Landsat Image Based Temporal and Spatial Analysis of Farm Dams in Western Victoria

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Biography

Rakhshan Roohi

After completing M.Sc. from Punjab University, Lahore, joined Pakistan Agricultural Research Council as a Research Officer in 1981. In 1985 proceeded to USA and completed MS and PhD from Colorado State University. In 1989 rejoined the duties at PARC and worked in various capacities including Senior and Principal Scientific Officer, Programme Head, Director and Professor. During this period established a Geoinformatics programme and developed a multidisciplinary team of scientists. Several projects related to remote sensing and GIS were executed. Initiated climate change research in agriculture sector and was part of the national committees on climate change policy. As a Professor and Adjunct faculty, was involved in postgraduate teaching and research. Joined LaTrobe University as an Honorary Associate in August, 2010. The major activities I am involved in include image analysis for farm dam temporal analysis, Hyperspectral data handling for mineral explorations and developing class material for graduate level hands on training in RS and GIS.

John Webb

I completed my BSc and PhD (1982) at University of Queensland, and was appointed as a lecturer in geology at La Trobe University in 1986. I am currently Associate Professor in Environmental Geoscience, and I lead a research team that works mostly on hydrogeology and hydrochemistry, including 5 PhD students studying the influence of land use and climate change on water resources in Victoria. Remote sensing forms part of a suite of techniques being employed to study different aspects of these projects, which are supported as part of the National Centre for Groundwater Research and Training. I also work on the remediation of acid mine drainage, developing improved neutralization methods.

Abstract

With the continuing pressure on Australia's water resources and inter- and intra-annual rainfall variability, farmers, especially in rainfed agricultural and pastoral zones, have been developing farm dams as a mean of providing additional water sources for irrigation and stock. The density of farm dams has increased over time, and an accurate knowledge of the spatial distribution of farm dams is essential for water resource management at the catchment level.

There are more than 2 million farm dams across Australia, most with a storage area of <5-10 ha. These small dams are frequently unlicensed. In Victoria stock and domestic dams do not require a license, so more than 90% of farm dams, contributing 85% to the total storage capacity, are not documented, despite their significant impact on water resources and stream flow.

To document farm dam distribution and historical trends in their development, an approach has been developed using medium resolution Landsat images coupled with Google Earth images. This approach is cost-effective, time-efficient, reliable, accurate and repeatable. Various image manipulation/enhancement and analysis techniques were evaluated, and showed that even small water bodies can be identified using False Colour Composites further enhanced by using image enhancement and transformation techniques and combined with the band 5/4 ratio. Density slicing of the mid-infrared band (5) was not useful for very small farm dams as the water reflectance is highly variable due to available water quantity and quality.

Using the Landsat data for 1973 to 2004 for a small area in western Victoria, 99% of farm dams identified using the high resolution Google Earth images were successfully located, showing that Landsat data is a good compromise for this purpose, especially considering the cost. Over the 21 years from 1973 to 1993, there was a 276% increase in farm dams, driven by a dramatic increase in livestock population, particularly cattle, as the dams are mainly used for stock watering. The serious droughts of 1982-1983 and 1997-2010 had little influence on the rate of increase of farm dam numbers. After 1993 there was a much slower rate of dam construction, due to the fact that most suitable dam sites had already been utilized, and there was a shift from dryland pastures to dryland cropping, with a concomitant decrease in demand for watering points.

Key words: Farm Dam development, Landsat image, Image enhancement & analysis, Australia, temporal

Introduction

A farm dam is defined as "anything in which by means of an excavation, a bank, a barrier or other works, water is collected, stored or concentrated" on a farm (DSE, 2004, 2007). With the continuing pressure on Australia's water resources in agricultural regions due to rainfall variability and increasing agricultural production, farmers have been constructing farm dams as a mean of providing additional water for irrigation and/or stock and domestic use; small dams are mainly used for stock watering. The density of farm dams has increased over time, and an accurate knowledge of the spatial distribution of farm dams is essential for water resource management at the catchment level, because, besides evaporation losses, these dams are barriers to stream flow, and therefore, impact on downstream hydrological flow regimes (Neal et al., 2002; Schreider et al., 2002; Callow and Smettem, 2009).

Estimates suggest that more than 9% of total stored water across Australia is contributed by more than 2 million farm dams (Australian Water Association, 2006). The storage of these dams ranges from a few megalitres (ML) to 1000s of ML in larger dams used for commercial irrigation, but most are small, with a storage area of <5-10 ha. The farm dam accounting system varies between states, but in general only farm

dams built on water ways and/or used for irrigation or commercial purposes require a license. In Victoria stock and domestic dams do not require a license (DSE, 2007), so more than 90% of farm dams, contributing 85% to the total storage capacity, are not documented, despite their significant impact on water resources and stream flow.

To supplement the available licensing information on farm dam locations and volumes, numerous remote sensing investigations have been conducted across Australia to identify farm dams (SKM, 2000a, 2000b, 2001, 2007, 2008; Stanton, 2005), initially using 1:25,000 topographic maps (National River Health Programme, 2002), and later extended to aerial photography and then a combination of aerial photography and digital topographic information (Lett et al., 2009).

Mapping of farm dams using topographic data, including DEMs, has limitations in flatter areas (Martines et al., 2010), and automatic digital photograph handling often results in errors. However, Dare et al. (2001) extracted the farm dam number and area by density slicing and spatial filtering of the colored aerial photographs at a resolution of 1:40,000 which were later verified by LIDAR data. In addition, high resolution aerial photography and satellite images are costly to obtain and time-consuming to process due to the voluminous data handling required, restricting the extensive usage of this data for monitoring small water bodies like farm dams. Medium resolution Landsat data have considerable advantages with respect to cost, availability, the long archive period (since 1972) and repetitive capture, in addition to the 6-band spectral resolution. Several studies have looked at the effectiveness of Landsat data for the inventory and documentation of farm dams at a larger scale over a range of hydrological conditions, using image enhancement techniques to improve the level of accuracy.

Supervised and unsupervised multispectral classifications and density slicing of bands 4 and 5 of Landsat TM data or band 7 of Landsat MSS data have been used with varying degrees of success to map and monitor water bodies, wetlands and rivers (Blackman et al, 1995; Kingsford et al, 1997; Lee and Lunetta, 1995 and Manavalan et al, 1993; Baumann, 1999; Overton, 1997; Shaikh et al, 1997). Frazier and Page (2000) used both density slicing of band 5 and multispectral maximum-likelihood classifications to map water bodies on riverine floodplains. Supervised classification proved to be more sensitive than the density slicing method for detecting water bodies, and classifications using the infrared bands gave a much better representation of the water bodies than the visible bands, with an overall accuracy of 96.9% compared to color aerial photography acquired on the same day as the TM data. However, smaller water bodies (often less than a single pixel in size) were not well mapped, with an accuracy of only 48%. Johnston and Barson (1993) also found that simple density slicing of TM band 5 successfully detected lakes, ponds and wetlands areas, with a classification accuracy of 95 % compared to manual ground truthing. However, density slicing of Landsat MSS band 7 to map water bodies underestimated the area of water bodies by about 40 percent compared to digital aerial photography (Bennett, 1987).

Ramesh and Scott (2008) showed that pan-sharpened Landsat imagery was better at mapping water bodies than the original Landsat data for large reservoirs (96% accuracy), but the results for small water bodies were unsatisfactory. Krishna et al. (2010) used pan-sharpened very high spatial resolution Quickbird imagery to delineate highly fragmented small water bodies (dug-wells); verification of the results using field data showed an accuracy of 92%. Hesslerová et al. (2009) introduced a method of image analysis using principal component analysis, Normalized Difference Snow Index (NDSI) and subsequent density slicing of multispectral satellite data. In a similar study, Sanjay et al. (2005) concluded that the Normalized Difference Water Index (NDWI) is the best image analysis technique to identify and map water bodies.

This project uses satellite imagery to map the number and extent of farm dams, in order to provide accurate information that can be used to accurately monitor water resources, including prediction of

hydrological flow regimes and estimation of evaporation losses. The current approach has been tailored considering aspects like cost effectiveness, time efficiency, extensive coverage, reliability/accuracy and repeatability, in order to overcome the problems inherent in other survey techniques, particularly the cost and time involved in such surveys.

Regional setting

The study area lies within the Upper Hopkins Basin of the Glenelg Hopkins Catchment Area (Figure 1). Within this region agriculture is the dominant landuse, both grazing by sheep and cattle on largely cleared natural pasture, and cropping of cereals and oilseeds (Ierodiaconou *et al.*, 2005). There has been large-scale development of Eucalyptus tree plantations in the wetter areas of the region. Only a very small percentage of the original native vegetation remains.
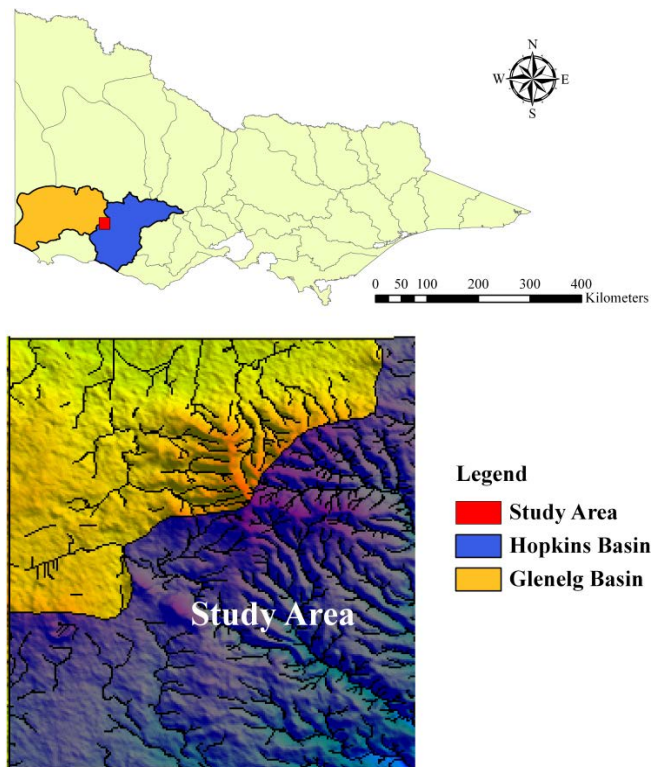

Figure 1: Glenelg-Hopkins River Catchment

The climate of the area is characterized by a rainfall maximum and temperature minimum over winter (July through September; Figure 2). Because of the variability in monthly decadal rainfall data, long term trends in rainfall are presented as a cumulative deviation from the mean (Figure 3); this clearly shows periods of above-average and below-average rainfall, particularly the droughts of 1982-1983 and 1997-2010.
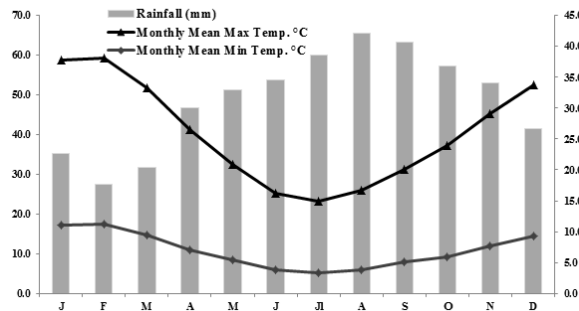

Figure 2: Average monthly rainfall, minimum and maximum temperatures over 40 years.
(Rainfall for Glenthompson (station #89075), Temperature Ararat Prison (station # 89085))
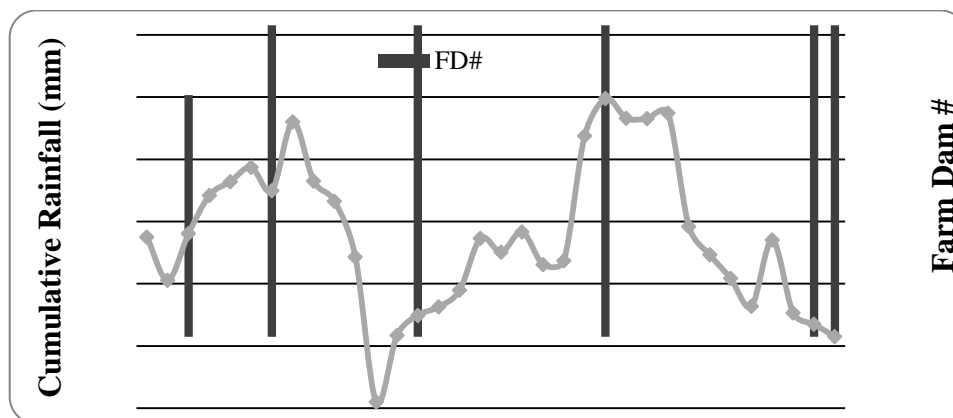

Figure 3: Cumulative rainfall vs. farm dam development

Materials and Methodology

An area 17 km x 22.5 km, including the town of Glenthompson, was selected for detailed study, as it contains a large number of farm dams located in three different topographic/geological settings: in the west, flat to undulating volcanic plains with a prominent volcanic crater, in the east, the strongly dissected Stavely Hills rising ~80 m above the basalt plain, and in the north, alluvial flats (Figure 4). The area has several lakes, both perennial and non-perennial, with varying degrees of water quality and quantity. The land use is dominated by grazing, with some cropping on the flatter volcanic and alluvial plains. There are no tree plantations, however, there is a small amount of native forest within the Stavely Hills.
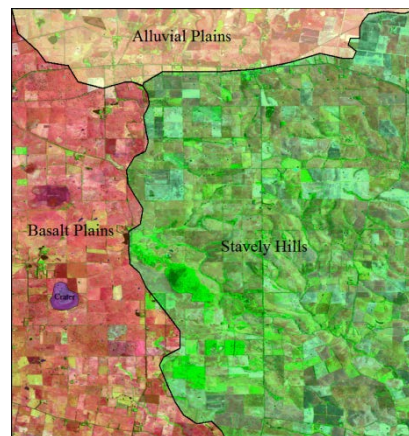
Figure 4: Geomorphology of the study area

Landsat imagery for the region including the study area (Zone SJ54) was obtained from the Australian Greenhouse Office (AGO) Landsat Product Suite (http://www.ga.gov.au/bin2/ago-tile?sj54) for the following dates: 25/8/1973 (Landsat 1 MSS), 18/9/1977 (Landsat 2 MSS), 26/12/1984 (Landsat 5 MSS), and 18/2/1993 and 17/2/2004 (Landsat 5 TM). Since the farm dams and water bodies have relatively more stored water during the post rainfall season and it is easy to segregate these bodies from the surrounding pixels on the image, so the data selection was based on the climatic conditions (especially the rainfall) prior to the data acquisition date. The bands available in the archive Landsat data of 1973, 1977 and 1984 are 1, 2, 3 and 4 whereas for 1993 only 3 bands (3, 4 & 5) are available. All the six bands are available only for 2004 Landsat data.

Vector data layers, including topography, roads, water bodies and streams, were downloaded for tiles sj5407 and sj5408 from the official website of GeoScience Australia (https://www.ga.gov.au/products/servlet/controller?event=DEFINE_PRODUCTS). Historical climate data (rainfall and temperature) was downloaded from the website of Bureau of Meteorology, Government of Australia (http://www.bom.gov.au/vic/). For rainfall, the data records for Glenthompson (weather station #89075) were used. As temperature data is not available for this station, the temperature records for Ararat Prison (station # 89085) were used.

The online Google Earth Imagery (GEI) for the study area consists of a mosaic of high resolution GeoEye images and a pan-sharpened 15m multispectral Landsat image for 5/5/2003. This imagery was used to determine the location of 1,100 farm dams; the data was imported in Global Mapper/Elshayal Smart Web GIS software, and a point map of farm dam locations created using the polygon of the study area. A detailed database was registered for each dam, containing the following parameters: shape, water level and water color (to evaluate the health of the dam and the catchment). The shape of the dams was recorded in five shape classes as circular, rectangular, square, oval and undefined. The water level was categorized in two classes as dry or variable, the farm dams having variable water level as appeared on GEI was grouped in the later class. The water color was categorized initially in variable shades of green and blue besides brown, white and unknown. For the analysis purposes the data for shades of green and blue were grouped in two broad classes as green and blue. Generally the dry farm dams are categorized in color class unknown but the ones having salt deposited at the periphery as appeared on GEI are grouped in color class white.

Using ENVI GIS software, the base map of farm dam locations developed using GEI and the enhanced Landsat image of 17/2/2004 were used to identify the farm dam locations in 2004. The Landsat image was handled in small blocks to overcome the high level of heterogeneity, and a mosaic was developed for the entire area after completion of the analysis. To start with, the False Color Composites (FCC) of various

band combinations like 345, 543, 546, etc. were created and the FCCs showing the maximum contrast between farm dams and surrounding features were selected. Generally, the infrared bands gave the best results, eliminating confusing pixels giving the apparent reflectance of water. The point layer of farm dams developed using GEI was overlaid on the best FCC image. The farm dams located using GEI were compared with the Landsat FCC image and the attribute data of the corresponding farms dams was updated for the 2004 layer. Since some of the farm dams were dry, any significant contrast from the surrounding pixels was considered. The geometry and surrounding features like drainage pattern were also helpful in identification. However, these band combinations identified only 85% of the farm dams on the base map, so to improve this accuracy, the best FCC was subjected to image enhancement and transformation techniques to further improve the contrast between the water bodies and their surroundings. Furthermore, the images of 4/5 band ratio and the Normalized Difference Water Index (NDWI) were also used to achieve a final accuracy of 99%.

Density slicing of band 5 was the least successful of the techniques used, as the water quality and quantity in the farm dams was highly variable, resulting in wide range of reflectance values that overlapped with the brightness of rural infrastructure and scattered trees. Similarly, the Water Index had limited scope for this inventory.

The methodology developed using the 2004 data was applied to the 1993, 1984, 1977 and 1973 Landsat images. The FCC used for each image depended upon the availability of bands; e.g. for the 18/2/1993 dataset, only the 543 FCC was used, due to the restricted number of bands available whereas four available bands for 1973, 1977 and 1984 were used for FCC . Because 99% of farm dams were identified using the Landsat imagery for 2004 (compared to the higher resolution Google Earth Imagery), it was assumed that a similar accuracy level applied to the other Landsat images processed, i.e. the number of farm dams identified was increased by a factor of 1.01 to correct for those that were missed.

To some extent the accuracy of farm dam identification depends on the rainfall preceding the date when the imagery was collected, as farm dams containing water are easier to identify. However, this appears to have had little impact on the results, e.g. the rainfall prior to and during the data acquisition period for the 1993 image was lower than the long term average, but there were only 28 fewer dams recorded than in 2004.

Results and Discussion

Farm Dam Distribution in 2003 (Google Earth Image)
More farm dams are present in the northern and eastern parts of the study area, where the topography is undulating and micro-catchments are available for water harvesting (Figure 5). Generally each paddock has at least one farm dam, especially if there is any drainage from the paddock. In some cases stream water has been stored by constructing a series of dams of variable sizes and shapes along the drainage line. The farm dam distribution is related to the geomorphology of the area. The majority (62%) are located in the Stavely Hills (58% of the study area), probably because dams are readily constructed along the well-defined drainage lines within the hills. Although the basalt plains make up 32% of the study area, they contain only 21% of the dams (including 2 in the crater of the volcano), perhaps reflecting lower intensity farming (also suggested by the relatively large paddocks in this area). The alluvial plains comprise 10% of the study area and have 16% of the dams; farming here is more intensive, and the paddocks are smaller than in the other geomorphological divisions.
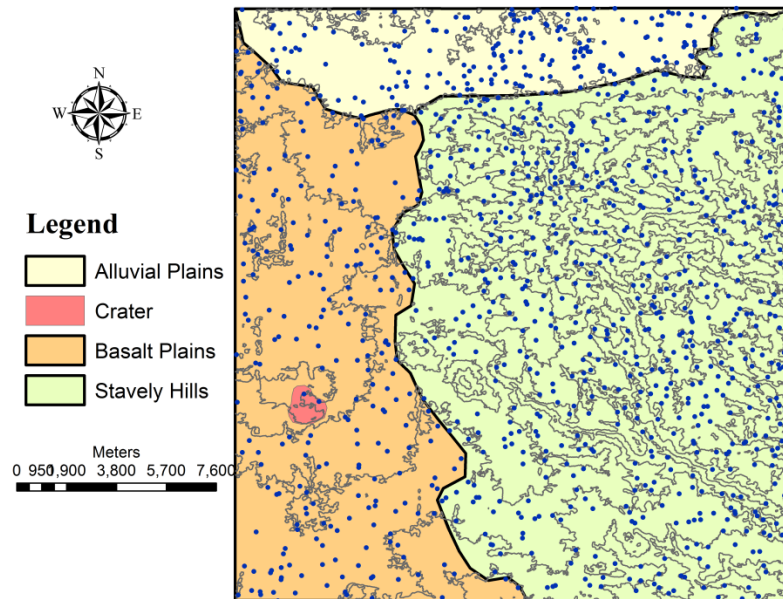
Figure 5. The distribution of farm dams in the study area (GEI_2003)

Farm Dam Types

The farm dams were classified into 5 shape classes: circular, oval, rectangular, square and irregular. The distribution of these shapes has no set pattern especially in relation to geomorphology. Out of 1,100 dams, most are rectangular or square (39% and 16% respectively) followed by irregular (39%), only 6% are either circular or oval.

Water Level

The majority of the farm dams (59%) were dry when the image was taken (May 5th, 2003), due to the prolonged drought at the time (Figure 6). The farm dams with variable levels of stored water (41%) are mostly present on the alluvial plains and the northern part of the Stavely Hills (Figure 7), probably because the rainfall that filled the dams was brought by northerly winds.
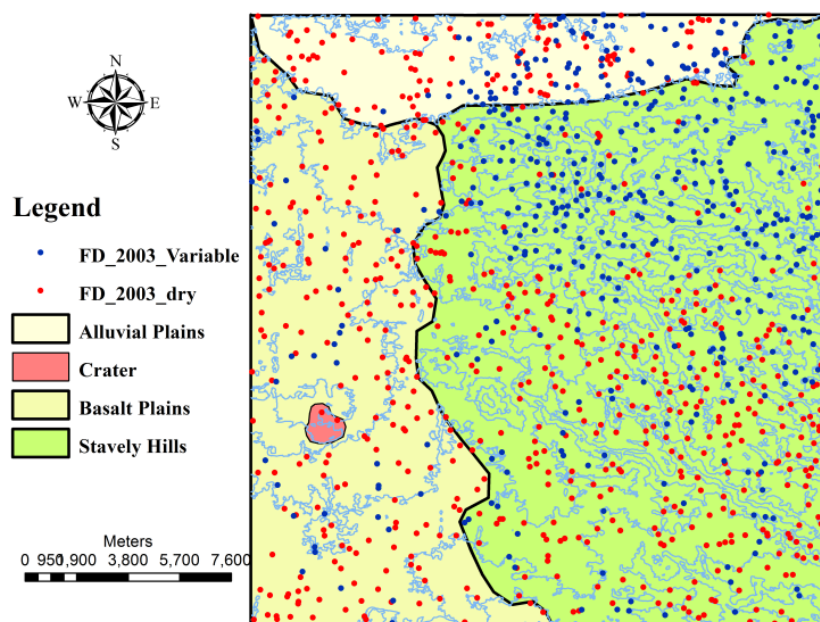

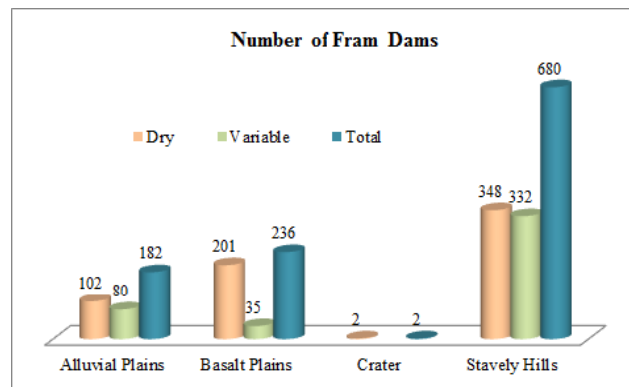Figure 6. Distribution of farm dams according to water level categories.

Figure 7. Number of farm dams in geomorphological classes.

Water Color

Of the 41% dams containing water, the water colour was mostly (81%) various shades of green, probably reflecting some algal content. Water in 7% of the dams was blue in colour, indicating good quality water, and was brownish in 12%, due to the presence of suspended sediment. Agricultural practices in the catchments of the latter dams need to be investigated to determine if they are exacerbating erosion. About 5% of the dams had very low water levels, and, due to evaporation, salts have deposited on their edges, appearing white on the image. Figure 8 presents the different water color categories for the farm dams containing water level (the dams in the crater were dry and not included in the data). In the Stavely Hills, the water in more than 90% of the dams is variable shades of green, whereas on the basalt plains there are only 77% of such dams. In the Stavely Hills there is a higher number of dams having water in shades of brown, due to suspended sediment eroded from the higher relief catchments in this geomorphological subdivision.
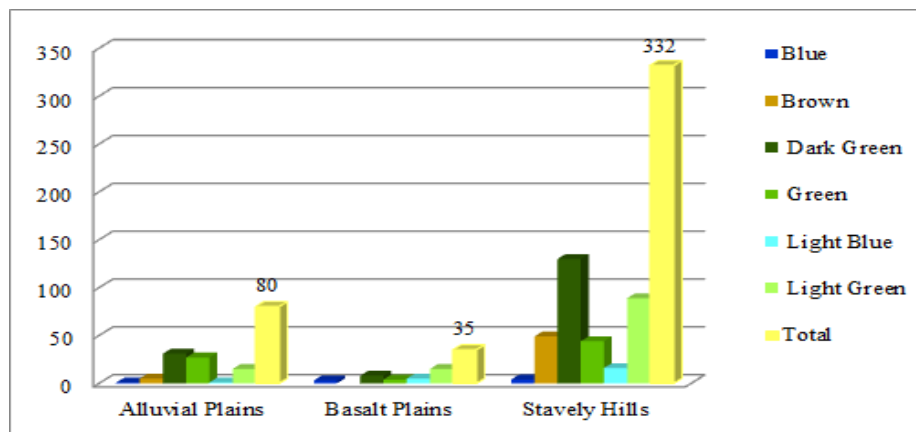

Figure 8. Number of farm dams according to water color classes

Farm Dam Distribution in 2004 (Landsat Image)

On the enhanced and transformed Landsat images of 2004, 1,088 farm dams could be identified (Figure 9), compared to 1,100 on the point vector layer extracted from the 2003 online Google Earth image, an accuracy level of 99%. Only 12 dams could not be identified, due to their small size and image resolution limitations.
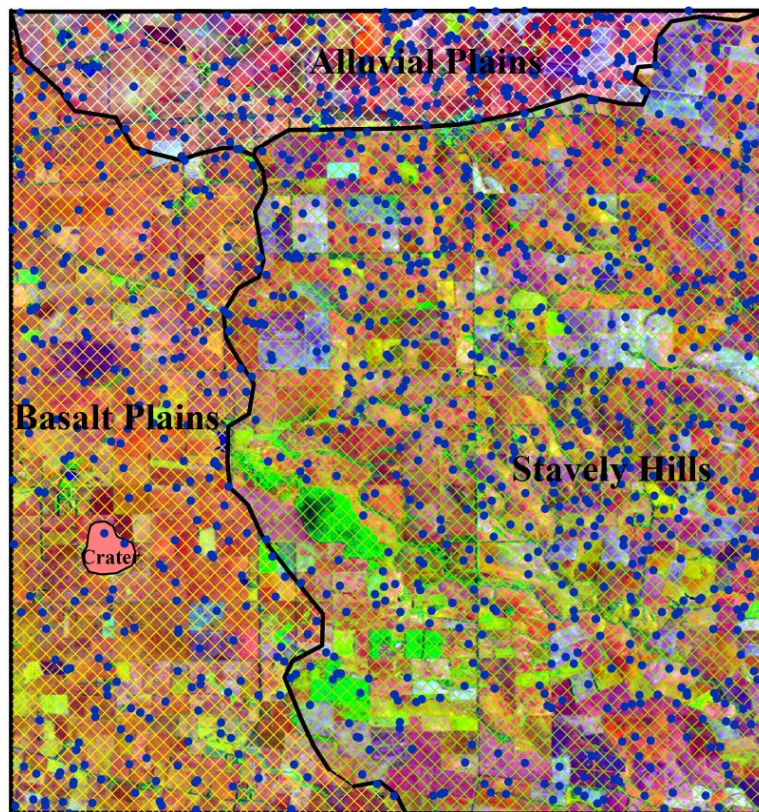
Figure 9: Distribution of farm dams in 2004

Temporal change in number of farm dams

Over the study period of 31 years, the number of farm dams increased from 388 on 25/8/1973, to 571 on 18/9/1977, 840 on 26/12/1984, 1,069 on 18/2/1993 and 1,100 on 5/5/2003 (Figure 10; all figures are corrected using the factor of 1.01 derived from the 2004 data, as described above). Overall, 711 dams were constructed in the study area during this time (284% increase; Table 1). However, the rate of construction was not uniform, averaging 27-47% from 1973 to 1993 (32-46 dams/year), but only 2% from 1993 to 2004 (3 dams/year). Comparison of the farm dam development pattern with the cumulative rainfall (Figure 3) shows little agreement; following the 1982-1983 drought, 288 farm dams were constructed between 1984 and 1993 (32 dams/year), a slightly slower rate than previously (40-45 dams/year for 1973-1984; Table 1). After 1993, including during the 1997-2010 drought, few farm dams (3 dams/year) were constructed, probably because the majority of potential sites were already utilized and there was a shift away from livestock farming (see below).
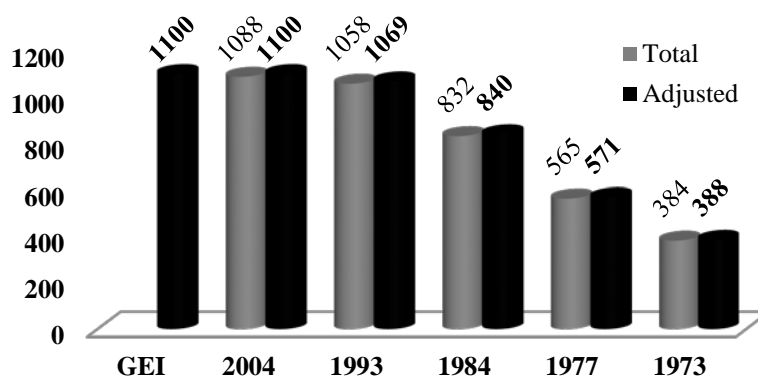

Figure 10: Farm dam development over 31 years

Table 1: Change in Farm Dam Number over 31 Years			
Period	**Increase Over time**		**% Annual Increase (#)**
	Number	**% Increase**	
1973-1977	183	147	47 (46)
1977-1984	270	147	47 (39)
1984-1993	288	127	27 (32)
1993-2004	30	103	2 (3)
1973-2004	**711**	**284**	**22 (23)**

Table 1: Change in farm dam number over 31 years

The spatial trend in farm dam development (Figure 11) shows that most construction of dams occurred in the eastern part of the alluvial plains and the Stavely Hills; in the latter area more dams were built on the hilly parts with good catchments. On the basalt plains more dams were added closer to the Stavely Hills.
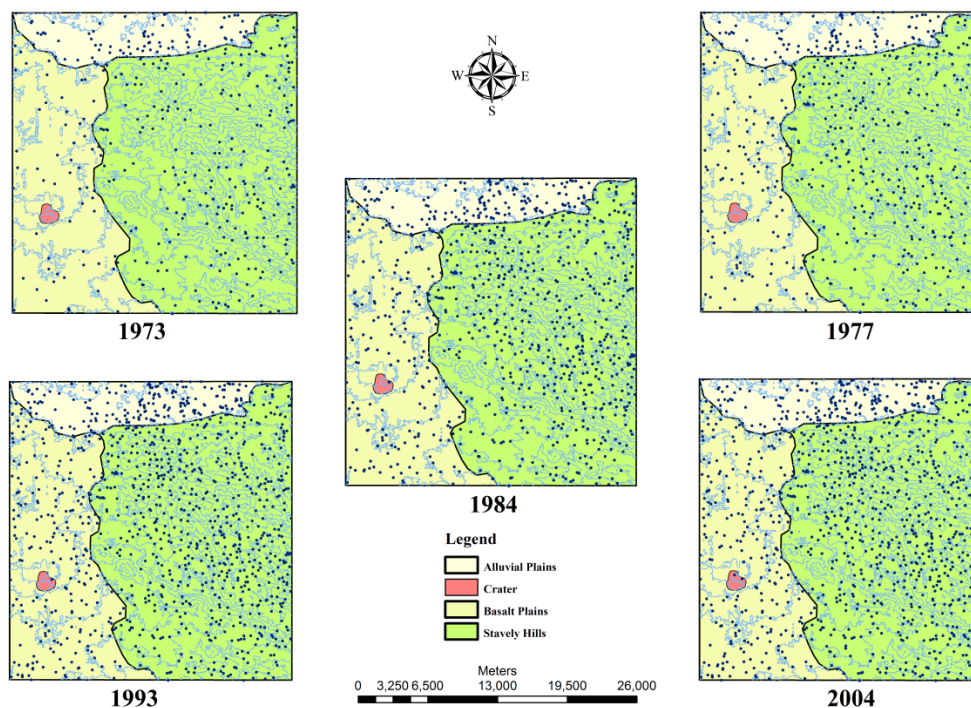

Figure 11: Spatial distribution of farm dams over different time periods

Relationship between farm dams and land use

The increase in the number of farm dams needs to be considered in the context of land use change in the Glenelg-Hopkins region over the same time period (Figure 9). During the 1970s and 1980s Australian agriculture was in a state of continuous flux as agriculturists experimented with new techniques (Laut, 1988), accompanied by a dramatic increase in livestock population (ABS, 2010). Over this period, sheep gave way to cattle with a big increase in cattle numbers, including in the Glenelg-Hopkins region (Jackson, 1995). The higher livestock densities drove a steady upward trend in construction of farm dams, which are mainly used for stock watering. This trend is clearly evident in the data from the study area (Figure 10).

However, in the 1990's and 2000's there was large-scale conversion of grazing to dryland grain crops, particularly wheat and canola, in the Glenelg-Hopkins region, especially during the years of below average rainfall, which alleviated water logging and promoted crop growth (Ierodiaconou et al., 2005). The increase in cropping was most concentrated in the north east of the region, including the present study area, and was accompanied by a small drop in groundwater levels (Yihdego and Webb 2011). Because small farm dams in the study area are generally used for stock watering, the decrease in grazing was probably partially responsible for the much slower rate of farm dam construction after 1993, in addition to the fact that there were a limited number of potential sites available by this time (as discussed above).
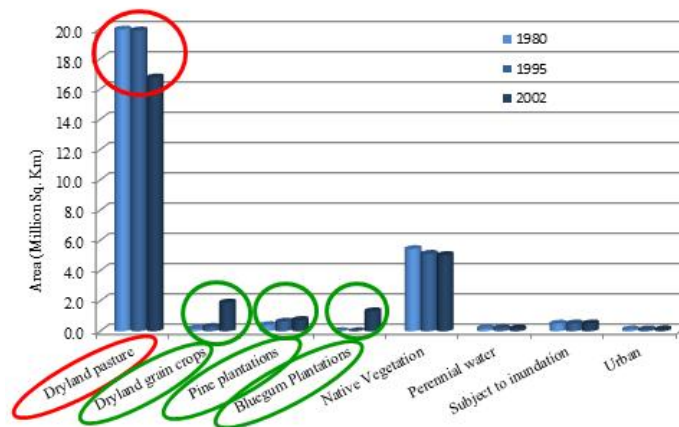

Figure 12: Landuse transition matrixes 1980-2000 in Glenelg Hopkins region, Victoria

Conclusions

The analysis of historical medium resolution Landsat imagery coupled with higher resolution online Google Earth Images, using simple image analysis/transformations/enhancement techniques, band ratios and NDWI enabled an accurate inventory and temporal analysis of farm dams. This procedure has the advantages of low cost, high accuracy, and short construction period.

False Color Composites, especially using the infra red bands, were most useful for identifying the farm dams, particularly when enhanced using image transformation techniques. Further improvement in the segregation of farm dams (especially with the small area) from the surrounding pixels was achieved using 4/5 band ratio and NDWI images. Handling the image in small blocks to overcome the high level of heterogeneity, and later developing a mosaic for the entire area, can good results.

Compared to the high resolution Google Earth Image, an accuracy of 99% was achieved in identification of farm dams using medium resolution Landsat data, demonstrating that in contrast to expensive high spatial resolution image data, Landsat imagery is a good option for this purpose, especially considering the time frame where the Landsat data is the only option .

Over a period of 31 years, the number of farm dams in the study area has increased by 284%. A rapid development in farm dams occurred from the early 1970s to the early 1990s, due to an increase in the cattle population over this period, as most farm dams in the study area are used for watering livestock. The severe droughts of 1982-1983 and 1997-2010 had little impact, with farm dam construction occurring at much the same rate as in high rainfall years. Farm dam construction slowed greatly after 1993, probably due to two factors: the majority of suitable sites had already been utilized, and there was a shift in land use from livestock to grain crops, with a concomitant decrease in demand for watering points.

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