements of the RMA. Steps are currently underway to improve the monitoring of groundwater uptakes through a compulsory program to install meters on all groundwater wells with an uptake of more than five litres per second before November 2016 (ECan, n.d.2). Remote sensing can easily be implemented as monitoring tool, and the Landsat program can help to provide an understanding of how agriculture and water use has changed over the last 40 years.

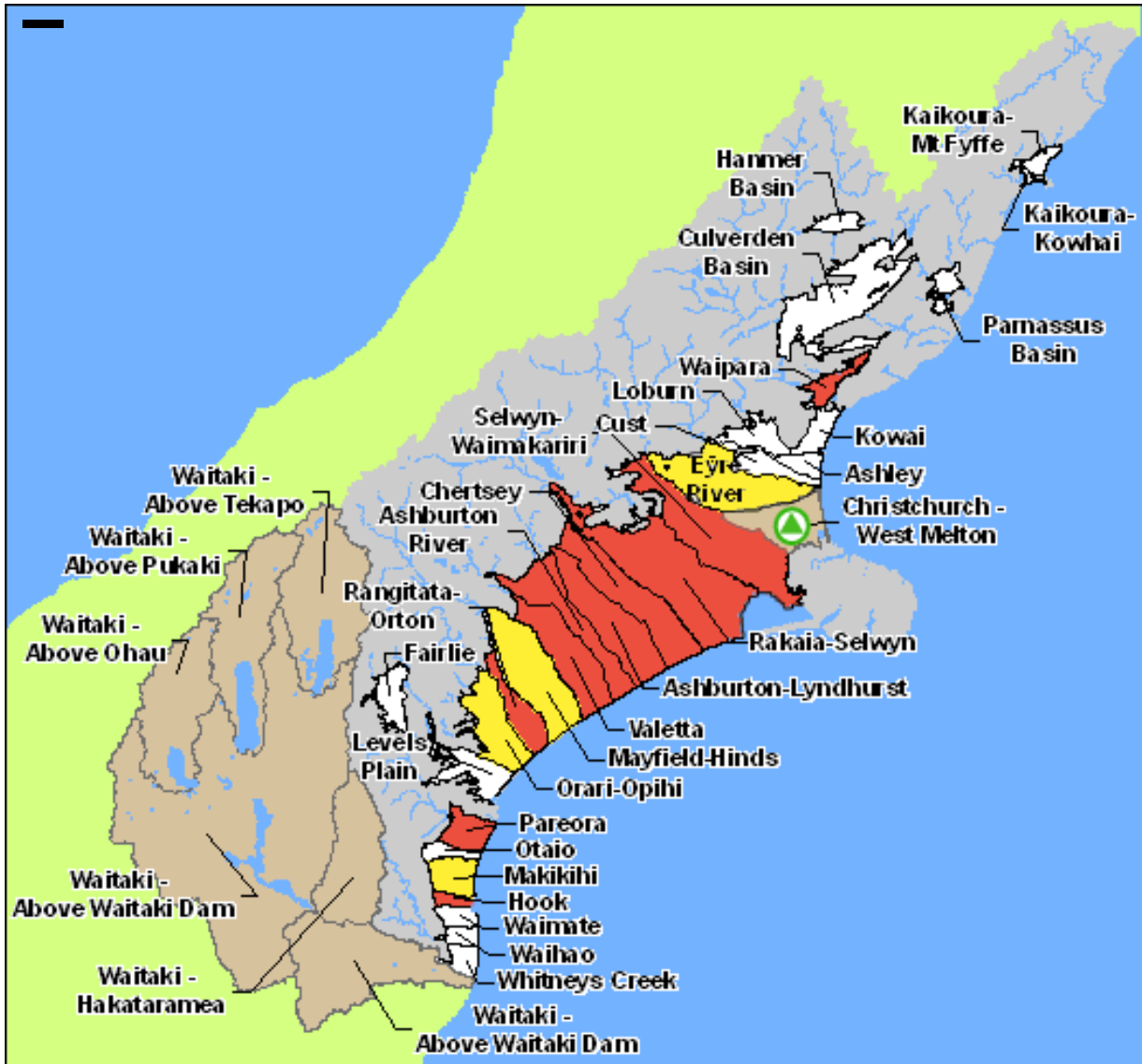


Fig. 4. ECan groundwater allocation zones and allocation amount (ECan, n.d.1. Reprinted with permission)

- Total amount of groundwater currently allocated exceeds the ECan maximum allocation limit.
- Total amount of groundwater currently allocated is more than 80% of the ECan allocation limit.
- Total amount of groundwater currently allocated is less than 80% of the ECan allocation limit.

Remote Sensing and Landsat

Remote sensing is the process of obtaining information about an object from a distance. This can be obtained from any distance whether it is just a few metres or from an orbiting platform such as a satellite (Jensen, 2005). The ability to obtain data from an aerial or orbiting platform allows for quick analysis of very large areas which would otherwise be very time

consuming. Remote sensing techniques can obtain information on many physical attributes such as location, elevation, depth, biomass, temperature and moisture content of a particular target. In order to obtain this information, remote sensing takes advantage of the different levels of radiation reflected from the target at varying spectral wavelengths. Vegetation in particular, stands out well when compared with other surfaces across the red and near infrared spectral wavelengths. In addition to this, the accuracy and resolution of remote sensing equipment is constantly improving, allowing for increased capability of remotely sensed data.

The Landsat program began in the early 1970's and is the longest running continuous series of remote sensing data capture (Cohen & Goward, 2004). Landsat has been used extensively across many disciplines since its existence. A simple search for 'Landsat' through the Scopus database returns over 20,000 results. Landsat 1 began with only four spectral bands with a 60 metre pixel size, while Landsat 8, the most recently launched Landsat Satellite collects eleven spectral bands, across a range of pixel sizes from 15m to 100m. This spatial resolution is sufficient enough differentiate the boundaries between different farms. Landsat 1 – 5 covers a range dating from as early as 1973 through to 2013. Landsat has a very consistent supply of data through these years for the United States. However, due to issues and costs with the privatisation of the Landsat program in 1985, New Zealand is missing many years of Landsat data (Leimgruber, Christen, and Laborderie, 2005). One of the most important advantages of Landsat imagery is that it is free for download (Landsat Missions, 2013). Landsat has been chosen for this study due to having the appropriate attributes required for the study and being easily accessible for download through the USGS website.

Remote sensing has a proven track record in monitoring changes in vegetation and more recently the ability to detect moisture content is becoming more and more important. One of the most simple but well proven techniques for measuring changes in vegetation is the normalised difference vegetation index. The NDVI takes advantage of the specific reflectance levels across the red and near infra-red (NIR) bands of the electromagnetic spectrum. Bands 2 and 4 of the Multi Spectral Scanner (MSS) on board Landsat 1 – 5 and bands 3 and 4 of the Thematic Mapper (TM) on board Landsat 4 and 5 capture the red and near infra-red spectrums. Following a simple calculation (shown over the page), the NDVI can help to identify vegetative masses that are under stress (Rouse, Haas, Schell & Deering, 1974). The NDVI creates an index with a range between -1 and 1. The healthier the vegetation, the closer it will be to reaching 1. In a natural environment, the highest level vegetation can reach is between 0.8 and 0.9, while the unhealthy vegetation will be around 0.2 (Weier & Herring, 2000).

$$\text{NDVI} = (\text{NIR}-\text{Red}) / (\text{NIR}+\text{Red})$$

Having the ability to measure vegetative health without having to make physical contact is a valuable tool, particularly for those involved in water allocation planning. During drier periods, agricultural areas that are being irrigated are more likely to retain high NDVI levels compared to non-irrigated areas which are likely to show weakened NDVI values. The NDVI is advantageous because of its simplicity which allows it to be applied to all Landsat satellite

products from the 1970's through to now, unlike some of the more complex moisture and vegetation detecting indexes.

Important NDVI studies

The ability to measure the health of vegetation on a regional scale is very useful, particularly for management purposes. The NDVI is a very useful tool that has been used in many scientific studies. Particularly useful is its ability to detect levels of stress which are often caused by a lack of water. Sönmez, Emekli, Sari, and Baştuğ (2008) undertook a study using remote sensing to investigate the relationship between Bermuda grass and water stress conditions using varied levels of irrigation. Through the use of hand held spectroradiometers set two metres above sample plots they were able to measure changes in spectral reflectance. It was found to exhibit a significant relationship between NDVI and water stress. The relationship showed that water stress led to decreased NDVI values, while irrigation which decreases water stress would increase NDVI values. Further analysis found it possible to extend the findings to satellite or aerial derived data. A study of Sahelian vegetation dynamics by Anyamba and Tucker (2005) used NOAA-AVHRR NDVI data to observe relationships between moisture and NDVI from 1982 to 2003. The NOAA-AVHRR is a satellite series which has been running since 1978 however with a spatial resolution of over 1km; the NOAA-AVHRR is more suited for larger scale projects (National Oceanic and Atmospheric Administration Satellite Information System [NOAA SIS], 2013). The main findings saw a significant period of drought from 1982 - 1983 which co-existed with weakened NDVI values, the period 1994 -2003 marked a wetter period that co-existed with healthier NDVI values. The relationship between moisture and NDVI is further backed up by Ji and Peters (2003) who found strong relationships between NDVI and the Standardized Precipitation Index (SPI) in a study based on the northern Great Plains of the United States. The SPI is an index based solely on precipitation. One of the important aspects noted in this study is the corresponding lag from rainfall to NDVI change. This study is particularly useful as the study area represents an area from which similar types of farmland to that of the Canterbury Plains. Ji and Peters (2003) also mention previous studies in the Great Plains which show varying response times from precipitation event to corresponding NDVI peak ranging from 14 to 61 days (Yang, Yang and Merchant, 1997; Liping, Rundquist and Luoheng, 1994; Rundquist, Harrington and Goodin, 2000; Wang, Rich and Price, 2003). Understanding that there can be a significant delay in NDVI response to precipitation is important in analysing changes in NDVI over time.

Key Objectives

This study aims to assess the capability of NDVI in mapping irrigation on the Canterbury Plains. In reaching this goal, the report can be broken down to two key sections; first, the analysis of the historical trends in groundwater, precipitation and irrigation, and second, the implementation of an NDVI irrigation map based on the findings of the previous section.

The first section involved building an understanding of how the changes in precipitation, groundwater and irrigation affect NDVI. This helped in establishing an accurate NDVI range to represent irrigation and in choosing images with the right preconditions for building an irrigation map. The second section used the acquired information to build and test the accuracy of an NDVI irrigation map. Accuracy testing helped to identify the strengths and weaknesses of the irrigation map created as well as identifying key areas which need further investigation.

Methods

Three key datasets were analysed: remote sensing data, rainfall data, and groundwater data. Once processed, these were then compared to help understand the relationships they had between each other. The key steps followed in order to achieve the desired objectives are set out in a flow chart as shown in figure 5.

Remote Sensing

The following steps outline the key steps involved in the analysis of the available Landsat data:

An initial assessment was made through Earth Explorer to filter out the images which were not useable due to excessive cloud cover. Of those chosen, around half were available for instant download, while the rest were ordered and available for download within a week.

Downloaded files were unpacked and loaded individually into the software package ENVI 5.0.

Following Rouse, Haas, Schell and Deering's (2001) dark object subtraction method, atmospheric processing was used to ensure greater accuracy when comparing images from multiple dates. This required finding the darkest pixel with over 1000 pixels at that value from each band. In order to do this, a histogram output was created for every band of every image in order to establish the 'darkest pixel' value. Using this information, ENVI was then able to calculate the dark subtraction.

The images were then joined and cropped in order to focus on the Canterbury Plains. This required creating a mosaic of the two images from each date using ENVI's 'Georeferenced Mosaicking' tool.

To set a border for the Canterbury Plains, a shapefile was created using ArcGIS. The northern limit was set to the Ashley River and the southern limit was set to the Waitaki River. The Eastern limit follows the coast from the south before going around Te Waihora Lake Ellesmere, Banks Peninsula and Christchurch. The suburbs of Halswell, Hornby, Belfast and Kaiapoi were included as part of Christchurch. The western extent of the plains and edge of Banks Peninsula were set using Landcare Research's 25m digital elevation slope model. This shapefile was then used to crop the mosaic image in order to focus on the Canterbury Plains.

An NDVI calculation was applied to the cropped images through the use of ENVI using band math to following the NDVI equation $NDVI = (NIR-Red) / (NIR+Red)$. As NDVI is a commonly used vegetation index, ENVI has an automated NDVI function which just requires the user to select if the Landsat data is from the Multi Spectral Scanner (MSS) or Thematic Mapper (TM) sensors.

Seven target areas were created within the Canterbury Plains with areas of 18.1km² that were spread out across the plains to act as representative samples of the varying regions. These target areas were located at varying elevations and distances to surface water. Where possible, the targets were located away from image gaps. The seven areas were named: Oxford, Cust, Hororata, Dunsandel, Ashburton, Orari and Glenavy. The seven NDVI target areas can be seen in figure 2 on page 13. These target areas were classified for their individual cloud cover for every image.

NDVI histograms were created for each of the target areas through the use of ENVI. This data was then transferred into excel where the histograms were visualised through five period moving averages derived from scatter graphs. Visualising the NDVI data this way creates distinct NDVI signatures for each date and location that can easily be compared with both rainfall and groundwater data.

For the final step in the image analysis, rainfall data was taken into account to choose the images most likely to be experiencing water stress. Using these images, a simple threshold was applied to highlight the pixels most likely to be irrigated.

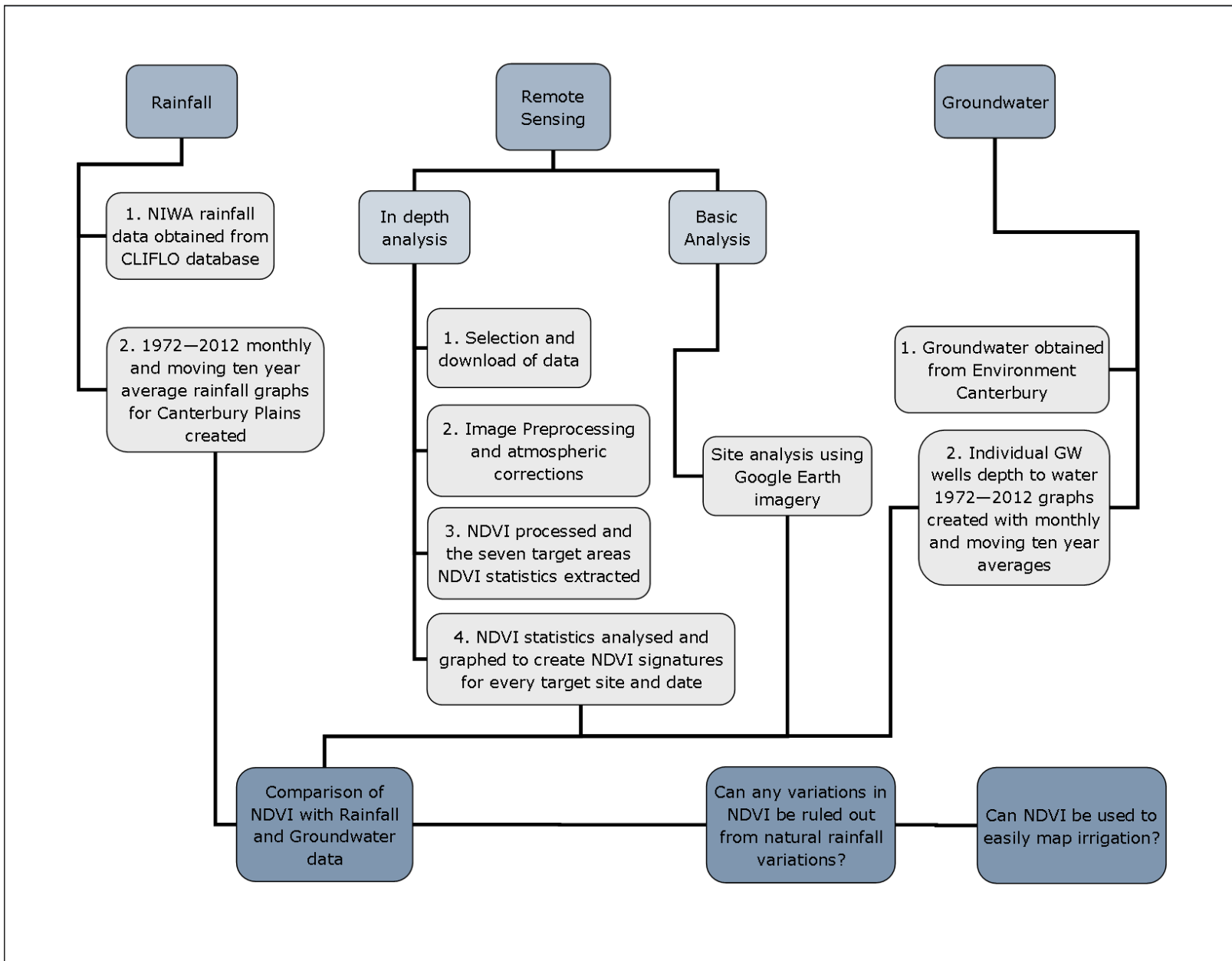


Figure 5. Key steps to method process.

Area Descriptions

Visual investigations were undertaken through the use of satellite imagery to identify key features currently evident in the landscape of each target area. Due to a scale limitation, Landsat images were not high enough to identify features smaller than the average paddock; therefore this step was completed using Google Earth images acquired between 2011 and 2013.

Rainfall

In order to better analyse the variances in NDVI, rainfall data was required to help gauge natural variances in NDVI against irrigation induced changes. Rainfall data was obtained from NIWA using their online national climate database “Cliflo”. Seven climate monitoring sites were chosen across the Canterbury Plains which have been recording rainfall data across the entire study period. The seven sites are shown in figure 2 on page 6.

From these seven sites, a Canterbury Plains average was created and then compiled into line graphs for three separate time periods in order to easily visualise and compare the amount of rainfall that had fallen in the months prior to a satellite image being taken. In addition to this, a ten year annual moving average of rainfall was created in order to help understand possible long term changes to rainfall on the Canterbury Plains.

As mentioned earlier, there are significant relationships between precipitation and NDVI, however with varying ranges in lag time for peak NDVI values. It is expected that similar relationships may be found however the lag may not be as noticeable due to the use of monthly rainfall data.

Groundwater

To obtain a better understanding of the possible impacts of irrigation towards NDVI, groundwater information was used to look for relationships with NDVI and rainfall. Water is often sourced from the complex Canterbury aquifer system to meet the heavy requirements of irrigated agriculture. Large areas of the Canterbury Plains are already over allocated for groundwater irrigation (Environment Canterbury, 2012), which suggests a link could be found between NDVI and groundwater data.

Historical groundwater data was obtained through Environment Canterbury. The data for this was limited and many wells are missing significant blocks of data at different periods of the study. The data obtained, included the GW recordings for 8 different wells with data collections beginning before 1980 and continuing until at least 2012. The locations of the varying wells are shown in figure 3 on the following page. This data was organised into individual monthly line graphs through the use of both Microsoft Access and Excel. Ten year averages were produced for all wells to gain a better understanding of the long term changes. This data was then compared with the NDVI and rainfall data to establish any relationships.

A low groundwater level would naturally coincide with low rainfall; however irrigation uptake from groundwater can interfere with this. If rainfall is following a natural pattern and

groundwater levels are unnaturally low with strong NDVI values, groundwater extractions for irrigation would likely be the cause.

Comparison of NDVI with Rainfall and Groundwater data

As shown in figure 5, this step involves a combination of the processed NDVI, rainfall and groundwater data. Once the analysis of the three different data sets has been completed, an investigation to specifically identify if a high NDVI value has occurred due to natural processes or irrigation. This involved identifying the unnaturally high range of NDVI values and highlighting them in the Landsat images as irrigated.

The results of this study are set out in four main stages. The initial stage is the analysis of the NDVI, rainfall and groundwater results. Following on from this is to identify the key links and trends within and between each data set. Images were then identified that were likely to have high levels of irrigation currently occurring. These images were then used to identify an NDVI value that could be linked with irrigation.

Creation of NDVI Derived Irrigation Maps

Using the results recorded, images with a high likelihood of containing irrigation were chosen and specific values were set for irrigation. Image thresholds were created and applied to these images to establish the feasibility of NDVI to identify specific irrigation targets or to calculate the total area of irrigation across the Canterbury Plains. Once created, the new maps will be compared with the available information on irrigation in Canterbury and as well as being visually investigated to identify potential errors.

Results

Target Site Analysis

Site analysis was undertaken to ascertain the current land features through Google Earth which provided high resolution imagery of the individual target locations. All sites are made up of primarily agricultural land, with variations stated in the individual descriptions depending on their location (Fig. 2). The seven sites were selected for their representativity of the diversity of the Canterbury plains.

The Oxford area is situated over the View Hill Stream between the Eyre River and the Waimakariri River at an elevation of 260 – 310m above sea level (asl). Small pockets of forestry make up less than 5% of the area. It was evident that irrigators were installed in the area. The Hill View Stream appeared relatively dry.

The Cust area is located east of the small rural community West Eyreton at an elevation of 80 – 120m asl. The Eyre River and riparian zone create a corridor through the site which makes up less than 5% of the area. There were two streams that appear to have no flowing water within the target area. Large irrigator systems were easily identified on majority of the land.

The Hororata area is located approximately nine kilometres south west of Hororata and five kilometres north of the Rakaia River at an elevation of 225 – 250m asl. Irrigation practices were clearly evident in imagery.

The Dunsandel target area is located approximately six kilometres south east of Dunsandel with elevations between 40 and 60m asl. Large irrigators were less evident in the area.

The Ashburton target area is located approximately 15 km west of Ashburton next to the Hinds River at an elevation of 135 – 175m asl. A small artificial lake was apparent which is connected to an extensive cannel network. Irrigation practices were clearly evident in the area.

The Orari target area is located approximately five kilometres south east of Orari at an elevation of 30 – 65m asl. The Orari river flows directly through this area, with the river and riparian zone covering approximately 10% of the area. Large irrigators are noticeable on both sides of the river, however the northern side appears much dryer in colour in comparison to the southern side.

The Glenavy target area is located just north of Glenavy at an elevation of 20 – 35m asl. An extensive channel irrigation network appears evident in imagery; however it is difficult to identify any large irrigators.

Diachronic Analysis of NDVI Across the Entire Canterbury Plains.

NDVI images were created to show the variations in vegetation health across the Canterbury Plains from 1973 – 2011 (figures 6 – 19). The darker areas show weaker NDVI values and the lighter areas strong NDVI values. The darkest areas tend to be either surface water bodies or cloud cover. Three of the earlier images had satellite data collections errors which caused

large areas of the image to not be recorded in the images. The February 5th, 1978 image is actually a mosaic of two images from February the 5th and February 6th, 1978.

The four NDVI images from before 1984 provide the closest replication to a non-irrigated agriculture system. However, there are some early surface water irrigation schemes in place which possibly impact this. Both summer images show weakened NDVI across the plains with small areas of strong NDVI values. The December, 1973 image appears to have weaker NDVI in comparison with the February, 1978 image. It would generally be expected that a late summer image should show weaker NDVI due to prolonged hotter and drier weather. The two 1981 spring images show high NDVI results across the entire plains with October showing higher NDVI than September. Both the spring and summer results across the Canterbury Plains follow the expected natural path of NDVI with higher rainfall in the winter causing increased NDVI in winter and spring, and lower rainfall and hotter temperatures drying out vegetation in summer leading to decreased NDVI.

The images dated from 2003-2011 tend to show similar results to pre1984 in the spring months with very strong NDVI. The July, 2004 winter result produced mid-range NDVI values, suggesting it is still recovering from the previous summer. Summer results tended to show a mixture of strong and weak NDVI values, with the exception of the December 3rd, 2003 image which was still showing mainly strong NDVI values. The March 11th, 2005 image is showing NDVI to be more similar to the summer images, while the March 28th, 2011 shows stronger NDVI values across most of the plains. The key difference between the pre 1984 and 2003-2011 images is in the summer images which show much larger areas of healthy NDVI values in the 2003 – 2011 years.



Figure 6. December 7th 1973 NDVI



Figure 7. February 5th 1978 NDVI



Figure 8. September 3rd 1981 NDVI



Figure 9. October 27th 1981 NDVI



Figure 10. September 14th 2003 NDVI



Figure 11. October 16th 2003 NDVI



Figure 12. December 3rd 2003 NDVI



Figure 13. February 5th 2004 NDVI



Figure 14. July 31st 2004 NDVI



Figure 15. March 11th 2005 NDVI



Figure 16. October 5th 2005 NDVI



Figure 17. February 16th 2008 NDVI



Figure 18. December 26th 2010 NDVI

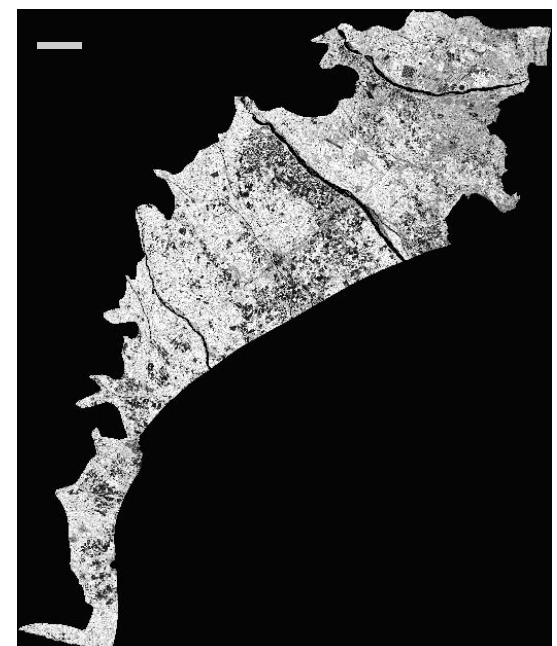


Figure 19. March 28th 2011 NDVI

Diachronic Analysis of NDVI at the Target Locations

Figures 21 – 41 on pages 26 - 36 show how the individual NDVI signatures of each target zone change both seasonally and over the entire study period. Table 2 shows the basic individual NDVI statistics of each location for every image.

Across all target sites, standard deviations show that variance is lower in winter and spring than summer and autumn. The same difference in standard deviation can be seen between the summer 1973-1981 and the summer 2003-2011 targets with the latter having higher standard deviations. This helps establish that significant changes have taken place between the two time periods.

Table 2. Individual target location and date NDVI statistics.

	Dec 7th 1973				Feb 5th 1978				Sept 3rd 1983			
	Min	Max	Mean	Stdev	Min	Max	Mean	Stdev	Min	Max	Mean	Stdev
Oxford	-0.128571	0.819549	0.317579	0.156838	-0.15493	0.728	0.317625	0.164674	-1	0.825243	0.512556	0.159444
Hororata	-0.088	0.876543	0.249208	0.153853	-0.137931	0.774011	0.357664	0.122474	0.019608	0.9	0.487736	0.137507
Dunsandel	-0.130435	0.80117	0.153657	0.175725	-0.209302	0.809524	0.289236	0.155429				
Cust	-0.138462	0.818182	0.301715	0.176719	-0.302326	0.815789	0.256293	0.17658				
Ashburton	-0.127072	0.797468	0.199305	0.186608	-0.081081	0.820513	0.415208	0.163012	0.014493	0.851852	0.581975	0.136437
Orari	-0.209677	0.895954	0.472245	0.235422	-0.219512	0.819355	0.36275	0.207994	-0.142857	0.837838	0.436483	0.177102
Glenavy	-0.307263	0.726708	0.228281	0.219602	-0.875	0.773333	0.265096	0.184386	-0.142857	0.814433	0.524713	0.14795
	Oct 27th 1983				Sept 14th 2003				Oct 16th 2003			
Oxford	-0.012658	0.885057	0.672931	0.155021	0.016393	0.771429	0.515857	0.14584	-0.011765	0.812081	0.567228	0.166377
Hororata	-0.037037	0.87013	0.62891	0.164787	-0.027027	0.777778	0.513868	0.157913	0	0.794118	0.602798	0.132818
Dunsandel					-0.2	0.773585	0.537341	0.151965	-0.384615	0.81457	0.607278	0.173428
Cust					-0.085714	0.790476	0.559964	0.1587	-0.190476	0.824324	0.621264	0.165853
Ashburton	0.046729	0.871921	0.649555	0.154635	-0.021277	0.72093	0.36552	0.154147	0	0.744681	0.485284	0.184747
Orari	-0.036364	0.909677	0.609954	0.197628	-0.170732	0.745098	0.370613	0.174219	0.014085	0.728395	0.434198	0.144967
Glenavy	-0.050505	0.892683	0.668388	0.149425	0.033333	0.791667	0.604373	0.115116	0.1	0.674074	0.529253	0.082261
	Dec 3rd 2003				Feb 5th 2004				Jul 31st 2004			
Oxford	-0.016393	0.803468	0.564028	0.14424	-0.018182	0.756098	0.430697	0.152187	-0.066667	0.727273	0.429862	0.134164
Hororata	-0.006993	0.806061	0.573028	0.132995	-0.092199	0.789474	0.370667	0.214817	-0.125	0.733333	0.470561	0.160068
Dunsandel	-0.277778	0.798817	0.534966	0.160212	-0.405405	0.792683	0.40442	0.229979	-0.222222	0.746032	0.486775	0.164438
Cust	-0.212121	0.802198	0.550077	0.162901	-0.222222	0.793939	0.453402	0.247817	-0.142857	0.764706	0.475201	0.167908
Ashburton	-0.282051	0.769231	0.413058	0.193362	-0.607843	0.798817	0.377741	0.213828	-0.111111	0.737705	0.395429	0.148682
Orari	-0.046296	0.751196	0.265883	0.208084	-0.016393	0.76	0.404967	0.205066	-0.142857	0.727273	0.380296	0.206247
Glenavy	-0.075594	0.771429	0.435182	0.22847	0.047619	0.676923	0.383179	0.10949	-0.066667	0.724138	0.470259	0.149418
	Mar 11th 2005				Oct 5th 2005				Feb 16th 2008			
Oxford	0	0.747899	0.340356	0.134305	0	0.811321	0.583248	0.162309	-0.035714	0.761006	0.310642	0.164796
Hororata	-0.037594	0.793651	0.541643	0.156144	0	0.809524	0.553732	0.169943	0.009524	0.816092	0.492489	0.168537
Dunsandel	-0.304348	0.794872	0.438041	0.200533	-0.37931	0.822222	0.611829	0.1311	-0.307692	0.798561	0.422444	0.232422
Cust	-0.068493	0.8	0.471869	0.213983	-0.045455	0.810811	0.556331	0.18606	-0.25	0.801418	0.400539	0.22529
Ashburton	-0.511111	0.791045	0.517894	0.139814	-0.416667	0.812081	0.555635	0.178344	-0.52381	0.808917	0.459603	0.212153
Orari	-0.090909	0.793103	0.451766	0.221278	-0.02439	0.80597	0.587434	0.163808	-0.463415	0.809524	0.451121	0.24203
Glenavy	-0.050847	0.798319	0.576909	0.123168	0.02381	0.814286	0.616073	0.138208	-0.058824	0.801324	0.594118	0.124901
	Dec 26th 2010				Mar 28th 2011							
Oxford	-0.086957	0.8	0.443548	0.167294	0	0.81982	0.556172	0.160236				
Hororata	0.020979	0.772727	0.493744	0.179612	0	0.826923	0.642116	0.118565				
Dunsandel	-0.333333	0.778947	0.439932	0.209715	-0.466667	0.813084	0.580425	0.154579				
Cust	-0.266667	0.789474	0.462009	0.205824	-0.111111	0.803922	0.527923	0.179865				
Ashburton	-0.540984	0.8	0.441225	0.215852	-0.4	0.813084	0.608218	0.163035				
Orari	-0.109091	0.787234	0.52458	0.179047	-0.06383	0.826923	0.515355	0.227792				
Glenavy	-0.030137	0.783784	0.484806	0.166594	-0.02381	0.793103	0.640181	0.09179				

The pre 1984 summer images tended to have NDVI values concentrated towards unhealthy vegetation values between 0.2 and 0.4, while spring values were all showing very healthy NDVI values closer to 0.8. Notably many target locations show December 1973 as having weaker NDVI values than February 1978. Orari showed the most significant difference to the other target areas in summer with a higher standard deviation due to a large spread of both healthy and unhealthy vegetation. The Orari River runs directly through this area, and the highest NDVI values were located closer to the river as shown in figure 20. This suggests that the river could be having a positive effect on NDVI values possibly through surface water uptakes for irrigation. However, Cust also has a river flowing through the target area but only shows a slightly larger spread of NDVI and the difference is not evident in the imagery.

The 2003-2004 period has provided a very useful analysis of a year-long NDVI cycle. Most areas show an easy to identify NDVI transition throughout the year. Orari and Glenavy are

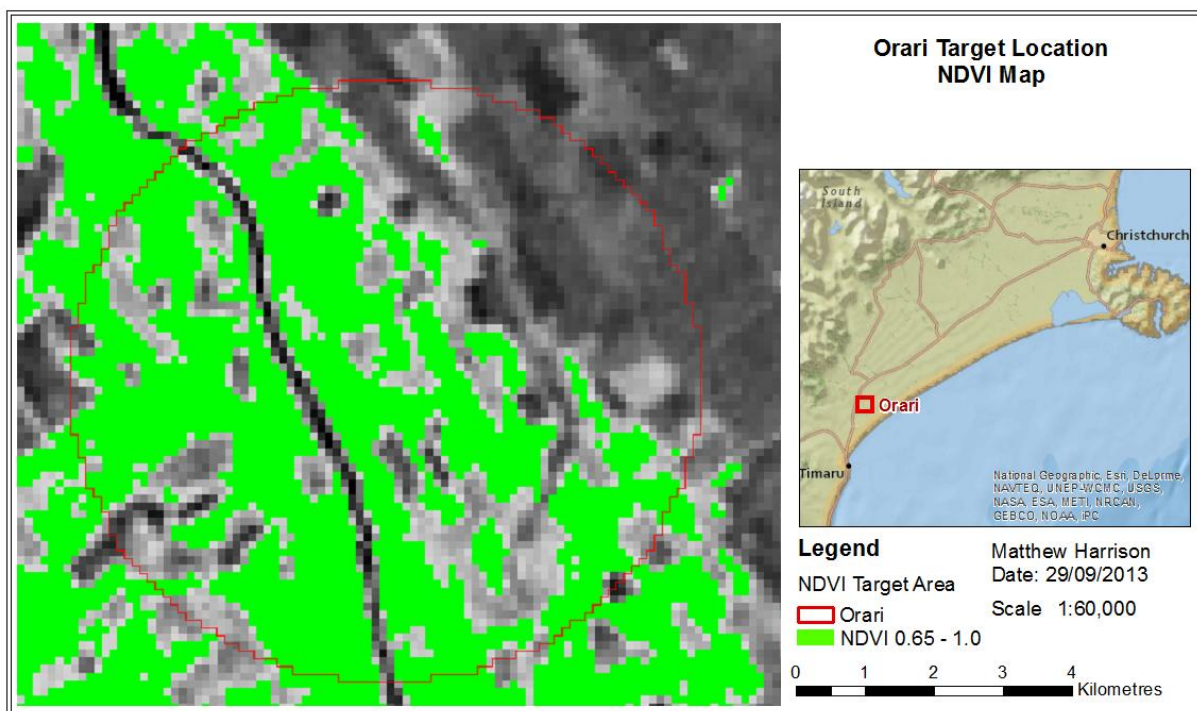


Figure 20. Orari target area (red circle) December 7th, 1973 with NDVI values between 0.55 and 1.0 highlighted. Orari River flows from top left to bottom centre of image.

difficult to follow in their cycle due to the impact of excessive cloud cover impacting some NDVI data as signified in their respective figures. The general trend shows the NDVI values building a peak towards 0.8 through the spring months of September and October, before beginning to spread back towards 0.2 in December. February then shows a very strong spread of NDVI values from very unhealthy to very healthy. July then shows NDVI values beginning to increase back towards a healthy state. Standard deviation follows a similar pattern throughout the year being lower in winter and spring with NDVI concentrated towards the healthy vegetation value of 0.8. When summer begins, standard deviation increases as the NDVI begins to spread back towards the unhealthy vegetation value of 0.2 while some areas maintain their healthy NDVI values.

2005 – 2011 shows most NDVI signatures following the seasonal trend observed in the 2003-2004 data. The March, 2011 image is an exception to this showing high NDVI values across all target sites which doesn't fit into the pattern observed in the 2003-2004 data. If it had followed this pattern, the NDVI would have produced lower NDVI values due to expected low rainfall at that time of the year. This suggests that the regional climate conditions may have varied from the usual pattern in the months prior to this date.

The most important observed changes to NDVI signatures are the differences between the summer values of the different time periods. The pre 1984 images provide an observation of the Canterbury Plains at a time when significantly less irrigation was taking place. The 2003 – 2011 images deliver an observation of the Canterbury Plains during a time when irrigation is significantly higher and continually growing. The key change in NDVI during summer is that previously, NDVI values were mostly concentrated between 0.1 and 0.4. The 2003 – 2011 NDVI signatures show that most target areas have developed significant amounts of healthy vegetation during summer. This healthy vegetation is likely to be irrigated land.

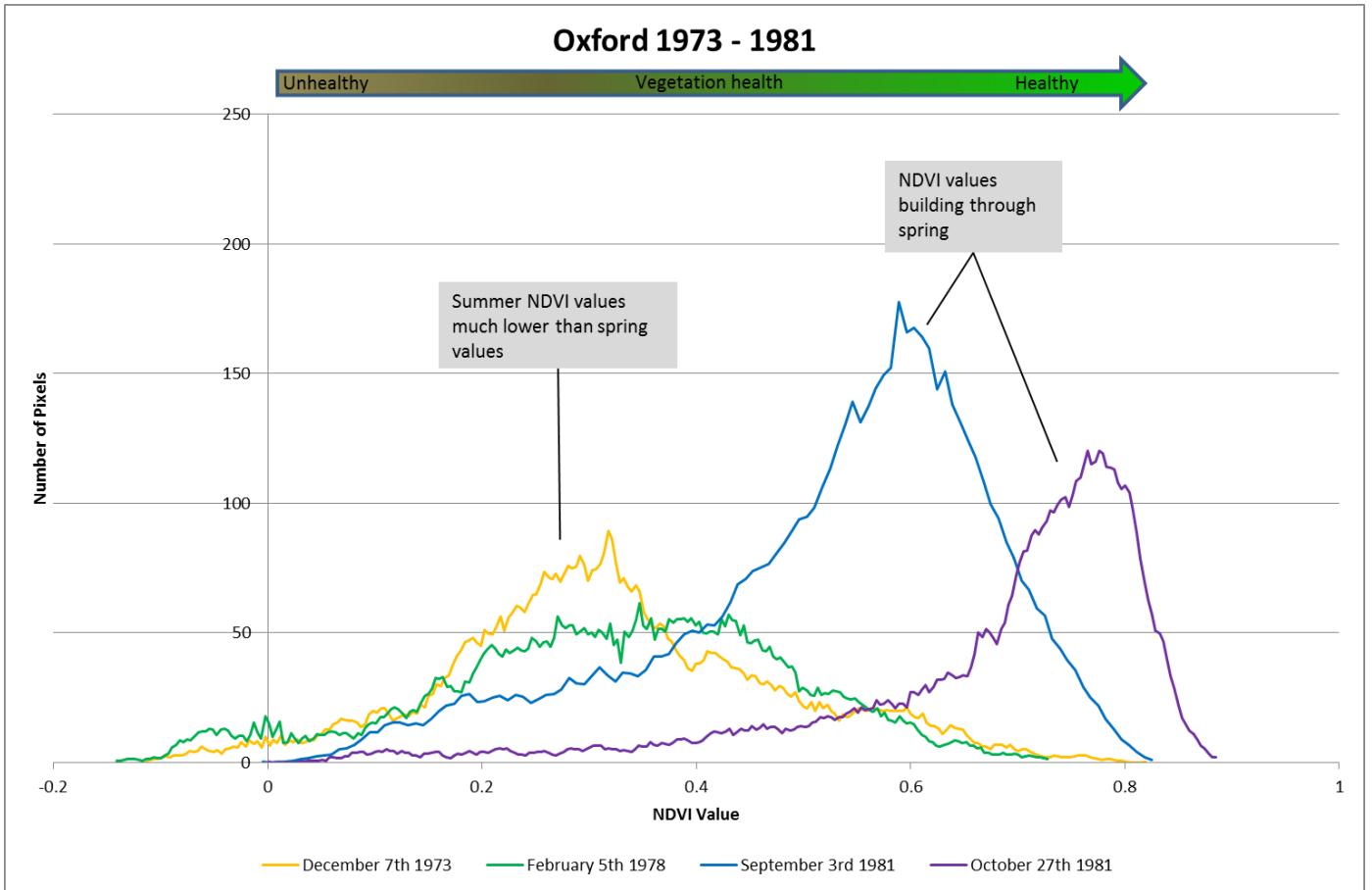


Figure 21. Orari target location NDVI signatures 1973 - 1981

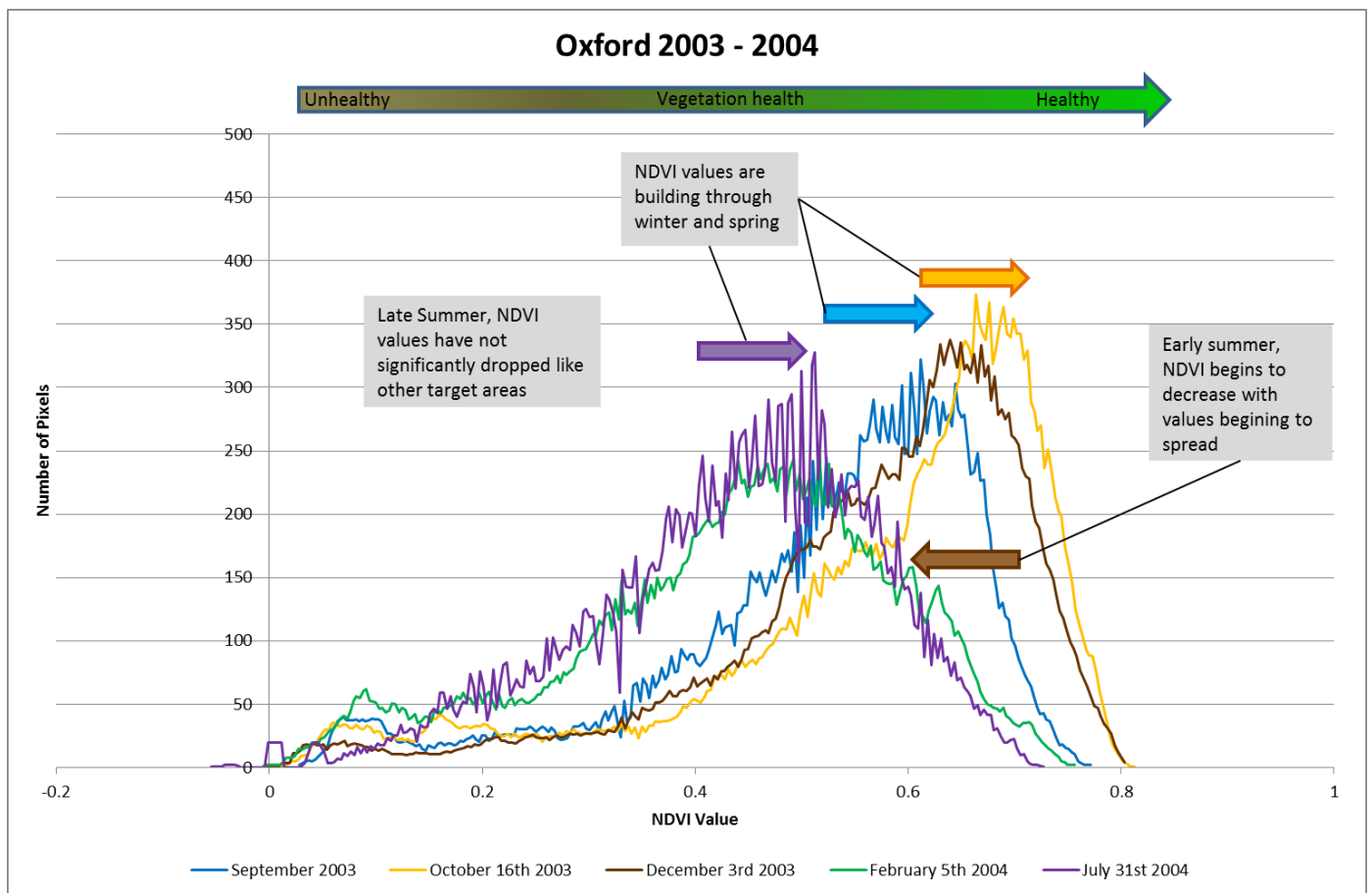


Figure 22. Orari target location NDVI signatures 2003 - 2004

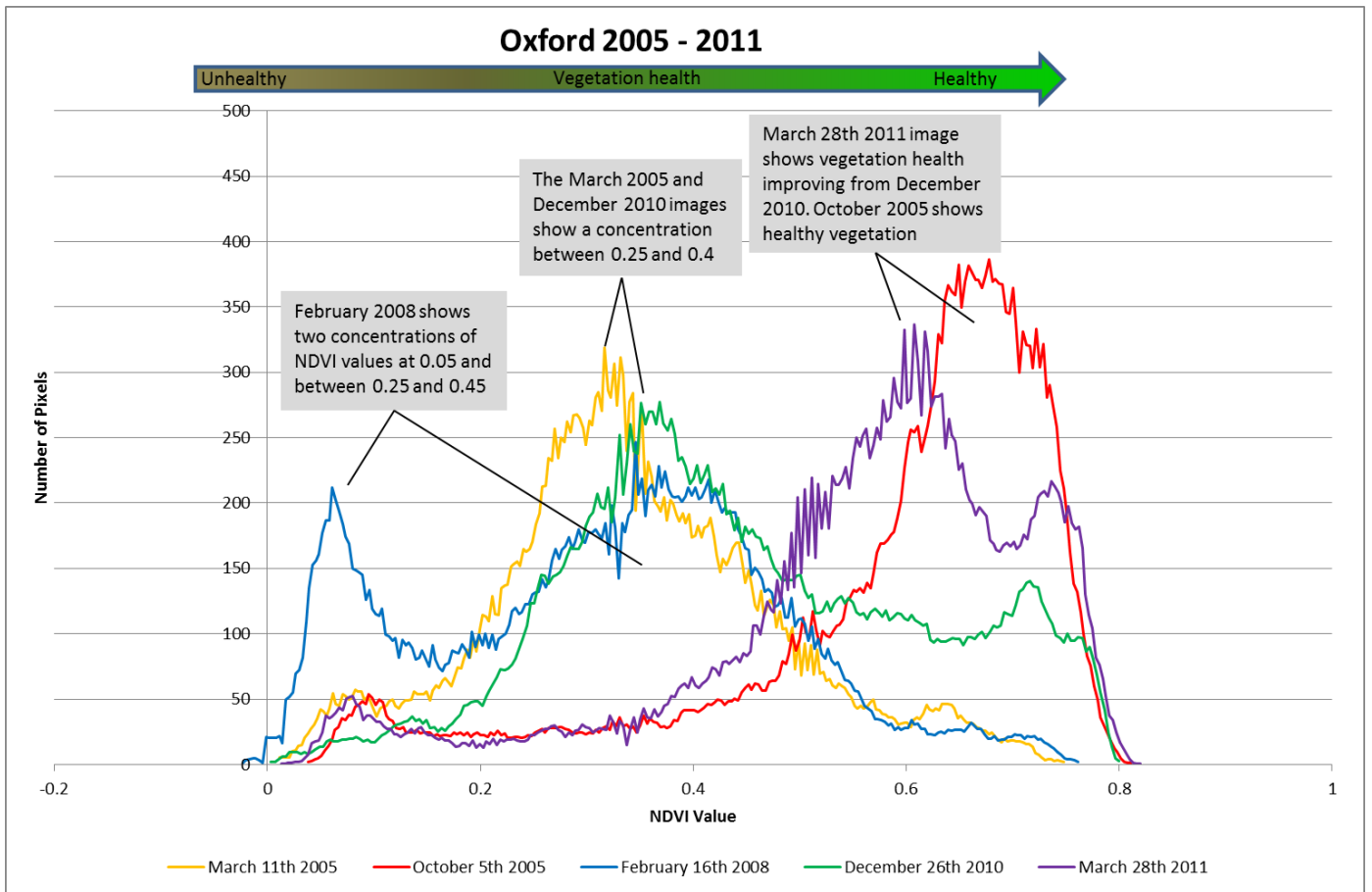


Figure 23. Orari target location NDVI signatures 2005 - 2011

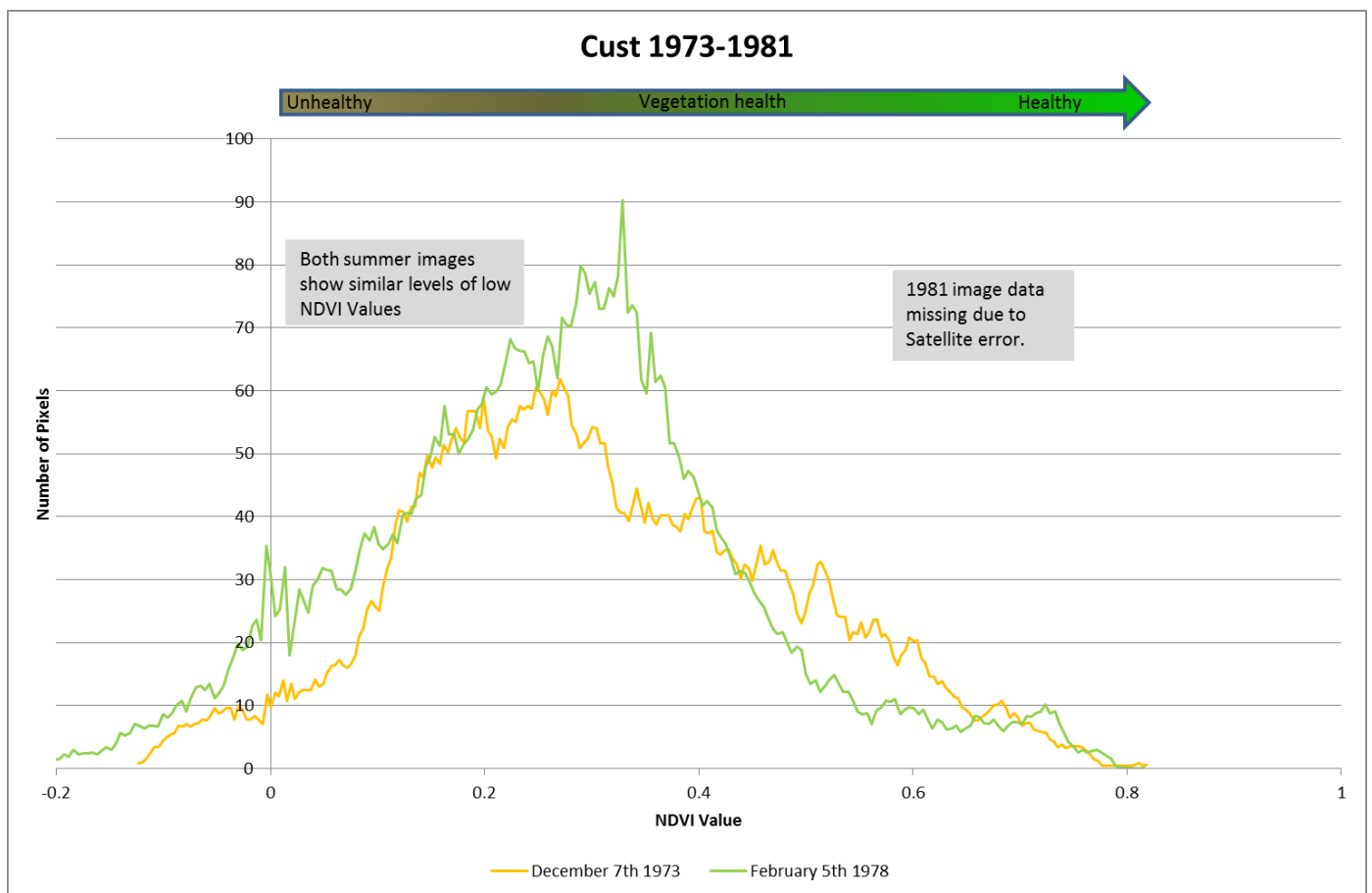


Figure 24. Cust target location NDVI signatures 1973 - 1981

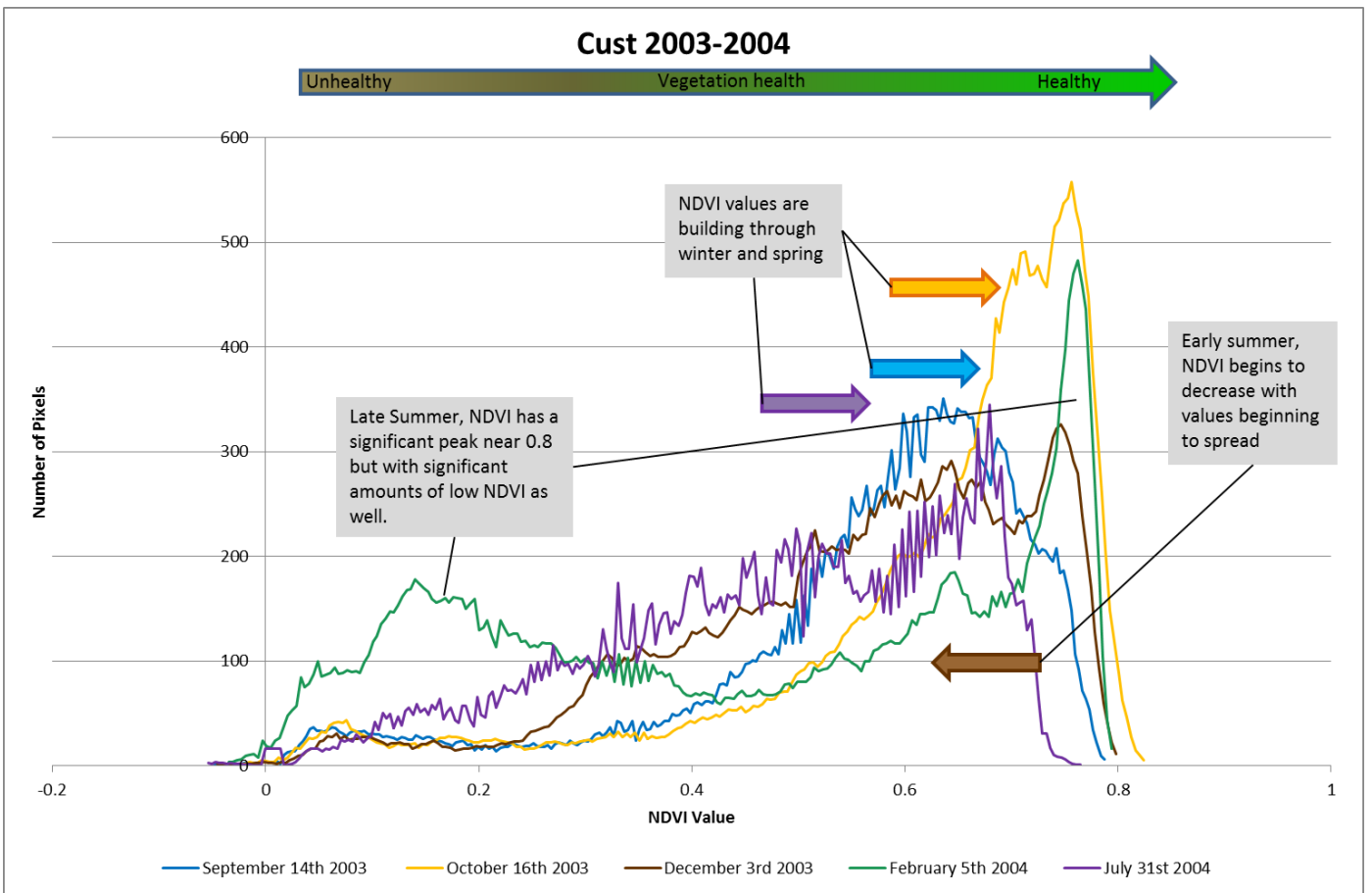


Figure 25. Cust target location NDVI signatures 2003 - 2004

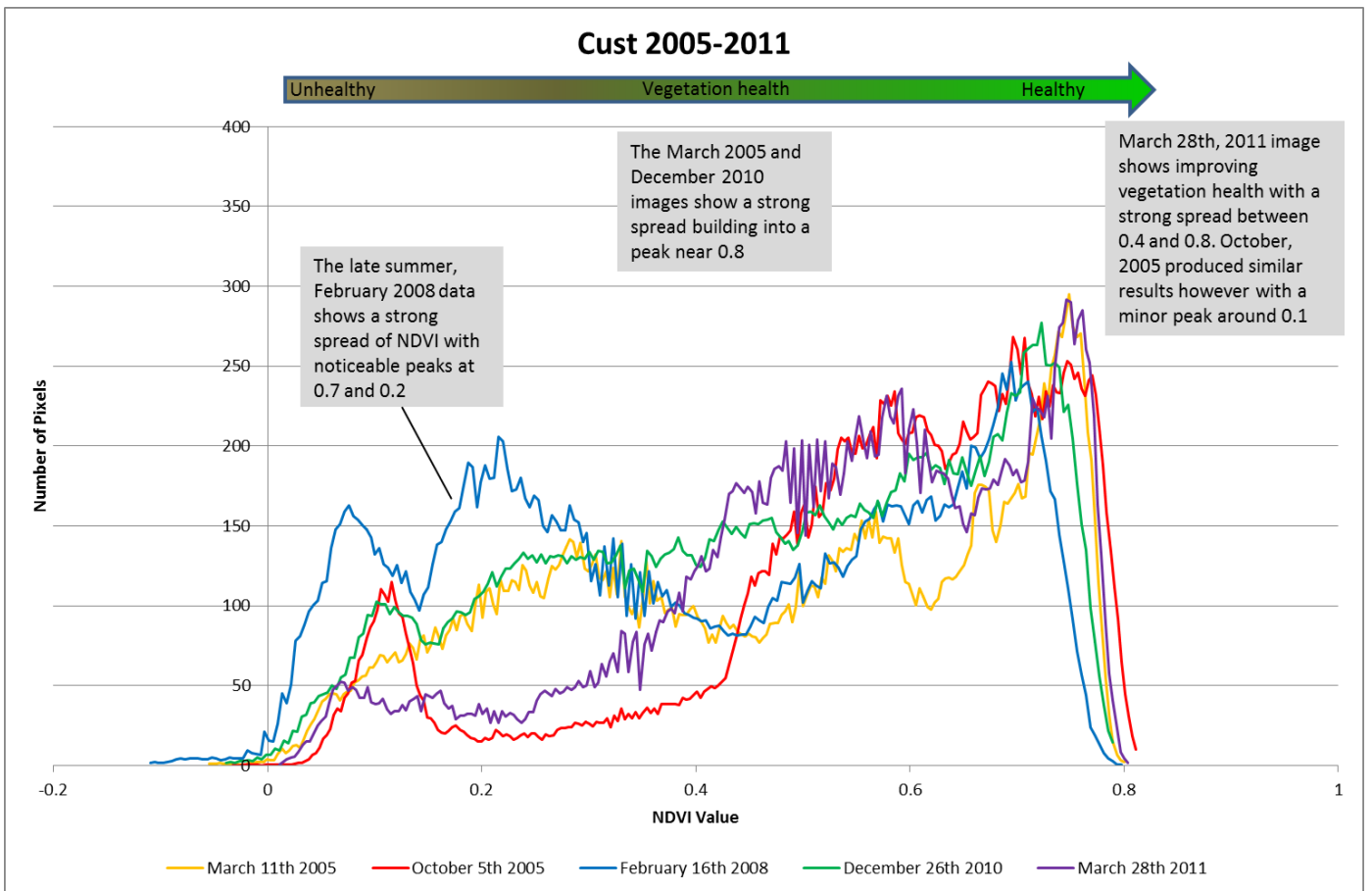


Figure 26. Cust target location NDVI signatures 2005 - 2011

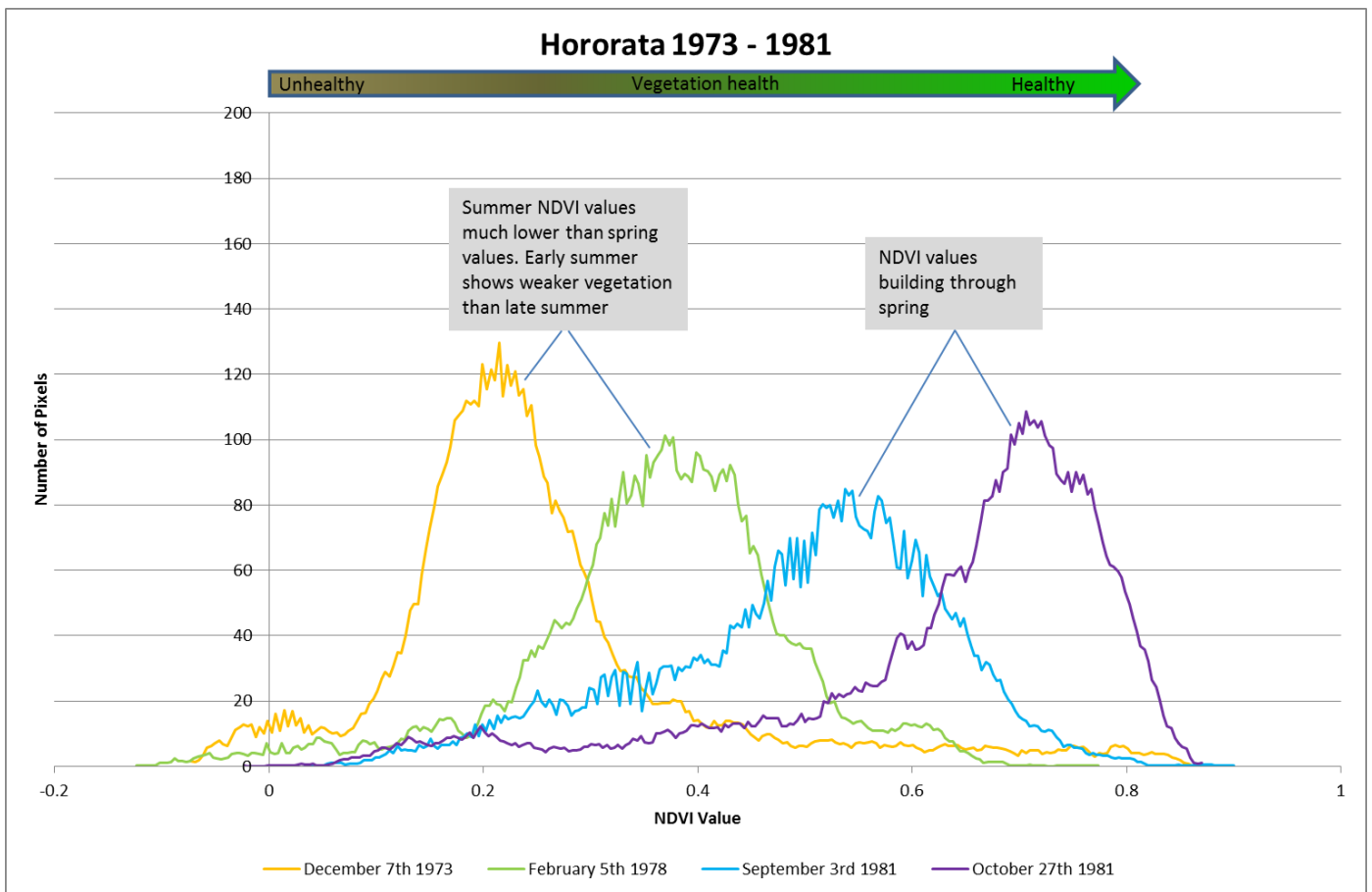


Figure 27. Hororata target location NDVI signatures 1973 - 1981

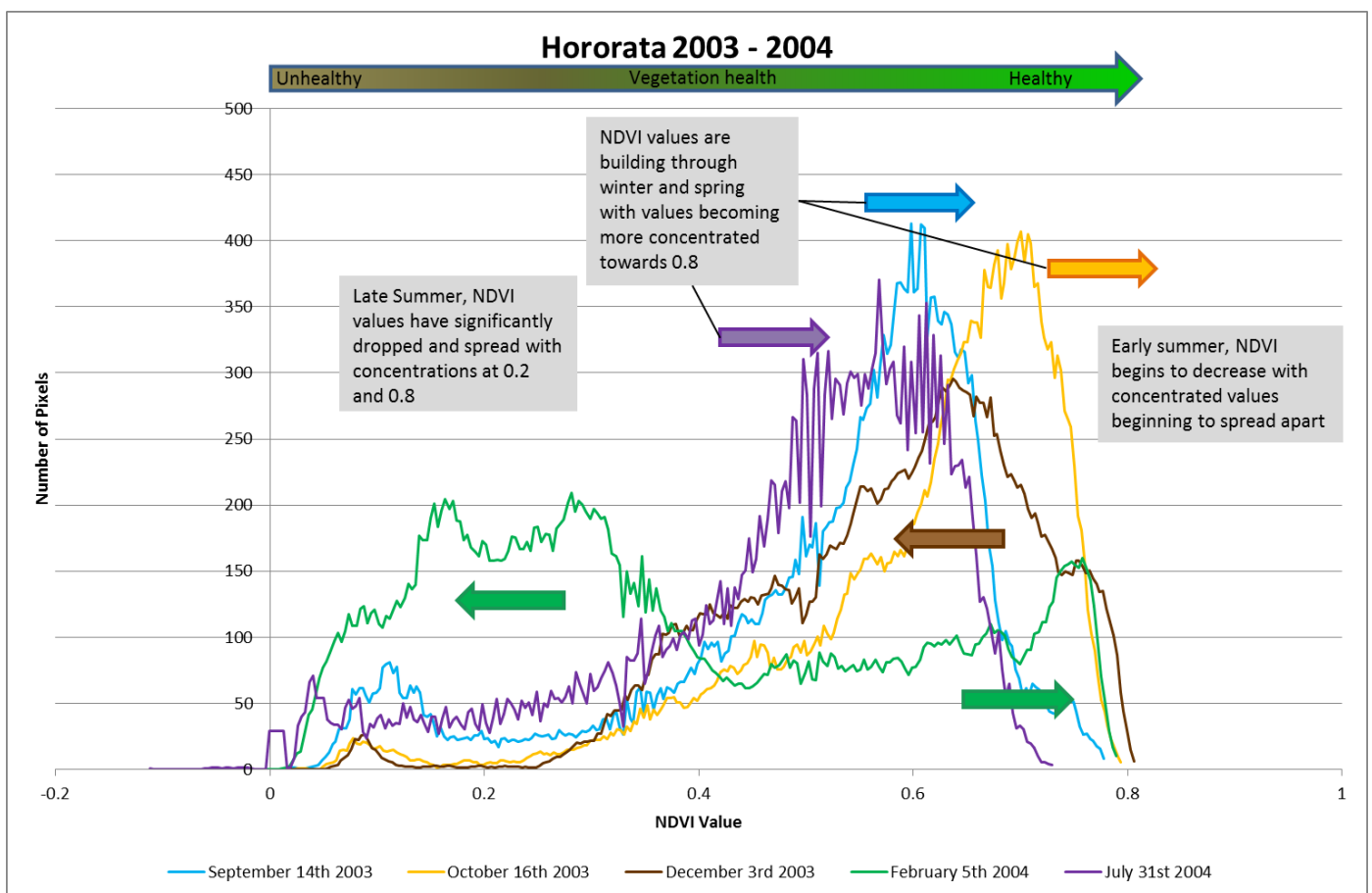


Figure 28. Hororata target location NDVI signatures 2003 - 2004

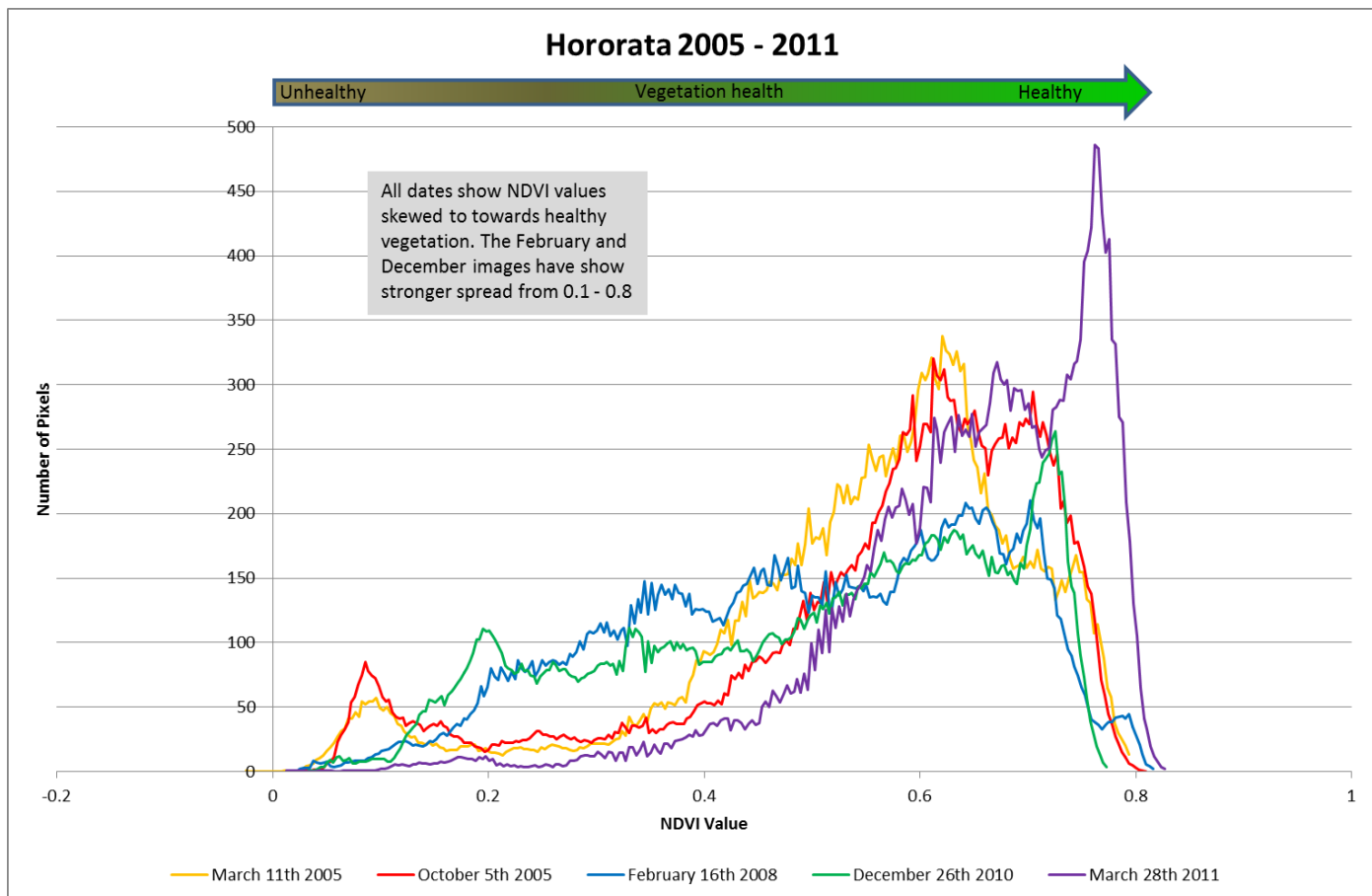


Figure 29. Hororata target location NDVI signatures 2005 - 2011

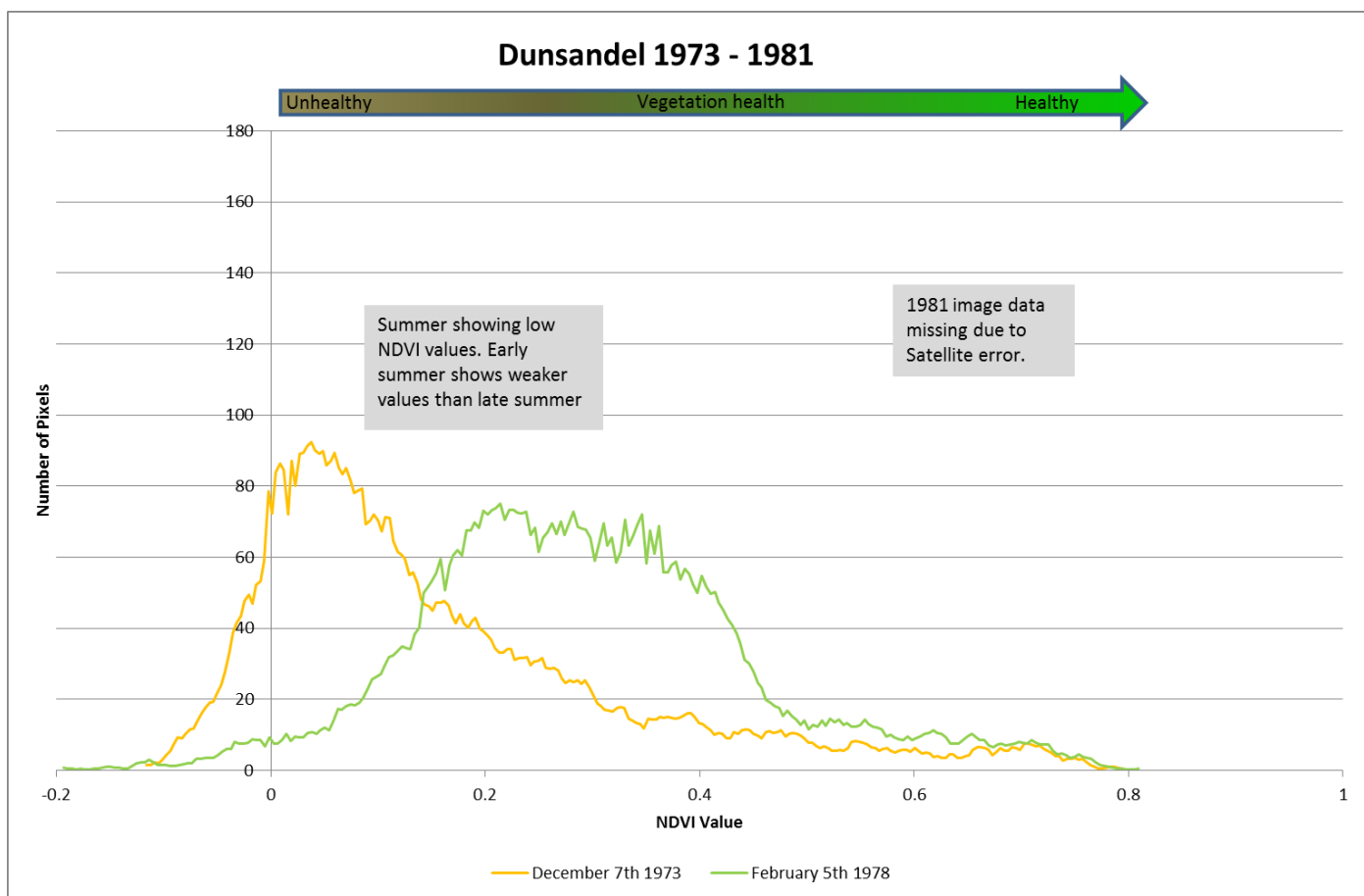


Figure 30. Dunsandel target location NDVI signatures 1973 - 1981

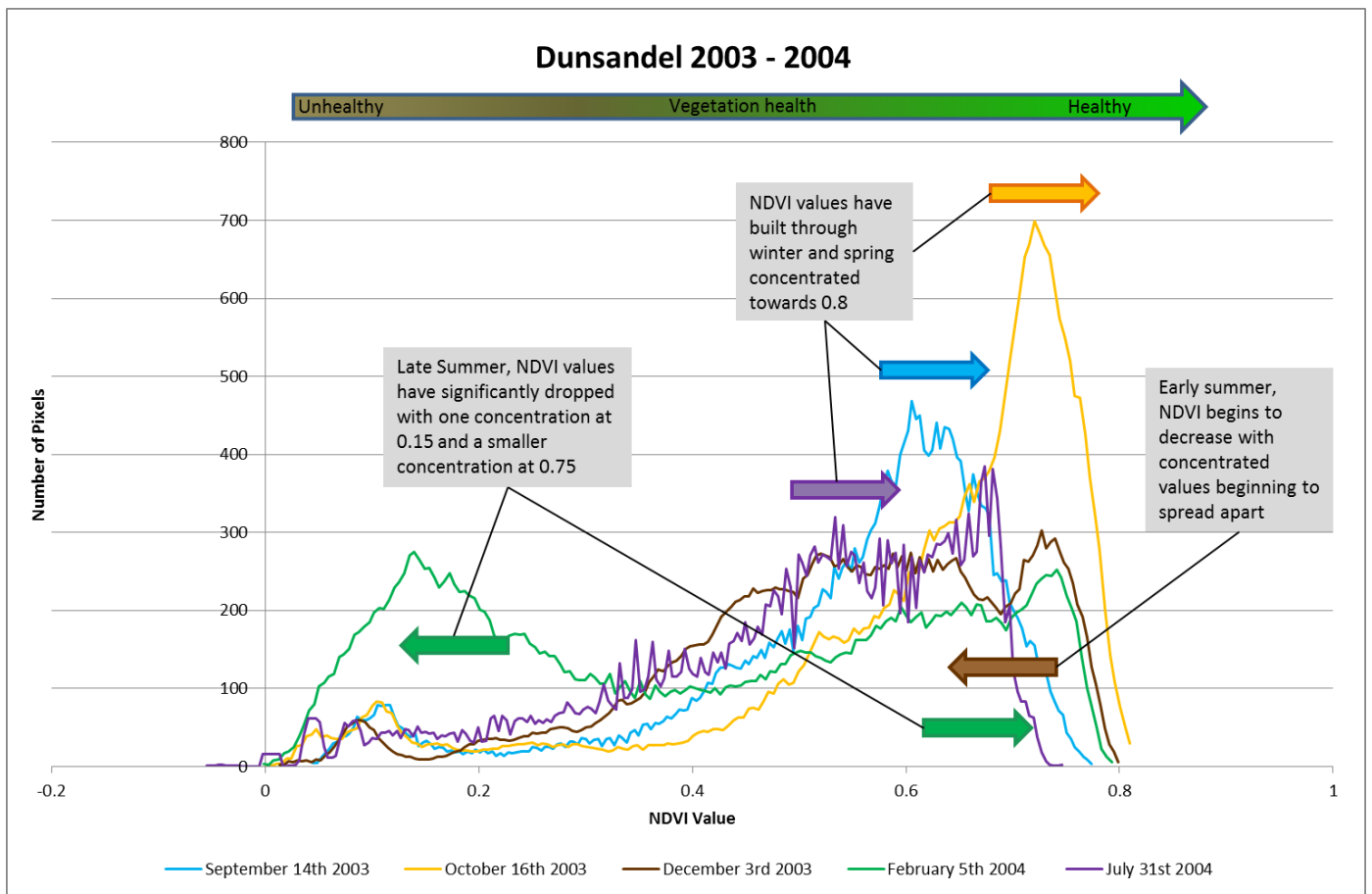


Figure 31. Dunsandel target location NDVI signatures 2003 - 2004

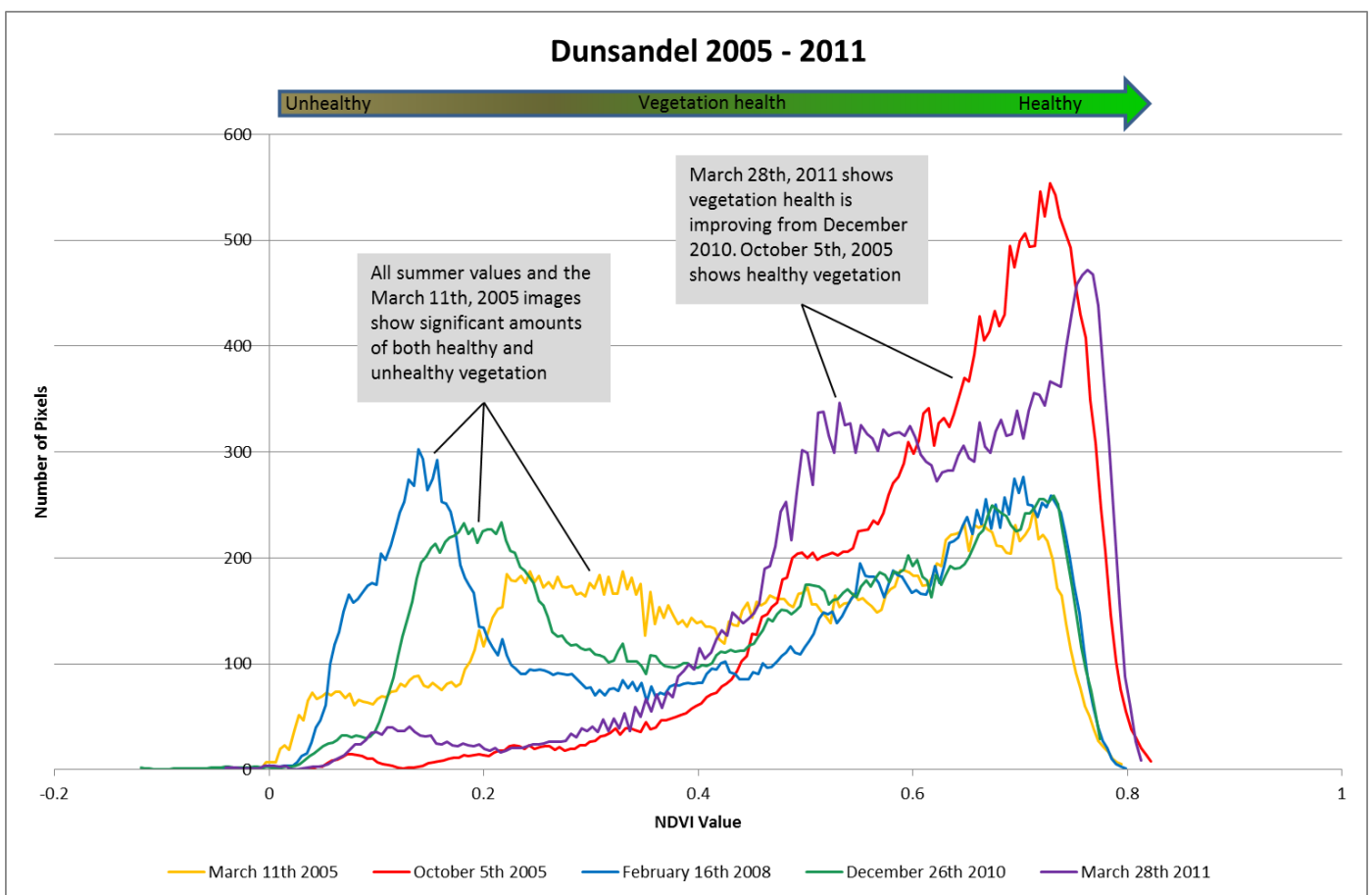


Figure 32. Dunsandel target location NDVI signatures 2005 - 2011

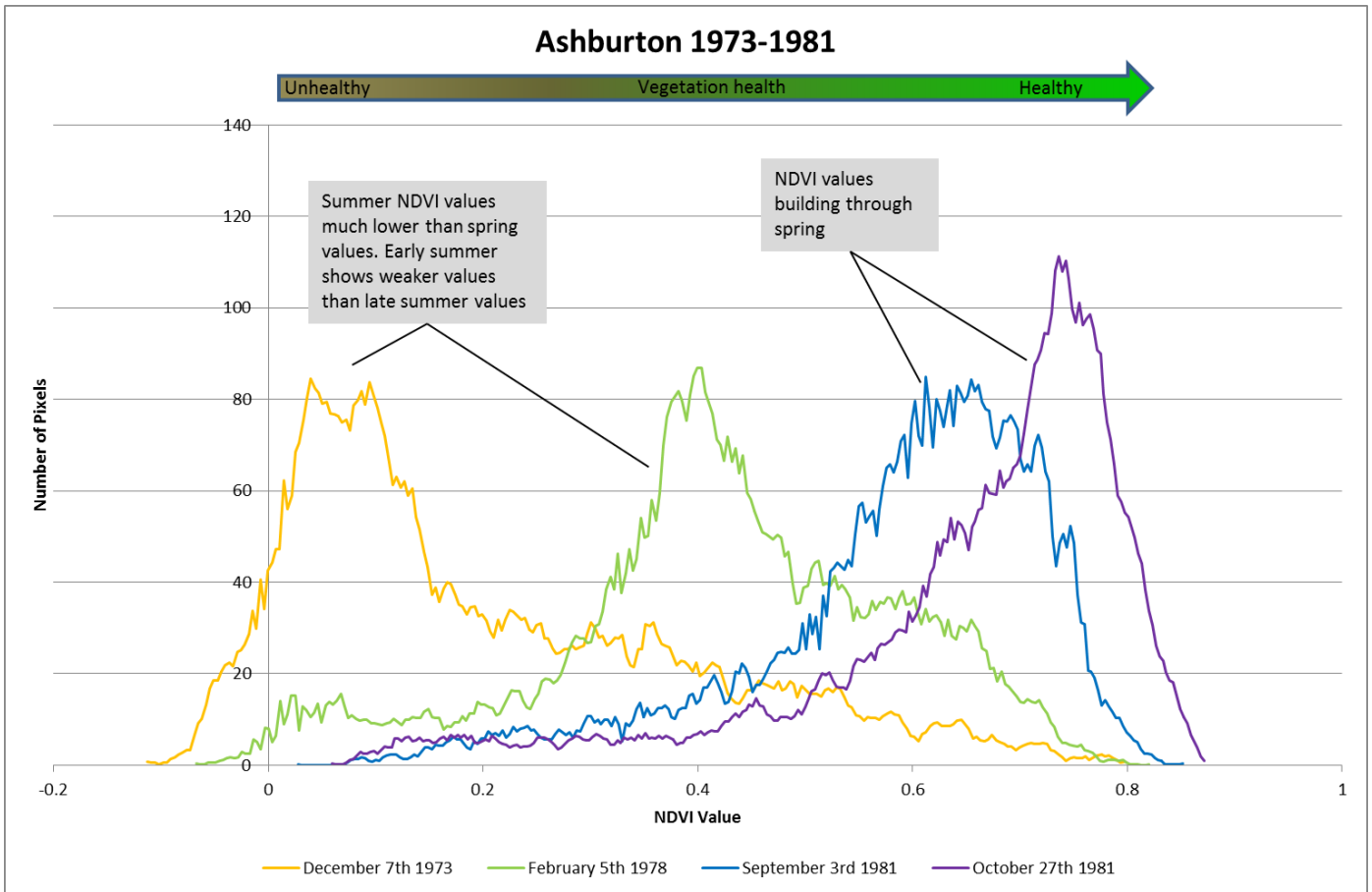


Figure 33. Ashburton target location NDVI signatures 1973 - 1981

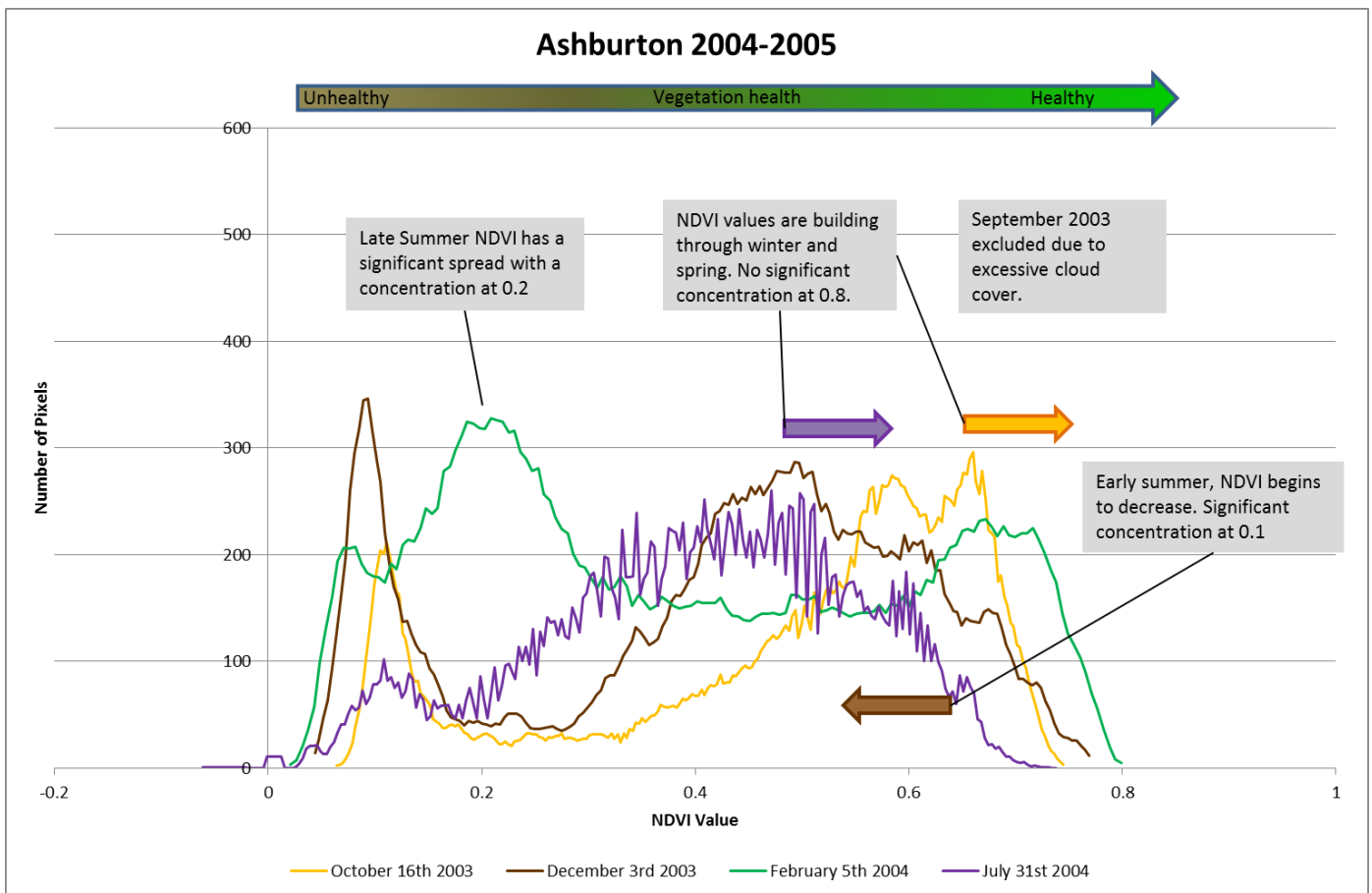


Figure 34. Ashburton target location NDVI signatures 2003 - 2004

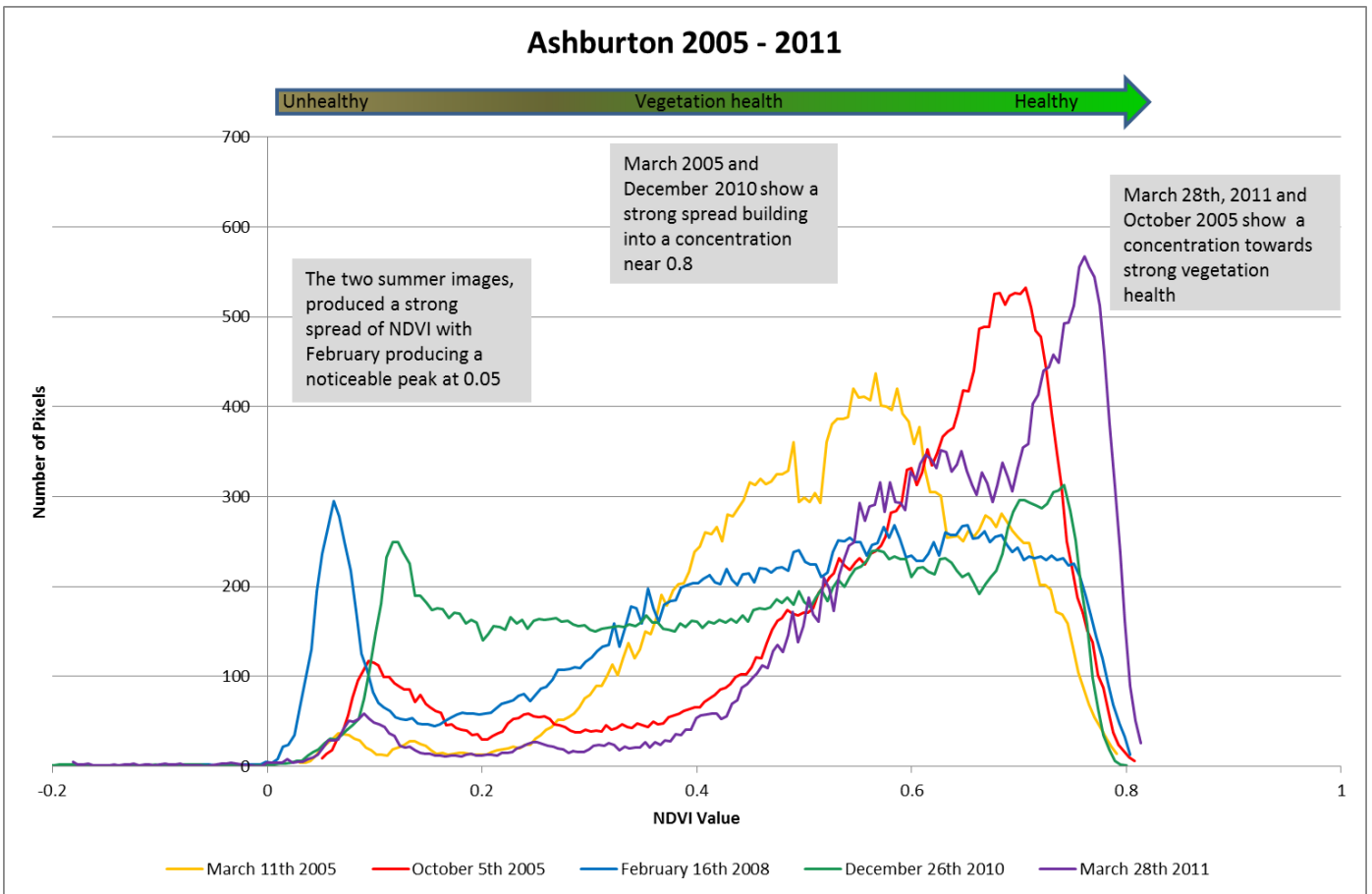


Figure 35. Ashburton target location NDVI signatures 2005 - 2011

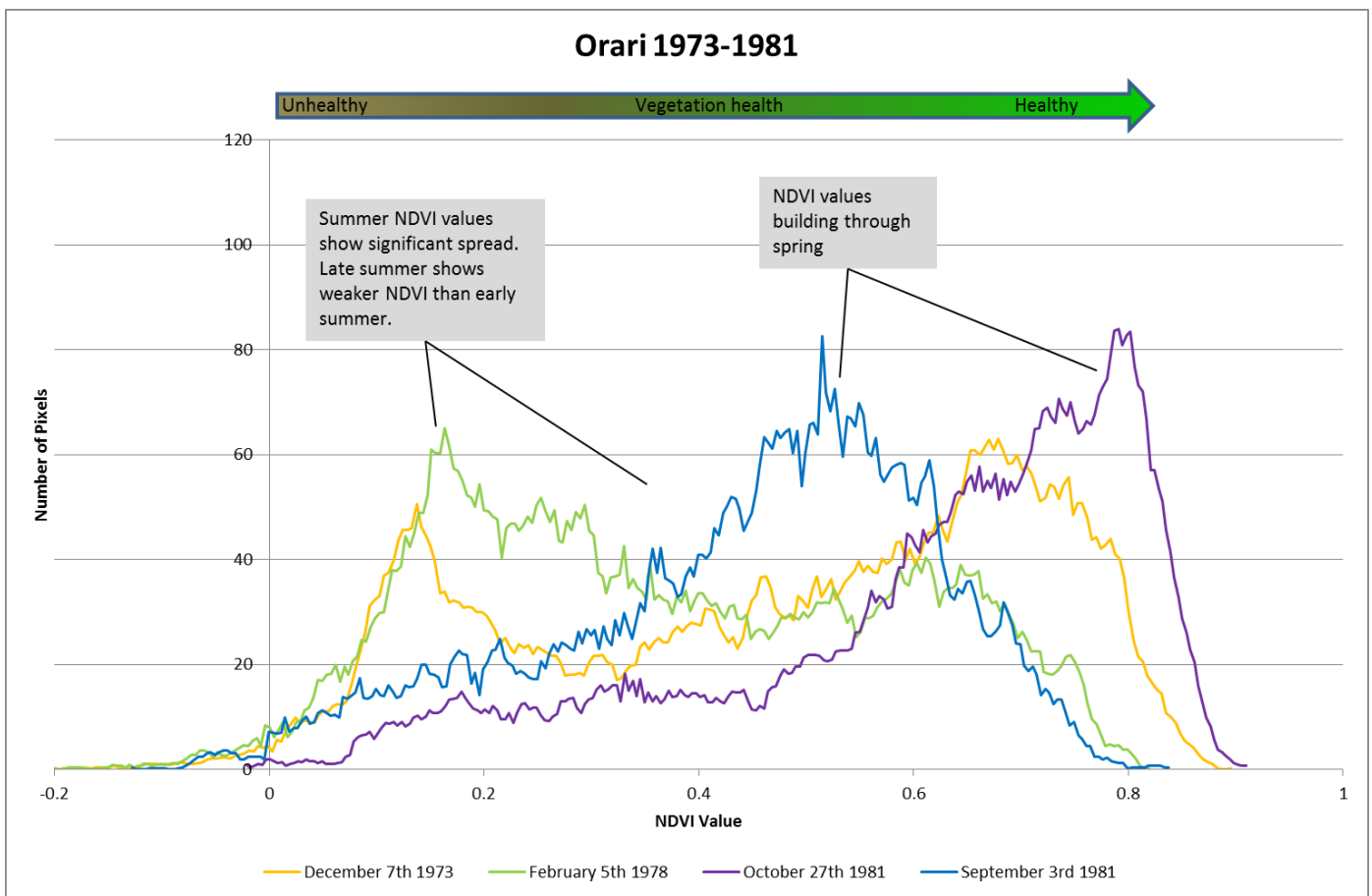


Figure 36. Orari target location NDVI signatures 1973 - 1981

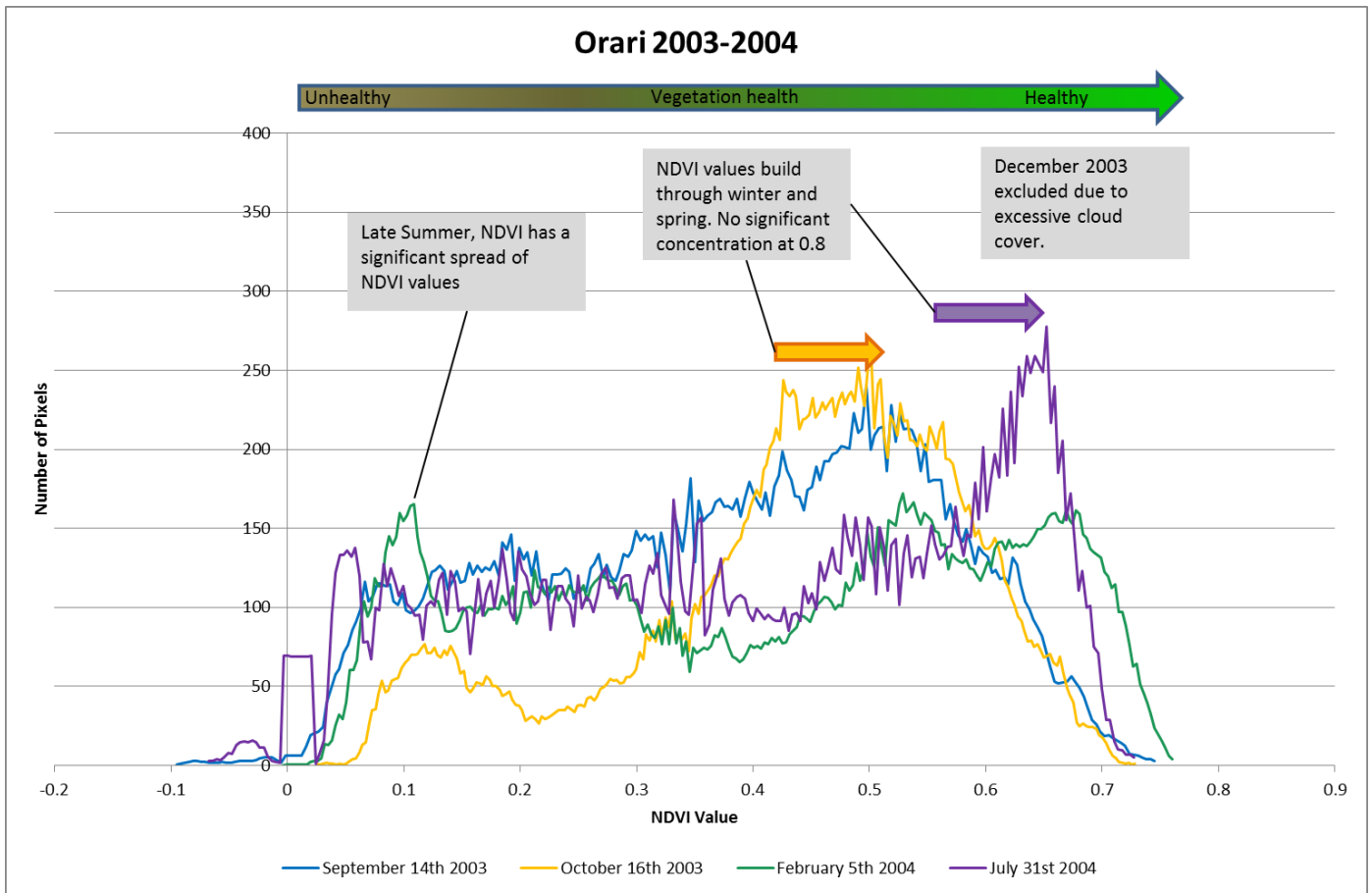


Figure 37. Orari target location NDVI signatures 2003 - 2004

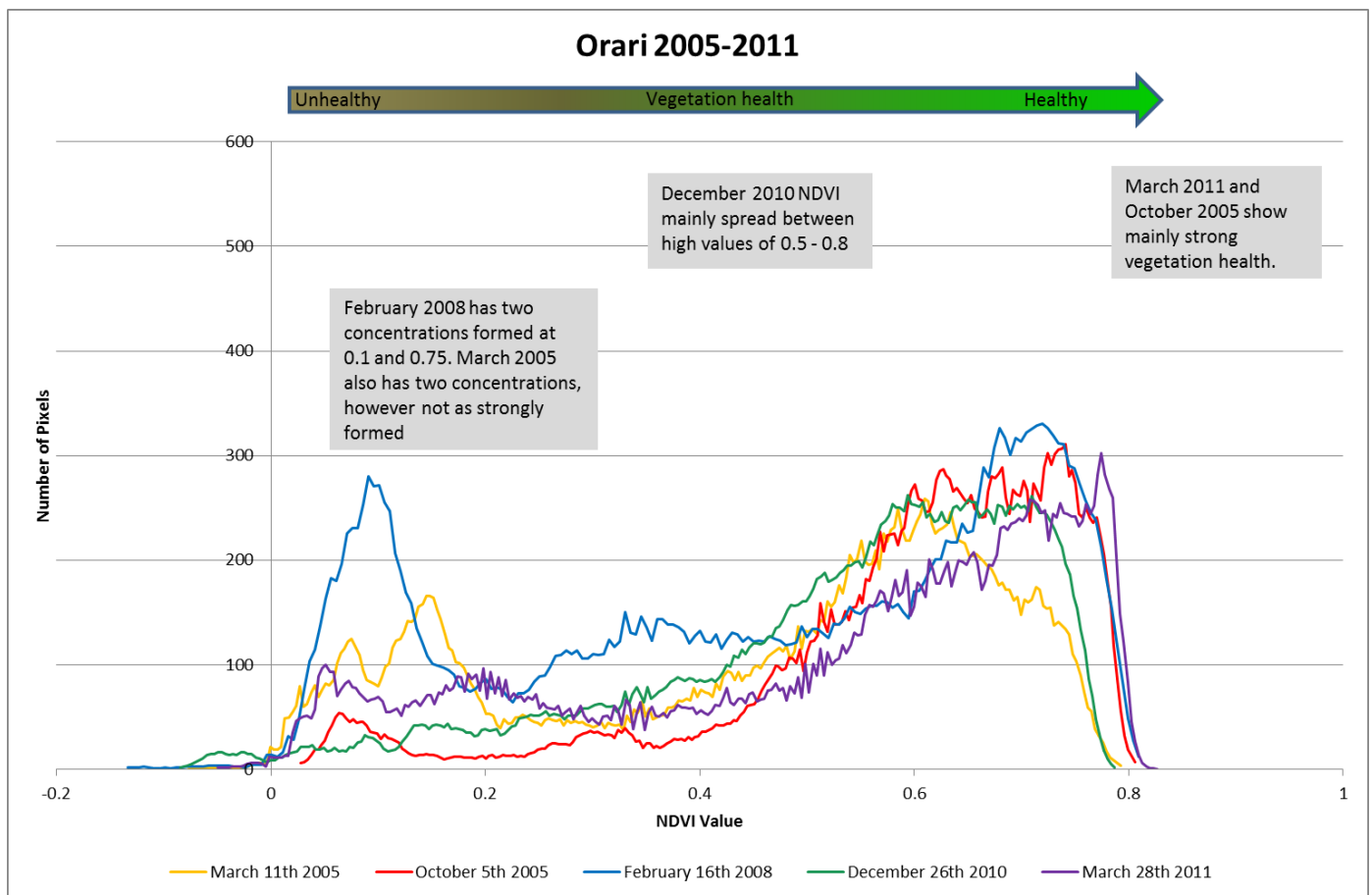


Figure 38. Orari target location NDVI signatures 2005 - 2011

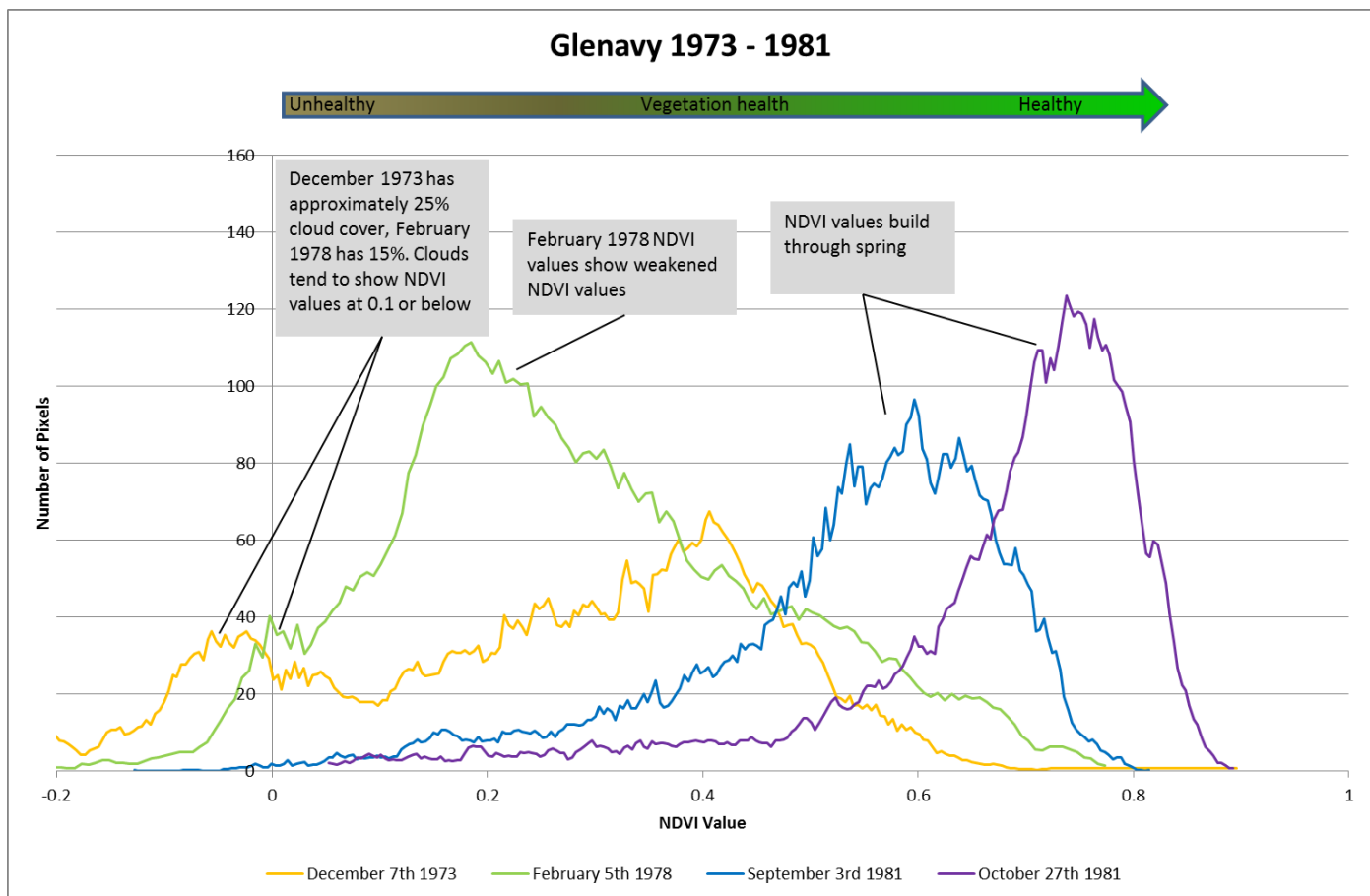


Figure 39. Glenavy target location NDVI signatures 1973 – 1981

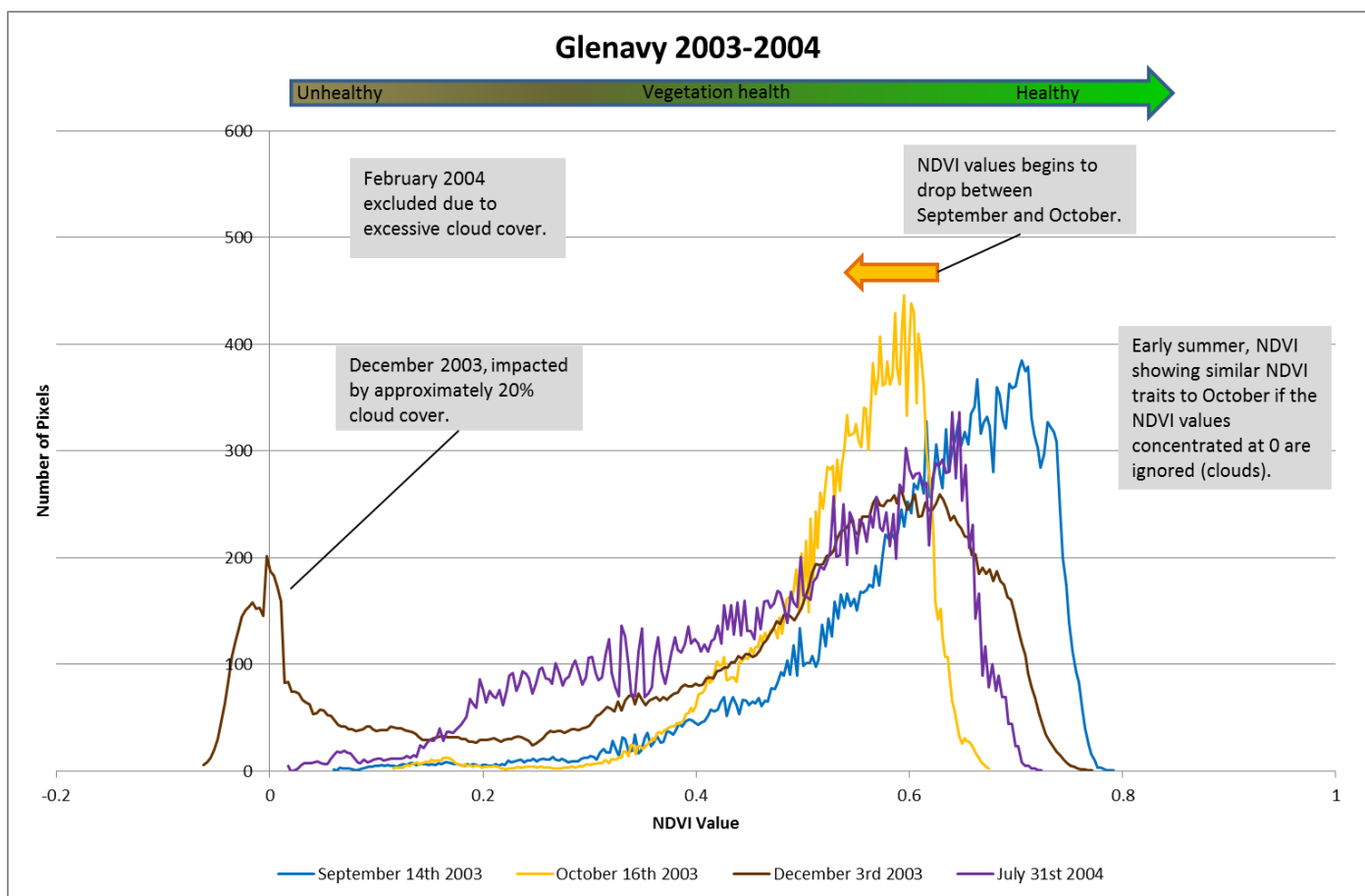


Figure 40. Glenavy target location NDVI signatures 2003 - 2004

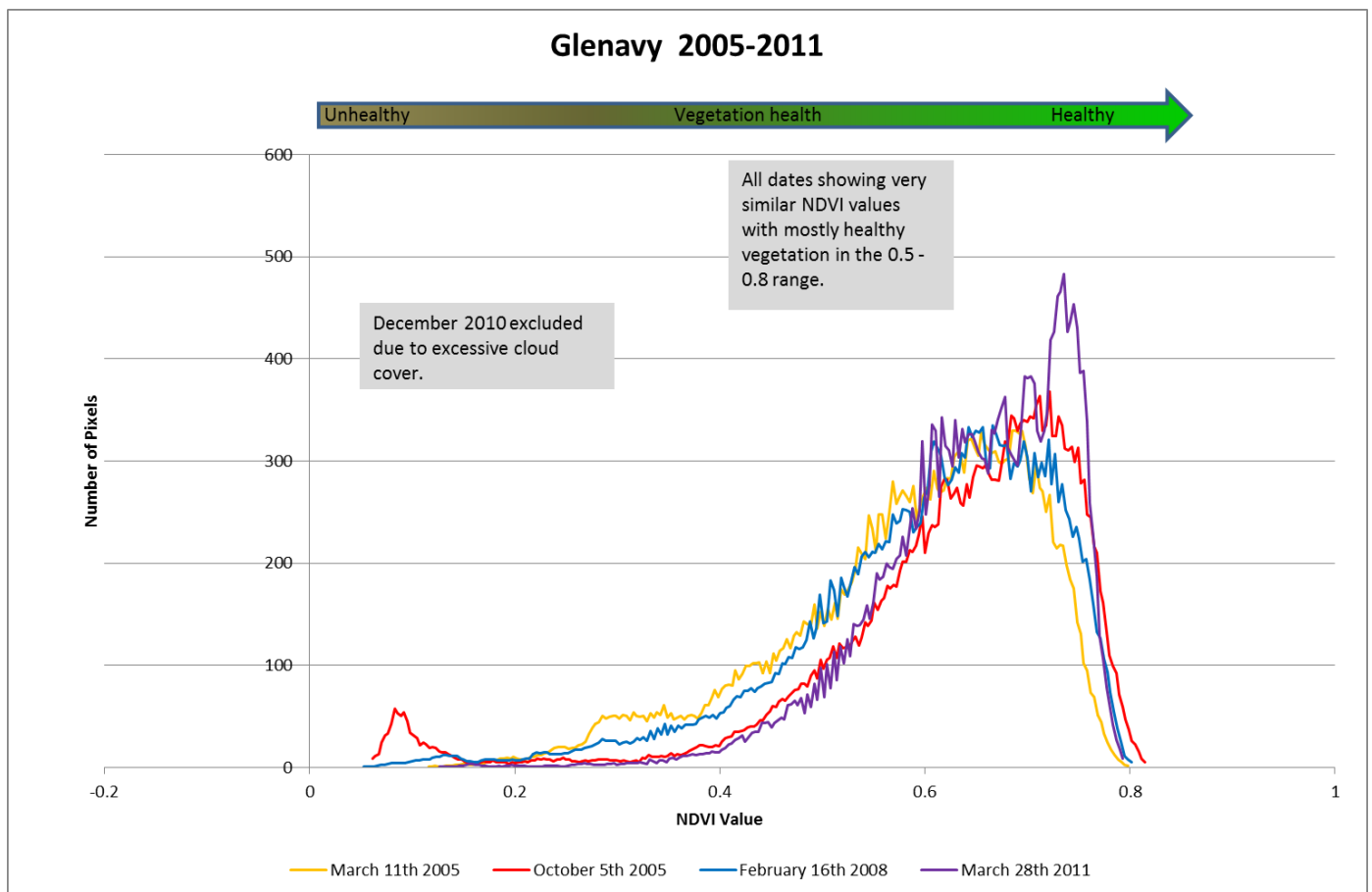


Figure 41. Glenavy target location NDVI signatures 2003 - 2004

Rainfall and NDVI

It is important to understand the different short term and long term trends in order to understand if the NDVI values observed are a response to rainfall or irrigation. Rainfall in Canterbury varies significantly from year to year, therefore understanding the long-term changes in rainfall are equally as important as the short term. The dates of the four satellite images analysed between 1973 and 1981 are shown in figure 43 as green arrows, while the dates of the images analysed from after 2002 are shown in figure 44. To help understand if the rainfall prior to image capture was above or below average, a monthly mean (40 year average) was added to these figures. In addition to this, a ten year moving average of rainfall was created to identify the long term trends as shown in figure 42.

Using a moving 10 year average of rainfall data, long term changes in precipitation were also observed. Early in the study period, significantly higher annual rainfall was recorded across the Canterbury Plains. This is important as it suggests that the increases in healthy vegetation during summers after 2003 are less likely to be a result of increased rainfall. However, standard deviation is still high which means that an individual year could still have much higher rainfall.

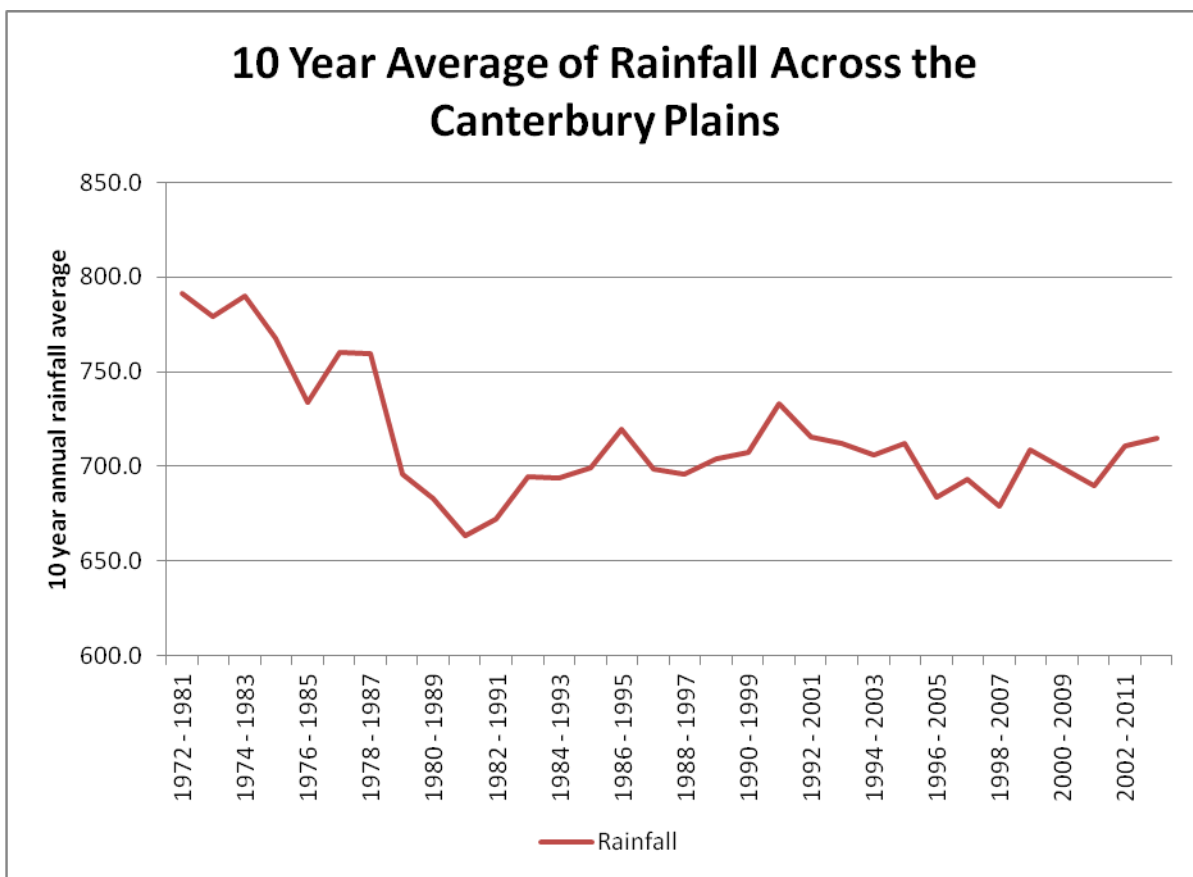


Figure 42. Ten year moving average of rainfall across the Canterbury Plains.

As shown in figure 43, the December 1973 image was taken after a significant dry period of three to four months at between 25 – 50mm of rain per month. This supports the weakened NDVI values found at this date. While the February 1978 image had more rainfall in the previous few months when compared to the 1973 image. This is a likely explanation for why the late summer 1978 image had higher NDVI values when compared with the early summer 1973 image. The 1981 images were taken following three to five months of consistent rainfall at around 80 – 100 mm per month with the exception of September. This relates well to the high NDVI values recorded in the two 1981 spring images.

The spring NDVI results for 2003 fit well with the rainfall received prior to image capture. Rainfall prior to the December image was lower than average and suggests that the NDVI values should have decreased more than what actually occurred. The February 5th image was showed concentrations of significantly weakened NDVI as well as concentrations of healthy NDVI. The rainfall prior to this date was well below average in October (41.5mm), November (43.0mm) and December (4.6mm), while January (58.8mm) recorded average rainfall. The low rainfall in the months prior to January would likely have had a significant impact on NDVI values. As January was recorded average rainfall it is expected that it would have had little impact on NDVI. This suggests that the areas of healthy NDVI for the February image are not rainfall related. The July image in the winter following this received lower than average rainfall, however being in winter, lower temperatures and sunshine hours result in less evapotranspiration allowing for better use of the available water which explains the large increase in NDVI.

The March 2005 image follows two months (January and February) of lower than average rainfall and one month of significantly higher rainfall (December 2004). The NDVI values for this image fit with rainfall well, showing improvements from expected summer values to concentrate around 0.4 – 0.6. The October 2005 image follows a period of around four months of lower than average rainfall (September 40.7mm, August 19.9mm, July 35.0mm, June 15.0mm). However, the NDVI values for the October image are still strong across most locations. As with the July 2004 image, lower evapotranspiration would have played a key role in maintaining NDVI values. The February 2008 and December 2010 images were preceded by three months of low rainfall, which should have resulted in NDVI values concentrating in the unhealthy zone. However, irrigation is likely to have caused significant amounts of vegetation to stay healthy. The March, 28th 2011 image was preceded by 3 months of average rainfall which fits with the NDVI values showing recovery from the December 2010 image.

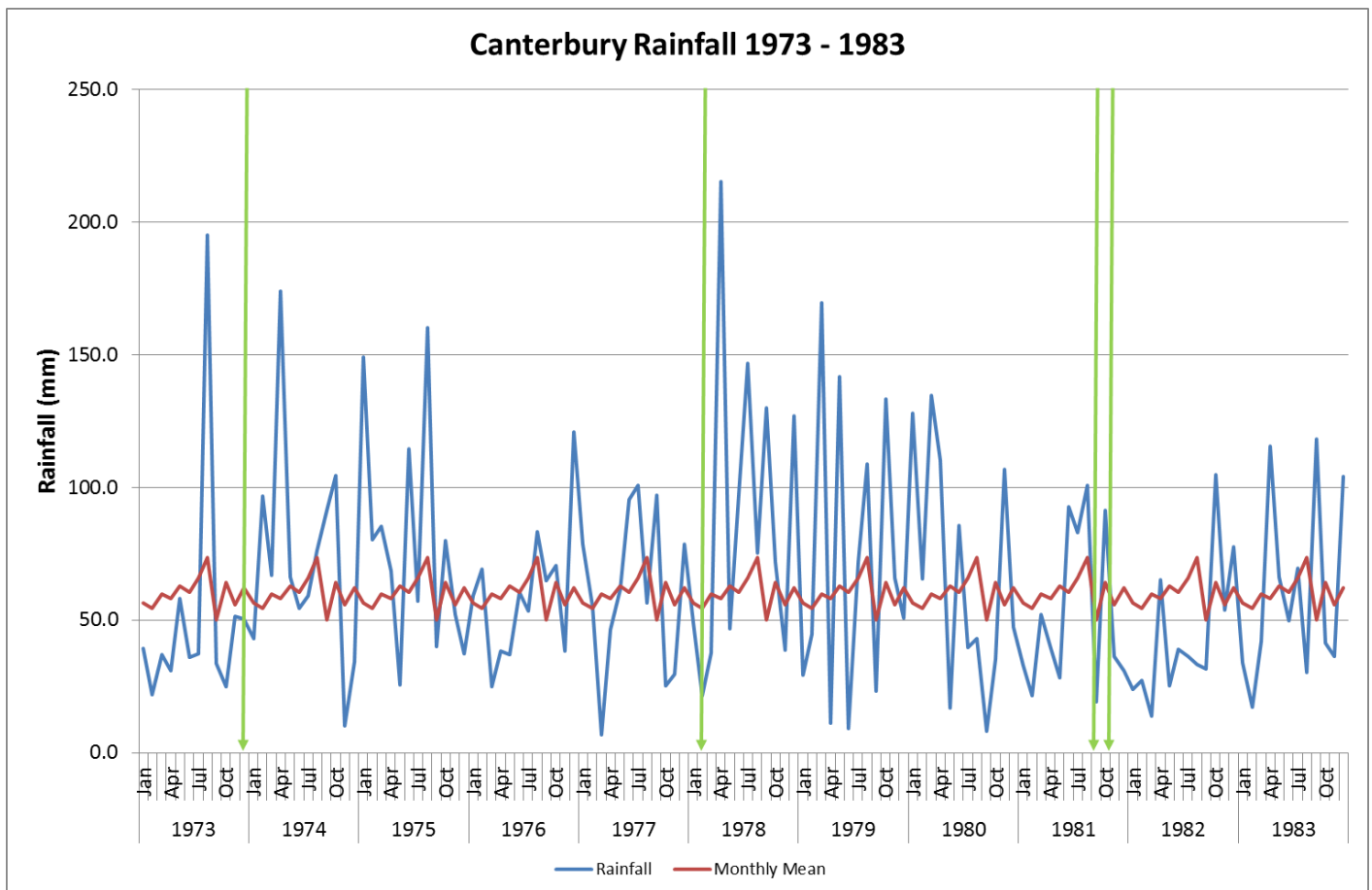


Figure 43. Canterbury Plains monthly rainfall from 1973 to 1983. Satellite image capture dates highlighted with green arrow. The monthly mean for the entire study period is shown in red.

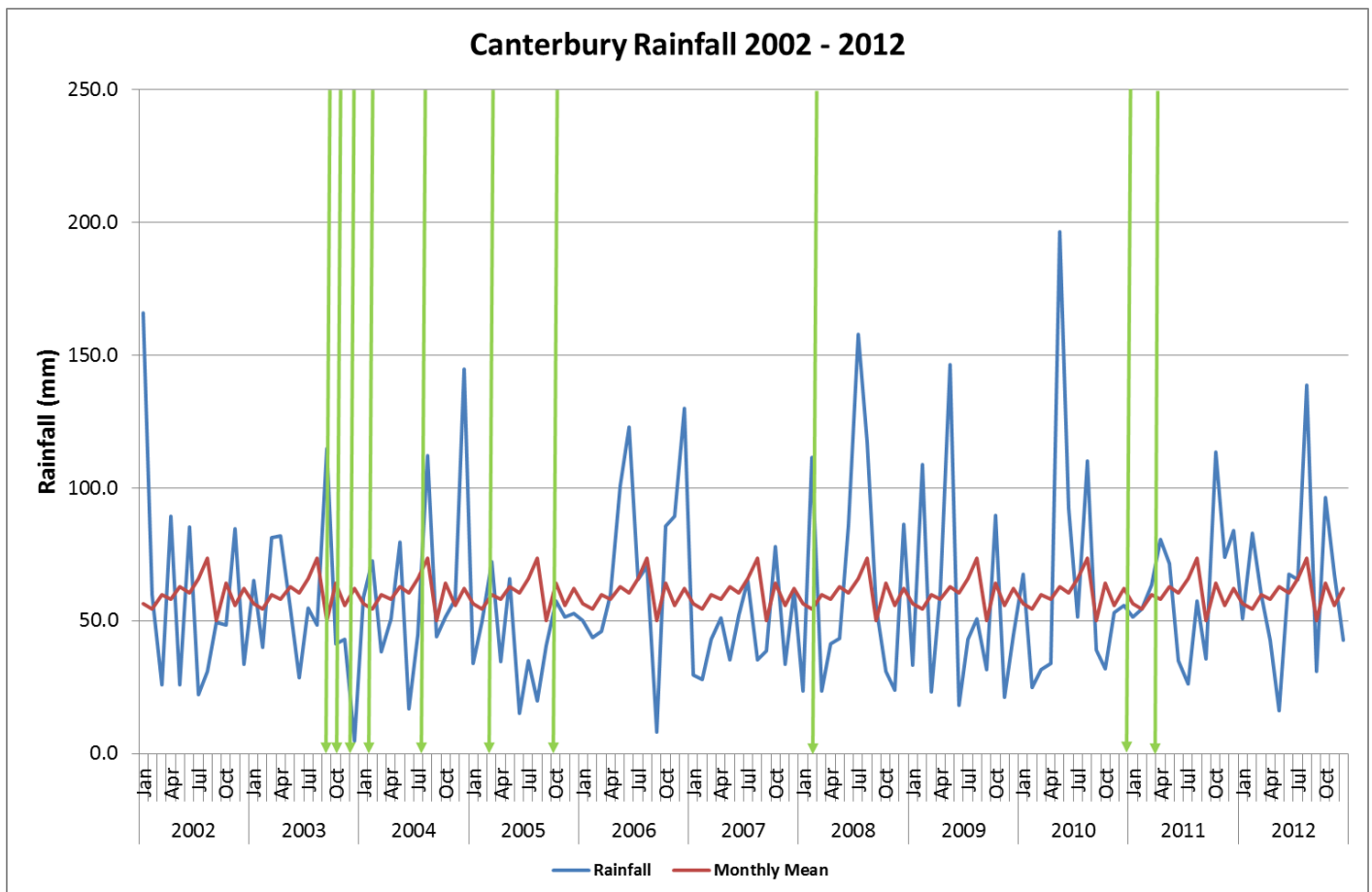


Figure 44. Canterbury Plains monthly rainfall from 2002 - 2012. Satellite image capture dates highlighted with green arrow. The monthly mean for the entire study period is shown in red.

Groundwater

Groundwater dating back as far as 1970 was acquired across the study region from ECAN. The consistency of data recordings prior to the year 2000 was very limited particularly in the southern half of the study area. However, from 2002 – 2012, groundwater data collection was much more reliable providing a near full record for all wells as shown in figures 45 and 46 below. In addition to this, ten year averages were created from the monthly data and combined with a ten year average of rainfall in a time series graph in figure 44 below.

The ten year averages provided useful guidance in how both precipitation and groundwater levels have changed over the past 40 years. The well K37/0335 was removed from the 10 year analysis due to having only one recording prior to 2000. Wells with greater depths to water generally showed greater variation over time, while those with shallower depth to water showed the less variation. While the well recordings prior to 1985 were less consistent, the recorded higher depth to water levels fit well with the increased rainfall also recorded at that time. Most wells recorded a higher 10 year average groundwater level during the 1970-1980 to 1979-1989 period compared to the 1993 – 2003 period. However, the 1970-1980 to 1979-1989 period recorded significantly higher rainfall when compared to all other time periods, which lead to a period of increased groundwater levels. The 1980 – 1990 to 1989 - 1999 period saw an initial drop in rainfall but gradually increasing back to an average around 700mm per year. Groundwater levels in wells M35/1080, L36/0142 and K37/0215 during this same period followed a similar pattern with an initial decrease followed by an increase. After this period, rainfall remained relatively constant around 700mm annually for each 10 year average until the 2002 – 2012 period with a slight drop around the 1997 – 2007 period.

However, from the 1992 – 2002 period onwards, noticeable drops in groundwater can be seen in all Groundwater wells except for M35/0058 and J40/0045. Significant drops of 2 and 3 metres can be observed in the L36/0142 and K37/0215 wells which happen to be located within the Rakaia-Selwyn and Valetta ECan groundwater allocation zones. The Rakaia-Selwyn zone is currently at 145% of its allocation limit and the Valetta zone at 138%. This helps to explain the significant drop at this location. All other locations that saw minor drops in GW were also located in over allocated GW areas. The two locations that showed a minor increase were located in zones at less than 100% of allocation.

Due to the limited Groundwater data before 2000, monthly data was only analysed from this year onwards. Groundwater wells L37/0451, K37/1792 and J40/0045 which were located closer to the coast tended to have less monthly variation and were less affected by rainfall events. The wells located further from the coast show easily identifiable links to rainfall events where significant rain generally leads to an increase in groundwater level. In addition to this, there is a slight lag that can be noticed when a rainfall event causes groundwater increases.

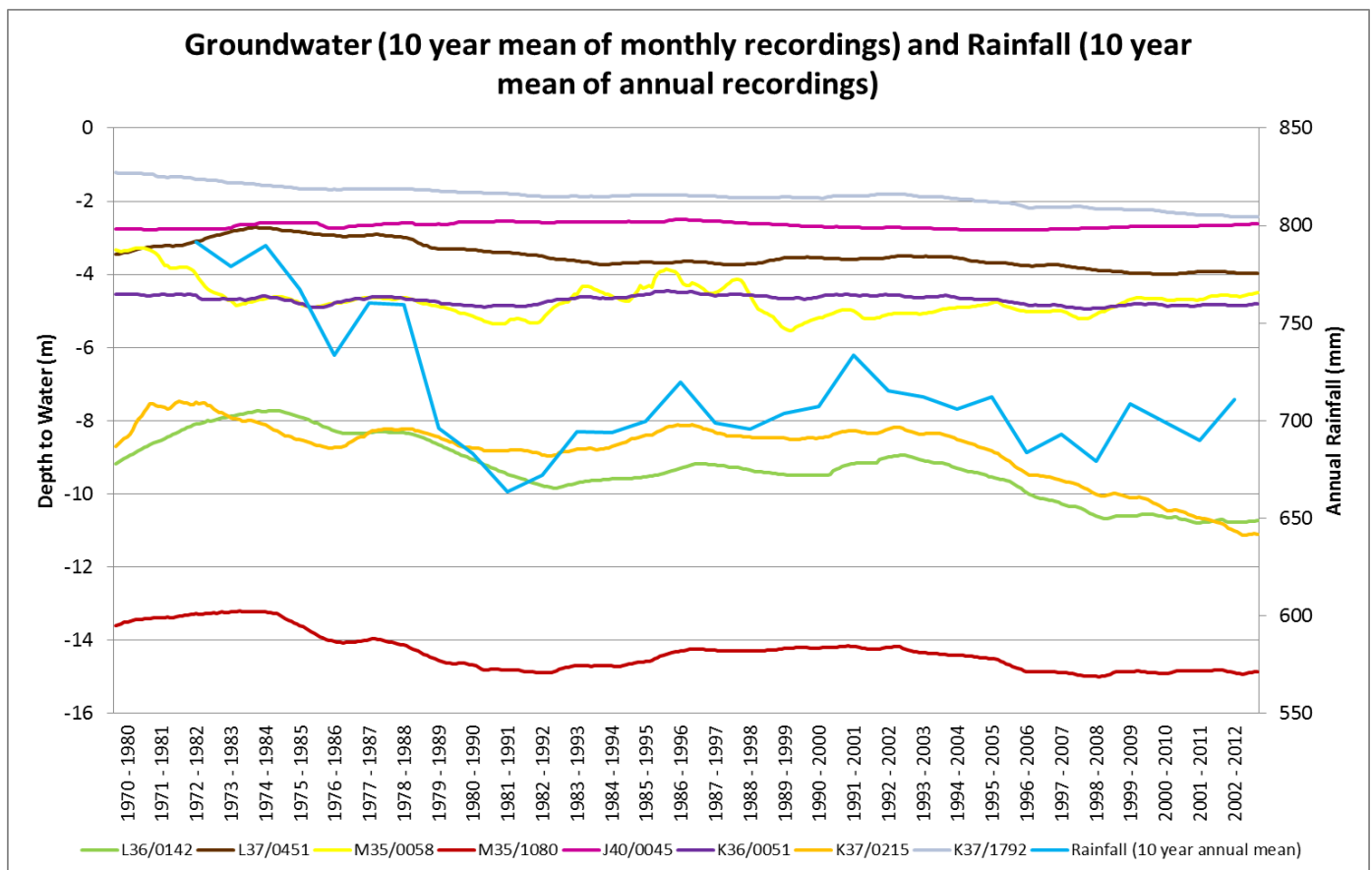


Figure 45. 10 year moving averages of groundwater and rainfall data across the Canterbury Plains.

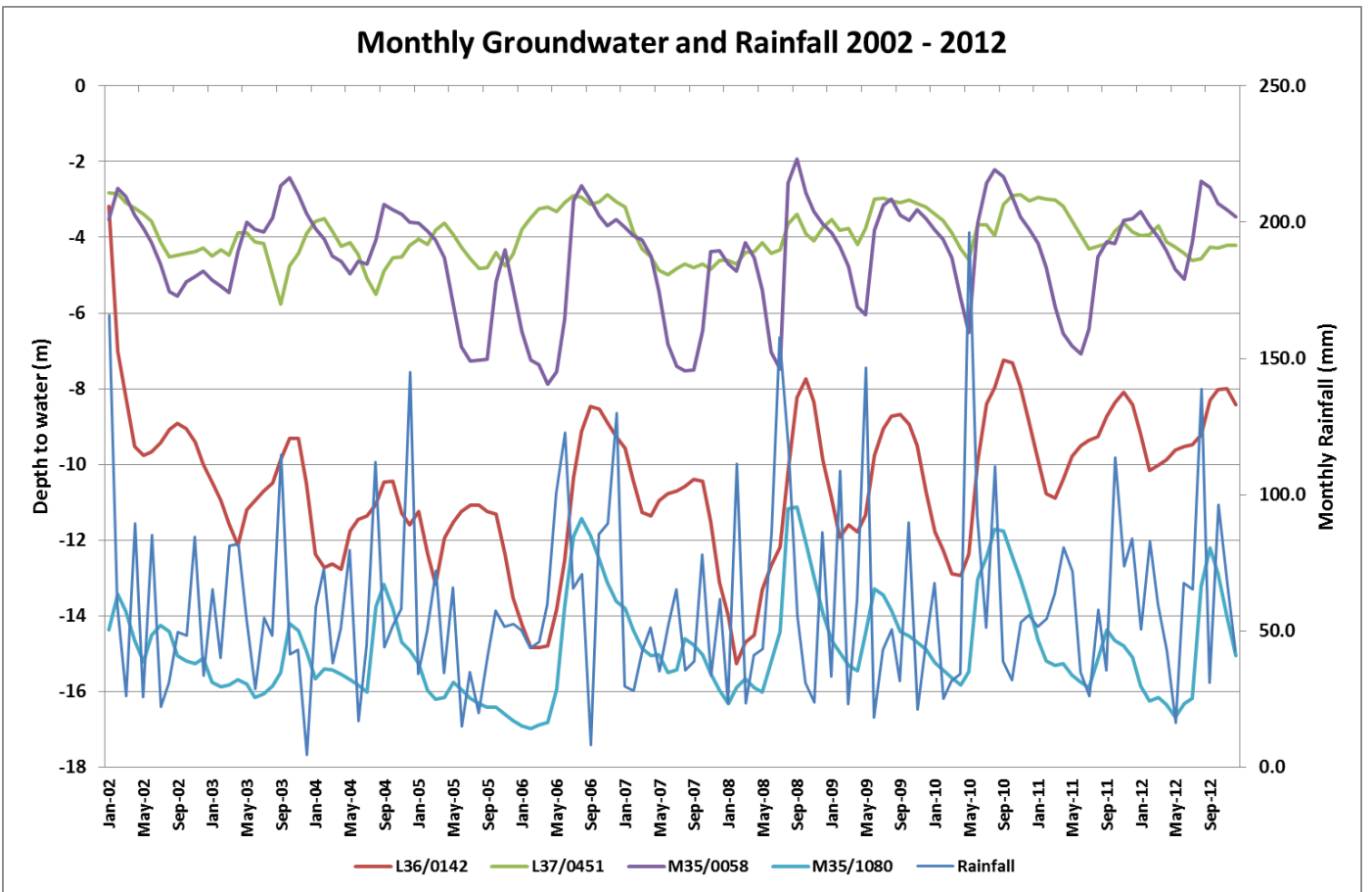


Figure 46. Northern groundwater well depths to water and rainfall 2002 – 2012

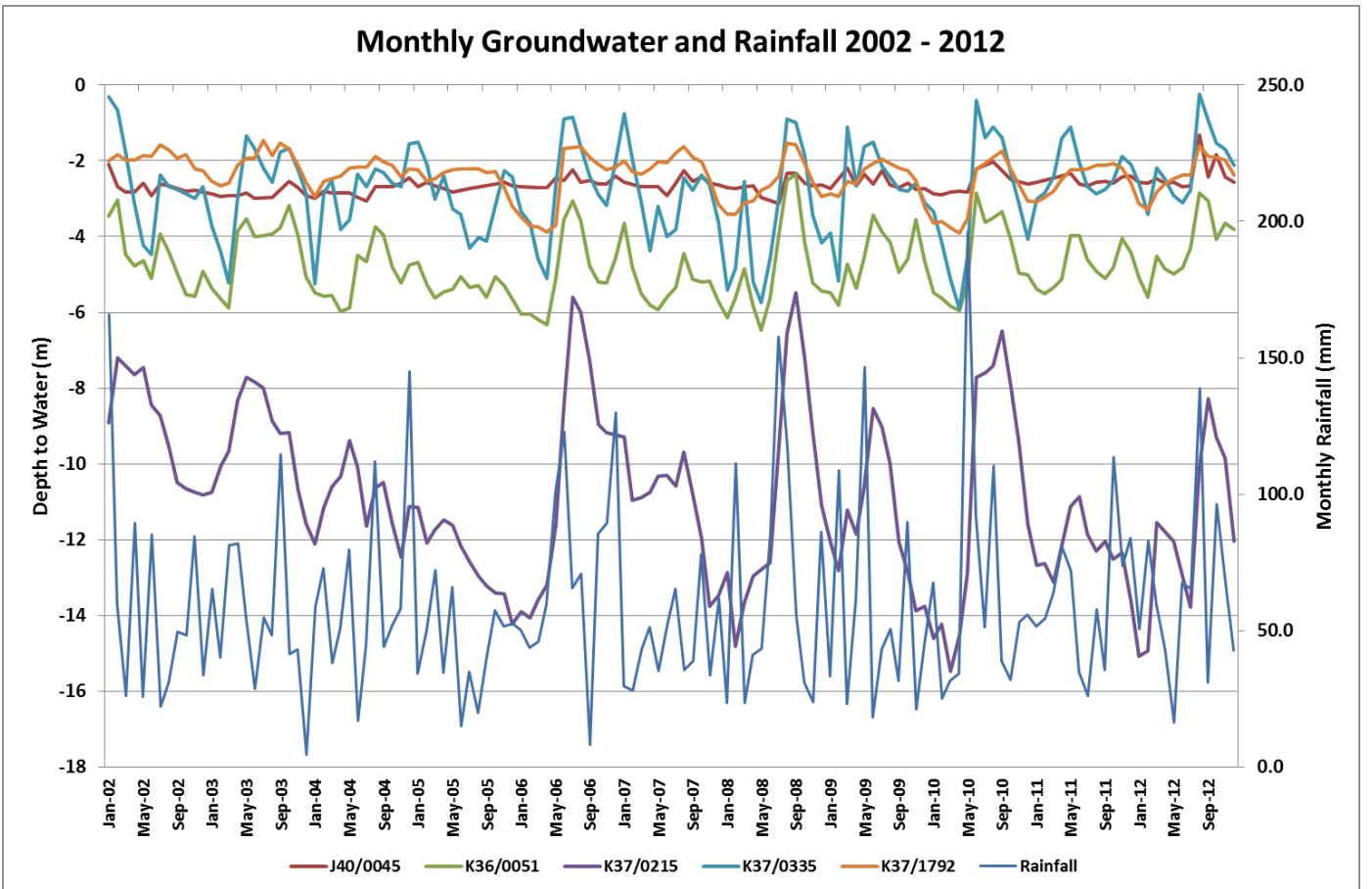


Figure 47. Southern groundwater well depths to water and rainfall 2002 – 2012

Mapping irrigation using NDVI

Through the use of the key identified characteristics of both seasonal and long term changes to NDVI in relation to rainfall and groundwater, three images summer images with high areas of suspected irrigation were chosen. A threshold between 0.55 and 1.0 was applied to each image to highlight the potential irrigation areas.

The total areas identified as being irrigated (see table 3) fits well with the available data on total irrigable land in Canterbury. The total area of irrigable land in Canterbury at June, 2012 was 444,777 hectares (Bascand, 2012). This covers the entire area of Canterbury which includes the major areas of the Culverden Basin, Waipara, and the Waitaki River catchment area. The study area does not include these areas and the December 2010 estimation allows for this as well as expected growth. Canterbury had an increase of 60,000 hectares in irrigable land between 2007 and 2012 (Bascand, 2012). The estimated area of irrigation follows this trend of increasing irrigation that Canterbury has followed during this same time period.

In order to test the ability of NDVI to identify specific targets, the irrigation threshold images were explored to identify if obvious errors were occurring. To do this, circular irrigators were searched for as they provide an easy to identify circular shape on the landscape. This search however resulted in finding many circular paddocks which were either not identified at all or only partially identified as being irrigated. Examples of these areas are highlighted in figure 48 over the page. Further investigation is required to identify the potential reasons for not showing higher NDVI levels.

Table 3. Total area of land with an NDVI value between 0.55 and 1.0 (hectares)

Image Date	Total area of estimated irrigation
February 5 th 2004	199,682
February 16 th 2008	263,697
December 26 th 2010	297,251

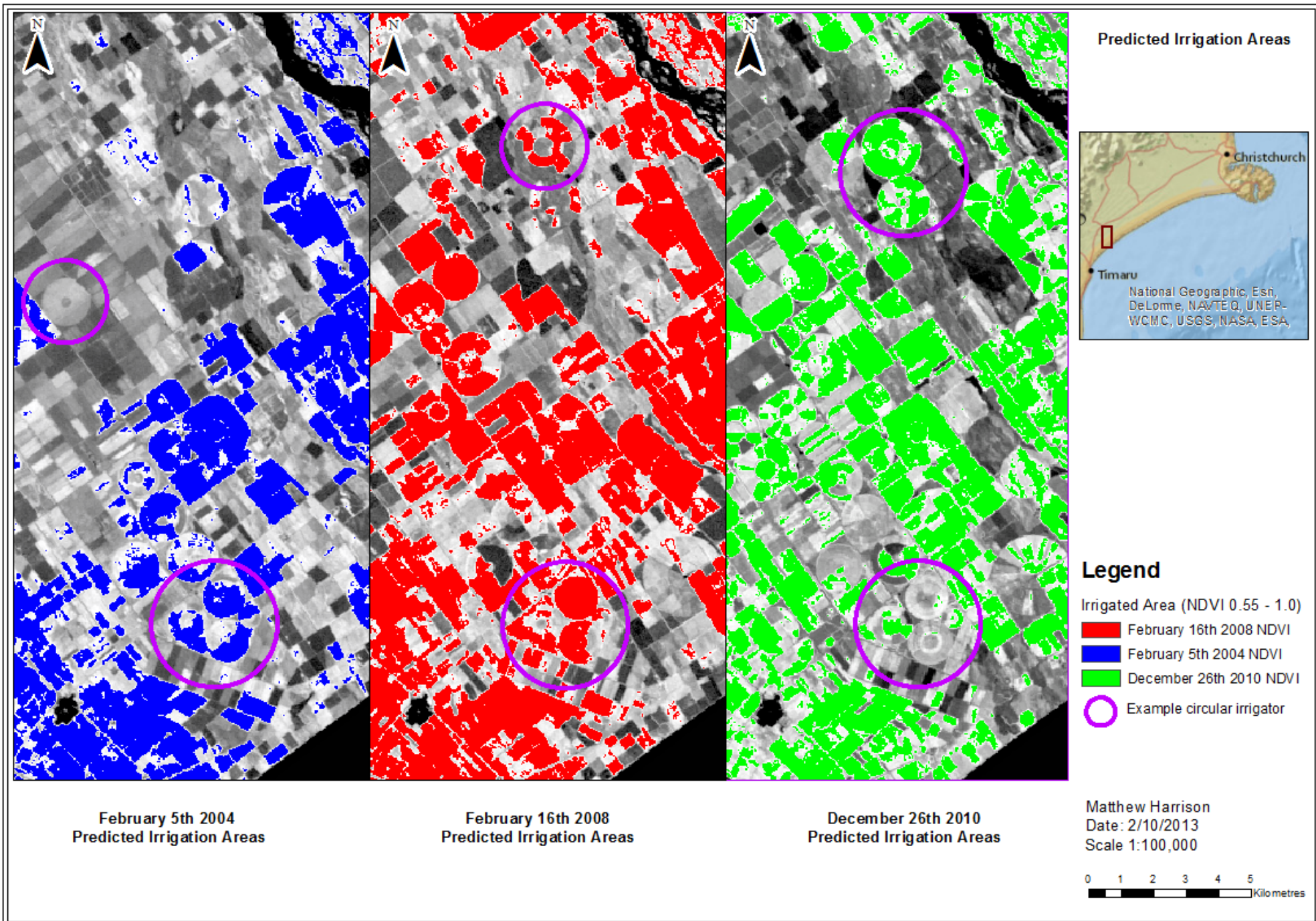


Figure 48. Predicted Irrigation areas for February 5th 2004, February 16th 2008 and December 26th 2008 highlighting potential errors.

Discussion

Canterbury is one of the driest and drought prone regions of New Zealand, yet it is one of the most agriculturally productive regions. Due to its drought prone nature, managing the freshwater resources of Canterbury sufficiently is paramount to maintaining this agricultural productivity for the long term. The normalised difference vegetation index is a very useful tool to assist in rural management. It can provide a very quick analysis of vegetation health across very large areas. This vegetation health can then potentially be used to identify areas under irrigation. A remote sensing tool which can quickly create an irrigated area map is particularly useful in times of heavy drought. Accurate irrigation maps would benefit regional council in monitoring irrigation use, particularly when water restrictions are in place. Improving the ability to quickly and efficiently monitor irrigation will be very useful for the management of freshwater resources. The decreases to groundwater in the past decade have been occurring largely as a consequence of poor management in the over allocation of groundwater resources.

Groundwater is becoming an increasingly important issue for ECan and the groundwater trends found in this report support this. Most of the Canterbury Plains are already over allocated for groundwater irrigation use and currently have little in the way of monitoring actual usage. Groundwater levels, particularly in the last decade have seen significant declines. Two of the groundwater wells that had the biggest drop in groundwater level are also in two of the highest over allocated zones. This highlights the importance of managing and monitoring irrigation efficiently. Due to the inconsistency of groundwater data before 1981, it was difficult to establish a base of non-irrigated groundwater trends to work from in identifying NDVI to groundwater relationships. While 2002 – 2012 saw some short term links between groundwater and rainfall, significant links between increased summer NDVI values and groundwater could not be identified. While no obvious links were found, Statistics New Zealand reports show that Canterbury has gone through significant increases in dairy farming and irrigable land in the past ten years (Bascand, 2012; Tinkler & Golby, 1999). This when coupled with the fact that most of the Canterbury Plains are over-allocated for groundwater use (figure 4) helps to explain the decreased groundwater levels. While no links were specifically found within the short term groundwater and NDVI data, the long term trends do suggest a possible connection with the increased summer irrigation NDVI concentrations.

The information gathered in regards to Canterbury agriculture prior to 1984 suggests that highly extensive agriculture was predominant across the Canterbury Plains. While after this date, due to a reduction in the government subsidies available to farmers, agriculture began to change towards intensive agriculture (Smith and Montgomery, 2004). The last decade has seen particularly high levels of intensification, notably in the increase in irrigable land largely as a result of increased dairy farming (Bascand, 2012). Extensive agriculture requires much less human input and therefore less irrigation when compared intensive agriculture. Using the four images created before 1984 as a base for natural vegetative growth, it can be seen that a natural agriculture system is more likely to have NDVI values concentrated towards a specific value. When compared with the 2003-2011 images, the spring values match, while

the summer values of the latter dates show concentrations at both unhealthy and healthy NDVI values. The dates which have concentrations of both healthy and unhealthy vegetation are likely to be a result of irrigation. In order to map irrigation areas using NDVI, it was required to limit the potential of rainfall to impact the NDVI values.

Through the analysis of ten year moving averages of rainfall, it was identified that the 2003 – 2011 period recorded less rainfall than the 1973 – 1981 period. As Anyamba and Tucker (2005) suggest, long term rainfall patterns can have long term impacts on NDVI levels. This supports the idea that the increased NDVI values found in the 2003 – 2011 images are less likely to be rainfall related and are likely the cause of human induced changes. However the examination of rainfall in the months prior to each image provided a better opportunity to investigate the capability of using NDVI to identify irrigated land.

The normalised difference vegetation index was found to be significantly affected by the amount of rainfall in the months prior to image capture. Many studies highlight this link and particularly the fact that there can be varying amounts of lag time between a rainfall event and the corresponding change in NDVI levels (Yang, Yang and Merchant, 1997; Liping, Rundquist and Luoheng, 1994; Rundquist, Harrington and Goodin, 2000; Wang, Rich and Price, 2003). The results found are backed up by these studies; however a specific lag time was not identifiable due to the use of monthly rainfall data and the inconsistent time frames between images. Further investigation through the use of daily imagery and rainfall would be required to establish set NDVI lag times for the Canterbury Plains.

The results for short term rainfall helped to further establish the link with NDVI. Importantly, these results aided in identifying specific dates which show concentrations of high NDVI values that are not likely to be a result of rainfall. These dates were identified based on a combination of the rain/NDVI lag information obtained from Ji and Peters (2003) and the rainfall that occurred in the two to three months prior. The selection of specific dates was important because if too much rainfall had occurred in the months prior, it would be difficult to differentiate between the effects of irrigation and rainfall. Also the need to monitor irrigation during wetter months is not as important as monitoring during the drier months when groundwater and surface water levels are at higher risk of overuse. The three dates chosen for irrigation mapping are useful in that there is significant information in regards to the changes in irrigation and farm types that closely match the timeframe (Bascand, 2007; Bascand, 2012; Tinkler & Golby, 1999). The information in regards to the changes that Canterbury went through during this time is valuable as it provides a rough guide of what changes to expect in irrigation for the smaller area of the Canterbury Plains.

There is potential in using NDVI to specifically map irrigation. For this to work, the imagery used must be taken after a period of around 3 months of lower than average rainfall. Using NDVI across the entire Canterbury Plains produced results that fit well with the total area and growth rate of irrigable land in the entire Canterbury region. However, at a smaller local scale, the accuracy is questionable and requires further investigation. The NDVI maps created suggest that many irrigated areas were not recorded as being irrigated. However, this is based on the idea that the circular shapes evident in paddocks are from circular irrigators currently

in use. Further field studies to investigate some of the unmapped circular irrigation fields could help in understanding why these fields did not show as being irrigated. A comparison of vegetation and soil types as well as surveying the farm's irrigation use could explain as to why the NDVI did not raise to a high enough level. In addition to this, work is needed to fine tune the chosen irrigation NDVI range of 0.55 – 1.0. This value was chosen based on the NDVI signatures created, however an investigation to identify the best possible range of NDVI for the Canterbury Plains would improve irrigation identification.

Limitations

There were some important limitations in this project, particularly in the availability of consistent groundwater and Landsat data. The lack of good quality Landsat imagery made analysing a consistent flow of images from the 1970's until now difficult. From 1981 until 2003, no images were found to be of use, which removed the possibility of seeing the growth of irrigation during the 80s and 90s. Similar issues were found in the groundwater which had large gaps in data recordings prior to 2000. This limited the capability of comparing the 1973 – 1981 images with the 2003 – 2011 images in relation to groundwater fluctuations. If a complete track of monthly groundwater recordings had been available for analysis, relationships between NDVI, irrigation use and groundwater may have been easier to identify.

Conclusion

The Canterbury Plains is an area which is under significant pressure for freshwater resources. Groundwater trends identified in this report show significant decreases, particularly in the last decade. This is due to the significant agricultural changes the Canterbury Plains have gone through since the 1970's. These changes were a result of changes in governmental policy towards agricultural subsidies in 1984. This produced significant differences between the agriculture of the last decade compared to that prior to 1984. Importantly, this created significant difference in the amount of irrigation used. This provided an opportunity to compare non-irrigated land and irrigated lands through Landsat imagery using the normalised difference vegetation index. Using this comparison, in combination with groundwater and rainfall data, NDVI was tested in its ability to map irrigation. Across the entire plains, it performed well, however at the local scale issues were evident. While the performance of NDVI in mapping irrigation did not reach expectations, the potential for using NDVI to map irrigation is still evident. Additional fine tuning and field work to improve accuracy are required to meet its full potential.

Bibliography:

Aitchison-Earl, P., Scott, D., Sanders, R. (2004). Groundwater Allocation Limits: Guidelines for the Canterbury Region. Environment Canterbury Report No. U04/02. Retrieved from <http://ecan.govt.nz/publications/Reports/U0402.pdf>

Anyamba, A., & Tucker, C. J. (2005). Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003. *Journal of Arid Environments*, 63(3), 596-614. doi: <http://dx.doi.org/10.1016/j.jaridenv.2005.03.007>

Bascand, G. (2007). *Agricultural Production Statistics (Final): June 2007*. Wellington: Statistics New Zealand Te Tari Tatau. Retrieved from <http://www.stats.govt.nz>.

Bascand, G. (2012). *Agricultural Production Statistics: June 2012 (final)*. Wellington: Statistics New Zealand Te Tari Tatau Retrieved from <http://www.stats.govt.nz>.

Brown, L. J. (2002). *Groundwaters of the Canterbury Region*. (R00/10). Christchurch: Environment Canterbury.

Cohen, W. B., & Goward, S. N. (2004). Landsat's role in ecological applications of remote sensing. *BioScience*, 54(6), 535-545.

Environment Canterbury. (2009). *Canterbury Water Management Strategy*. Environment Canterbury. Retrieved from <http://ecan.govt.nz/our-responsibilities/water/pages/default.aspx>

Environment Canterbury. (2011a). *Groundwater in the Canterbury Region*. Environment Canterbury. Retrieved from <http://www.ecan.govt.nz/advice/your-water/groundwater/Pages/Default.aspx>

Environment Canterbury. (2011b). *Natural Resources Regional Plan, Chapter 5 Water Quantity*. Environment Canterbury. Retrieved from <http://ecan.govt.nz/publications/Pages/chapter-5-nrrp.aspx>

Environment Canterbury (2011c). *Groundwater allocation summary*. Environment Canterbury. Retrieved from <http://ecan.govt.nz/services/online-services/monitoring/groundwater-allocation/Pages/groundwater-allocation-summary.aspx>

Environment Canterbury. (2012). *Groundwater Allocation Monitoring*. Environment Canterbury <http://ecan.govt.nz/services/online-services/monitoring/groundwater-allocation/pages/default.aspx>

Environment Canterbury (n.d.1) *Groundwater allocation zone map*. Environment Canterbury. Retrieved from <http://ecan.govt.nz/services/online-services/monitoring/groundwater-allocation/Pages/zone-map.aspx>

Environment Canterbury (n.d.2) *Water measuring deadlines*. Environment Canterbury. <http://ecan.govt.nz/advice/your-water/water-metering/pages/water-meter.aspx>

FAOSTAT database. (n.d.). Food and Agriculture Organisation of the United Nations. Retrieved from <http://faostat.fao.org/>

Irrigation New Zealand. (n.d.). *Irrigation Schemes*. Retrieved from <http://www.irrigationschemes.co.nz/>

Ji, L., & Peters, A. J. (2003). Assessing vegetation response to drought in the northern Great Plains using vegetation and drought indices. *Remote Sensing of Environment*, 87(1), 85-98. doi: [http://dx.doi.org/10.1016/S0034-4257\(03\)00174-3](http://dx.doi.org/10.1016/S0034-4257(03)00174-3)

Jensen, J. R. (2005). *Introductory Digital Image Processing* (3rd ed.). Upper Saddle , New Jersey: Pearson Prentice Hall.

Weier, J. & Herring, D. (2000). Measuring Vegetation. NASA Earth Observatory. http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_1.php

Kelly, D., Davey, A., & James, G. (2006). Freshwater Ecosystems, 'Like a fish out of water': life in a disappearing river. *Water & Atmosphere*, 14(1). Retrieved from <http://www.niwa.co.nz/sites/default/files/import/attachments/river.pdf>

Landcare Research Information System Portal (LRIS Portal). (n.d.). Landcare Research LRIS Portal. Retrieved 30th July, 2013, from <http://lris.scinfo.org.nz/>

Landsat Missions. (2013). *USGS science for a changing world*. Retrieved 25th March, 2013, from <http://landsat.usgs.gov>

Liping, D., Rundquist, D. C., & Luoheng, H. (1994). Modelling relationships between NDVI and precipitation during vegetative growth cycles. *International Journal of Remote Sensing*, 15(10), 2121-2136.

Leimgruber, P., Christen, C. A., & Laborderie, A. (2005). The impact of landsat satellite monitoring on conservation biology. *Environmental Monitoring and Assessment*, 106(1-3), 81-101.

Ministry for the Environment. (n.d.). Climate change projections for the Canterbury region. Retrieved from <http://www.mfe.govt.nz/issues/climate/about/climate-change-affect-regions/Canterbury.html>

Lough, H., Williams, H. (2009). Vertical flow in Canterbury groundwater systems and its significance for groundwater management. Environment Canterbury. Report No. R09/45. Retrieved from <http://ecan.govt.nz/publications/Reports/vertical-flow-canterbury-groundwater-systems-significance-groundwater-management.pdf>

National Oceanic and Atmospheric Administration Satellite Information System (NOAA SIS), (2013). National Oceanic and Atmospheric Administration Satellite Information System. Advanced Very High Resolution Radiometer – AVHRR. Retrieved from <http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html>

Nightingale, J. M., & Phinn, S. R. (2003). Assessment of relationships between precipitation and satellite derived vegetation condition within South Australia. *Australian Geographical Studies*, 41(2), 180-195.

Cliflo Database. (n.d.) National Institute for Water and Atmospheric Research (NIWA). Retrieved from <http://cliflo.niwa.co.nz/>

Parkyn, S, & Wilcock, B. (2004). Impacts of Agricultural Land Use. In J. Harding, P. Mosley, C. Pearson & B. Sorrell (Eds.), *Freshwaters of New Zealand*. Christchurch, New Zealand: The Caxton Press.

Tinkler, R. & Golby, G. (1999). 1999 Agricultural production: national and regional changes. Statistics New Zealand. Retrieved from http://www.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry/1999-agricultural-production-national-regional-changes.aspx

New Zealand Government (1991). Resource Management Act. Wellington, New Zealand.

Rouse Jr, J., Haas, R., Schell, J., & Deering, D. (1974). Monitoring vegetation systems in the Great Plains with ERTS. *NASA special publication*, 351, 309.

Rundquist, B. C., Harrington Jr, J. A., & Goodin, D. G. (2000). Mesoscale satellite bioclimatology. *Professional Geographer*, 52(2), 331-344

Smith, W., & Montgomery, H. (2004). Revolution or evolution? New Zealand agriculture since 1984. *GeoJournal*, 59(2), 107-118. doi: 10.2307/41147802

Sönmez, N. K., Emekli, Y., Sari, M. A., & Baştuğ, R. (2008). Relationship between spectral reflectance and water stress conditions of Bermuda grass (*Cynodon dactylon* L.). *New Zealand Journal of Agricultural Research*, 51(3), 223-233.

Srinivasan, M. S., Schmidt, J., Poyck, S., & Hreinsson, E. (2011). Irrigation reliability under climate change scenarios: A modeling investigation in a river-based irrigation scheme in New Zealand. *Journal of the American Water Resources Association*, 47(6), 1261-1274.

Statistics New Zealand. (2012). Agricultural area in hectares by usage and region. 2012 Agricultural Census tables. Statistics New Zealand. Retrieved from http://www.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry/2012-agricultural-census-tables/land-use.aspx

Stewart, G. & Rout, R. (2007). *Reasonable Stock Water Requirements, Guidelines for Resource Consent Applications*. Horizons Regional Council. Retrieved from <http://www.horizons.govt.nz/assets/horizons/Images/one-plan-tech-reports-public/Reasonable%20Stock%20Water%20Requirements%20Guidelines%20for%20Resource%20Consent%20Applications.pdf>

Wang, J., Rich, P. M., & Price, K. P. (2003). Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. *International Journal of Remote Sensing*, 24(11), 2345-2364.

Waimakariri Irrigation Limited. (n.d.). *What is the Scheme? History*. Waimakariri Irrigation Limited. Retrieved from <http://www.wil.co.nz/the-scheme/history/>

Wilson, J. (2012). Canterbury region – Landscapes. Te Ara - the Encyclopedia of New Zealand. Retrieved from <http://www.TeAra.govt.nz/en/Canterbury-region/page-3>

Yang, W., Yang, L., & Merchant, J. W. (1997). An assessment of AVHRR/NDVI-ecoclimatological relations in Nebraska, U.S.A. *International Journal of Remote Sensing*, 18(10), 2161-2180.