RICE CRC

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PROJECT SUMMARY

Remote sensing of irrigated crop types and its application to regional water balance estimation

Dr Tim McVicar

The strengths of moderate to coarse resolution satellite remote sensing in both identifying crop types and estimating crop area has resulted in the widespread use of this technology for agricultural monitoring. Although the spectral information and cost of these remote sensing data are attractive, their spatial resolutions are often perceived as being inadequate for agricultural management at both the individual holding and the paddock level in the rice areas of New South Wales (NSW). Conversely, fine resolution remote sensing (e.g., aerial photography) very often contain spatial detail that will allow management decisions to be made at the paddock level, but these data can be expensive to acquire and subsequent manual digitisation of crop areas is labour intensive when performed each year. This raises at least two associated research questions for the rice industry in southern NSW: (1) 'how is the rice area best mapped when considering cost, accuracy, timing, and complexity while reconciling the above issues? '; and (2) 'how can spatial accuracy (concerning both areas and positions) be measured and related to relevant management practices in order to influence decisions?'.

Additionally, many operational users of remote sensing data perceive it as being an overwhelming data source as it often requires time consuming training and expensive computer software. This results in a further series of issues: (3) 'can remote sensing be used operationally within the NSW rice industry so that simple methods can be applied using inexpensive software with minimal training in order to achieve similar or increased accuracies?'. Furthermore, use of spatially accurate GIS paddock boundaries has been shown to increase crop classification accuracy. However, this raises further questions: (4) 'what is the influence of spatial error on management decisions?'; (5) 'how can the accuracy of GIS data be measured?'; and (6) 'how are these issues altered when considering the other major summer crops in the region?'. As satellite hyperspectral data (e.g., >100 spectral bands per image) are now available this again raises some questions, such as: (7) 'does this extra spectral information content translate into additional or more accurate agricultural metrics'; and (8) 'what is the current capacity in the rice industry of NSW to process this sort of information quickly as to impact management decisions?'.

These and other related issues have made up the vast majority of the research from project 1105. Recommendations have been made wherever possible regarding the improvement of spatial analysis or mapping efficiencies. Importantly, the research from project 1105 has been adopted by the local industry – this is proof of 'impact' as opposed to only producing 'outcomes'. The work reported here has concentrated on practical issues with an emphasis on transferring the knowledge gained to industry partners.

Prior to addressing these issues, a comprehensive literature review concerning the utility of remote sensing in rice base irrigation systems was performed to ensure that past, present and current opportunities (and constraints) concerning the use of time series remote sensing in the local, national and international context were known and understood.

Due to wanting to optimise research results by acquiring as many images as possible with our operating budget for image acquisition all new research (as opposed to the literature review) was conducted on the smallest irrigation areas in southern NSW: Coleambally Irrigation Area (CIA). Before methods can be transferred to the other irrigation areas (i.e., Murrumbidgee and Murray Valley Irrigation areas) some assessment of the similarities of the irrigation systems in terms of non-rice crops and their phenology needs to be performed.

1.   Background to the Project

Given the large areas of rice-based irrigation, the use of spatial technologies (combining remote sensing and GIS) is seen as a favourable way to provide better management and ensure environmental compliance targets are met. Project 1105 was established to harness the benefits from these technologies for rice based irrigation systems in southern NSW. Initially the project was established to be a PhD scholarship, however after a suitable applicant was not found, and in the 2nd year review of the Rice CRC it was suggested that the project employ a scientist to ensure that the project objectives were met. Tom Van Niel was the successful applicant originally working 100% on the project for a 3-year term (Jan 2000 to Dec 2002) that was extended for 18 months (Jan. 2003 to Jun. 2004). For the final 12 months (Jul. 2004 to Jun. 2005) Tom was 50% assigned to 1105. Throughout the entire project Tim McVicar has been a 25% in-kind contribution by CSIRO Land and Water to 1105. Strong links have been made with other Rice CRC researchers (specifically Brian Dunn, Geoff Beecher, John Angus Craig Russell) and to non-Rice CRC researchers (specifically David Jupp and Bisun Datt from CSIRO Earth Observation Centre, Jay Pearlman from NASA, and Dr Shunlin Liang from University of Maryland) during the course of the project.

2.   Objectives

There were 5 major objectives of project 1105; these were refined during the course of the project as per direct consultation with our sub-program leader (Geoff Beecher), program leader (Liz Humphreys) and director (Laurie Lewin). These 5 major objectives are labelled by a descriptive name and outlined below, and are also described separately (where appropriate) further below.

2.1 *Literature Review:* Review previous literature to assess the past and current worth (and future potential) of regional remote sensing for monitoring the irrigated farming systems of southern NSW. To provide estimates of costs to develop suitable monitoring systems.

2.2 *Rice Admin:* Assess and improve spatial aspects of yearly rice administration. Refine methods to map rice using satellite remote sensing and to assess the errors within this product. This includes both rice identification procedures and area estimation issues. Attempt to make these techniques as "user-friendly" as possible (optimise based on accuracy, simplicity, and cost).

2.3 *Tech Transfer:* Perform technology transfer of these improved and simple rice identification methods to local irrigation company to ensure use of improved techniques in local management.

2.4 *Other Crops:* Determine best practice use of satellite remote sensing for identification of other irrigated summer crops (other than rice).

2.5 *Hyperspectral:* Inspect the value added to the management of rice-based irrigation farming systems from hyperspectral remote sensing (*e.g*., > 100 spectral bands per image).

3. Introductory technical information concerning the problem or research need

The problem or research need is addressed below against the initial 5 objective categories. A brief introduction to these problems is given.

3.1 *Literature Review:* The past, current and future potential (and constraints) of regional remote sensing for monitoring the irrigated farming systems of southern NSW is essentially unknown to the rice industry. The relative costs of purchasing relevant satellite data has not been summarised recently (or ever).

3.2 *Rice Admin*: **Issue 1 – accurate spatial data***:* Irrigation management relies upon accurate spatial data. However, without assessing their accuracy, management decisions based on these data can be put into question as lacking a tangible basis**.** ***Issue 2 – increase accuracy while simplifying the methods****:* Low-cost medium-resolution satellite imagery has been proven to accurately classify rice. However, the often complicated processing of satellite imagery and the potential need for expensive image processing software is particularly limiting the use of remote sensing in the rice industry of NSW.

3.3 *Tech Transfer:* Improved methods for identifying rice in the region using satellite imagery is of little to no use if a detailed step-by-step report is not provided to the users. In addition to written material project staff have spent time directly communicating the procedures developed in 1105 to the operational GIS staff from Coleambally Irrigation Co-operative Limited (CICL).

3.4 *Other Crops:* Little is known about the ability to identify other major summer crops in the region with low-cost satellite imagery. An initial and thorough investigation is required to determine both the accuracy achievable and the best-practice recommendations for timing of imagery and simple methods for integrating multiple satellite dates into a higher accuracy product.

3.5 *Hyperspectral:* The value of time-series hyperspectral remote sensing to the rice-based agricultural community in southern NSW is essentially unknown. What level of expertise is needed to process these types of images? What extra value is added by having so many spectral bands? An initial study addressing these issues is required.

4. The Methodology

4.1 *Literature Review:* A thorough literature review was performed in the remote sensing and rice/agriculture fields regarding the issues related to irrigated rice-based systems. An initial assessment of the costs associated with purchasing

satellite imagery was performed for the 3 irrigation areas. The justification for this is that a summary of the status of rice-based remote sensing is of use to agricultural managers as it demonstrates how remote sensing can currently influence management. Likewise, this summary also highlights key areas of management where remote sensing is currently under-utilised, and is thus equally important to agricultural researchers. The issues concerning the monitoring of rice from remote sensing are also of considerable interest specifically within Australia, because the management of this multi-million-dollar Australian industry will likely become more reliant on technology in order to remain sustainable. See publications 10.2 and 10.10

4.2 _Rice Admin:_ **Issue 1 – accurate spatial data**: Two separate analyses of the accuracy of important spatial data at the CIA were conducted. The first one concerned with the base GIS dataset – the high resolution aerial photographs, which at that time were being acquired every year. This dataset's accuracy was assessed using the accepted methods in the literature (based on survey points of well-defined features) and were reported against both the digital accuracy standards of the USA and the map accuracy standards of Australia. The well defined features consisted of 85 GPS points of road intersections within the CIA (publications 10.8 and 10.12). The second analysis assessed the accuracy of the important road network (which was being used to correct the aerial photographs). This analysis consisted of the traditional point-based assessment described above, as well as a novel line-based methodology. The point- and line-based methods were compared (publication 10.7). **Issue 2 – increase accuracy while simplifying the methods:** An analysis was performed comparing the accuracy of rice identification using a sophisticated classification algorithm in rather expensive image processing software using all available Enhanced Thematic Mapper (ETM) bands to that of a simple density slice of a single ETM band in a generic GIS software package (ArcView that is currently in use by CICL staff). The justification (and premise) of this work was that the identification of rice might be performed just as successfully by very simple methods when a specific spectral feature is inspected. In this case, we isolated 'environmental moisture' defined by the depth of ETM band 5 when compared to neighbouring bands (i.e., ETM bands 4 and 7 - see Figure 1); our hypothesis was that this is a major physical aspect that would separate rice from non-rice crops (publications 10.3 and 10.4).
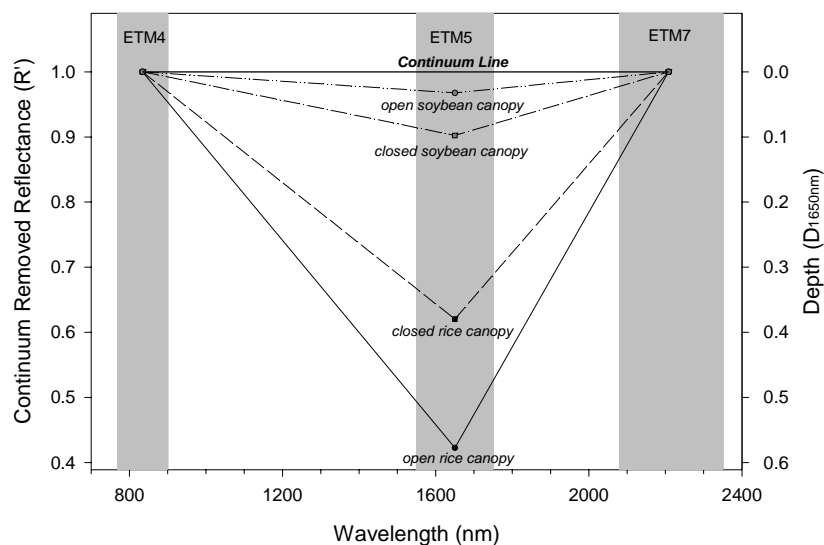
Figure 1. Depth of ETM band 5 clearly separates crops of varying moisture content and background surfaces.

4.3 <u>*Tech Transfer:*</u> The technology transfer of the bulk of the research from project 1105 was associated with the rice administration user's guide document (publication 10.9). This document was created in close consultation with CICL GIS staff and based on the 2002-03 growing season in which Reuben Robinson was trained in the entire procedure over the telephone and via summary documents. These summary documents were enhanced and appended into a single document. Over the 2003-04 growing season, Reuben Robinson and David Klienert of CICL performed rice administration again using satellite imagery, but this time they followed the steps in the document, essentially unaided by 1105 staff. They provided valuable comments and were reviewers of the client report. In 2004-05, Tracey Singh of CICL performed rice administration by using this same document. The justification for this work is that it provides CICL a means to implement the spatial science outlined in project 1105.

4.4 <u>*Other Crops:*</u> Other major summer crops at the CIA were inspected, including maize, sorghum, and soybeans; all are planted on elevated rows and intermittently irrigated. Currently low water allocation for irrigation has resulted in a reduction of rice area in NSW, due to catchment-level diversion limits, increased water use for the environment, and an extended drought which has reduced the stored water supply over the 2001-02, 2002-03, and 2003-04 summer growing seasons. If this continues, it may impact both the relative importance and proportion of these lower water using non-rice crops. Subsequently, a study of the timing of optimum separability of these other crops is probably more important than ever before in the region. Therefore, a characterisation of the best time in the growing season was performed based on classification accuracy. Also, simple methods were compared in order to

combine information from multiple dates in order to determine which procedure resulted in highest accuracy, see publication 10.1.

4.5 *Hyperspectral:* The hyperspectral research associated with project 1105 was mainly concerned with two questions: (1) 'What pre-processing is needed before using this type of data in agricultural research?'; and (2) 'What extra information is there in hyperspectral data that might be useful in agricultural management?'. We acquired and processed 25 satellite hyperspectral images (Hyperion), and 2 airborne hyperspectral images (HyMap) during the 2000-01 and 2001-02 growing seasons. The complexity and time involved in pre-processing these images was inspected (publication 10.6 and 10.11). Also, we expended a major effort collecting appropriate field data to serve as ground truth for these hyperspectral data. Finally, initial studies concerning important agricultural metrics and their relationship to hyperspectral data have been conducted (publications 10.5, 10.13 to 10.19).

5. Detailed results - including the statistical analysis of results

5.1 *Literature Review:* The literature review resulted in a technical report (10.10) and an international peer-reviewed journal paper (10.2), which both highlighted areas of research and management where remote sensing was currently providing useful information and those where there was currently a gap. These reviews also covered in detail what might be the theme of future remote sensing based research for irrigated agriculture (water use issues). The cost estimates for specified commercially available remotely sensed data was also summarised in Table 1 by each irrigation area during the initial stages of project 1105 (March 2000). These estimates gave potential users of remotely sensed data a general idea of the costs involved, and allowed the irrigation companies in the region to define whether remote sensing management was cost-effective at their site.

Table 1. Cost estimates for specified remotely sensed data shortly after project 1105 began (March 2000).

Site	TM	ETM	SPOT PAN	SPOT X	IKONOS[1]
CIA[2]	$750	$600	$1,530	$1,430	$41,500
MIA[3]	$2,375	$2,200	$7,600	$6,800	$235,900
MIL[4]	$3,025	$2,400	$9,500	$8,500	$361,200

1 IKONOS column represents the price for either 1m panchromatic or 4m multispectral data.

2 CIA estimates for TM and ETM, were based on one prices for one ninth scene (up to 3,600 sq km) (map oriented price). SPOT PAN and SPOT X costs are based on one half scene (up to 1,800 sq km) (map oriented price), and IKONOS costs are based on price per area (931 sq km * $44.60 AUS/sq km = $41,522.60).

3 MIA cost estimates for TM and ETM are based on one full scene and one ninth scene (full scene is path image price and ninth scene is map oriented price). SPOT PAN and SPOT X costs are based on 4 full scenes (path image price), and IKONOS estimates are based on price per area (5,289 sq km * $44.60 AUS/sq km = $235,889.40).

4 MIL estimates for TM and ETM are based on one full scene, one ninth scene and one small scene (path image price for full and map oriented price for ninth and small). SPOT costs are based on 5 full scenes (path image price), and IKONOS costs are based on price per area (8,098 sq km * $44.60 AUS/sq km = $361,170.80).

5.2 *Rice Admin:* Results of this research are described in detail in 4 international peer-reviewed journal articles (10.3, 10.4, 10.7, and 10.8). ***Issue 1 – accurate spatial data:*** The errors in the roads dataset were characterised (Figure 2) and the errors in the high-resolution aerial photographs were minimised (see Table 2).
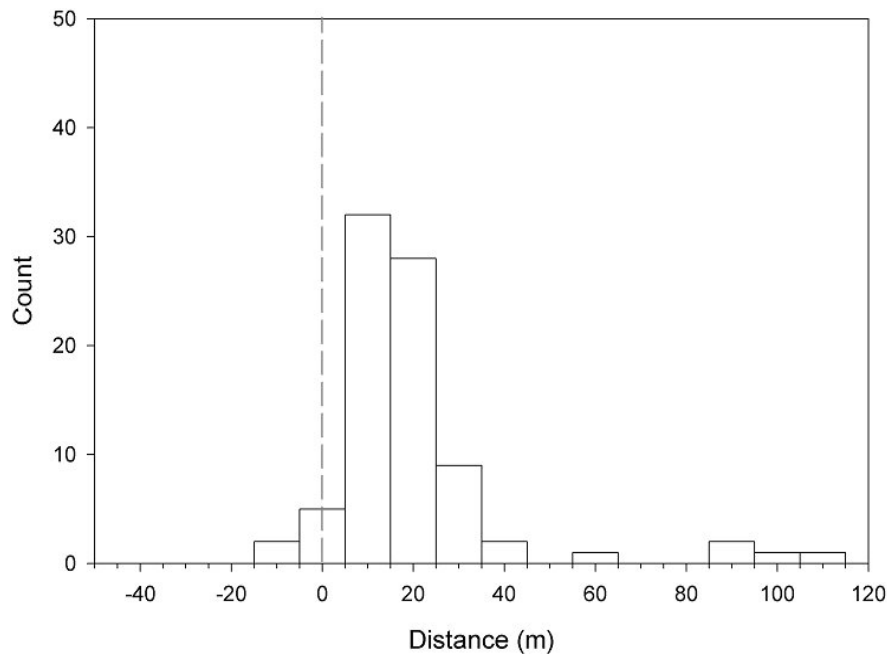

Figure 2. The detailed check of the accuracy of the CIA road network GIS dataset showed that there were large sections of roads in error by more than that allowed by the Australian standards and that the way in which the error was measured made a significant difference in the estimate of that error. The difference in error estimates is shown for the same dataset when measured using point *vs*. line methodologies.

The newly corrected photograph dataset became the new GIS baseline. The standards and methods described in this work were used to redefine the tender for aerial photograph acquisition in subsequent years.

Table 2. Horizontal positional accuracies calculated at the CIA. Results show that the original roads dataset and the original aerial photos exceeded the allowable error based on Australian standards. The aerial photographs were then corrected within project 1105, after which the much improved statistics then complied with Australian map accuracy standards.

Name	Mean Difference (m)	RMS Difference (m)	NSSDA 95%[*] (m)	Number Exceeding 25m[**]	Percent Exceeding 25m (%)[***]
Roads dataset	32.18	39.26	67.95	21 of 39	53.85
Original Aerial photos	20.00	23.01	39.83	10 of 21	47.62
Corrected Aerial photos	8.07	9.12	15.78	0 of 21	0.00

* NSSDA The US National Standard for Spatial Data Accuracy is based on the 95% confidence interval around the root mean squared (RMS) error.

** Number exceeding 25m The Australian mapping accuracy standard is based on counting the number of survey points that were in excess of a distance threshold based on map scale (in this case, 25 m).

Issue 2 – increase accuracy while simplifying the methods*:* Results showed that the simple analysis of a moisture spectral feature outperformed the more complicated classification using all ETM bands (Figure 3), but only during the early part of the summer growing season. The optimal time for determining rice from non-rice using this simplified method was late November. Research was also conducted in order to ascertain whether these already greatly simplified methods could be further simplified. One of the most complicated steps in the processing of satellite imagery is correcting for atmospheric effects. Our research showed that performing atmospheric correction actually diminished rice classification accuracy and could therefore be eliminated without negatively impacting results (Figure 4).
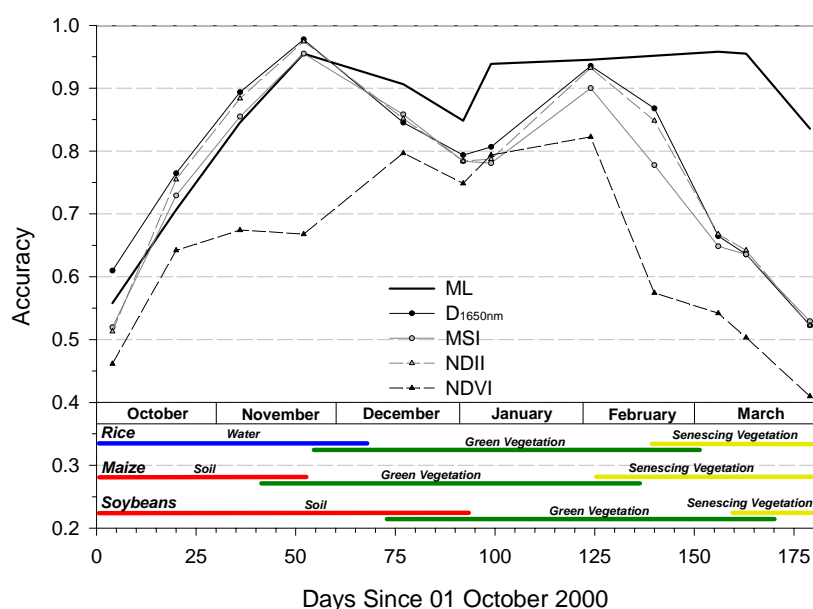

Figure 3. Depth of ETM band 5 (D1650nm) provides higher rice classification accuracy early in the summer growing season (2000-01 growing season shown) than more complicated Maximum Likelihood (ML) classification using expensive image processing software. Other vegetation moisture and greenness indices are also shown, including the Moisture Stress Index (MSI), the Normalised Difference Infrared Index (NDII) and the Normalised Difference Vegetation Index (NDVI).
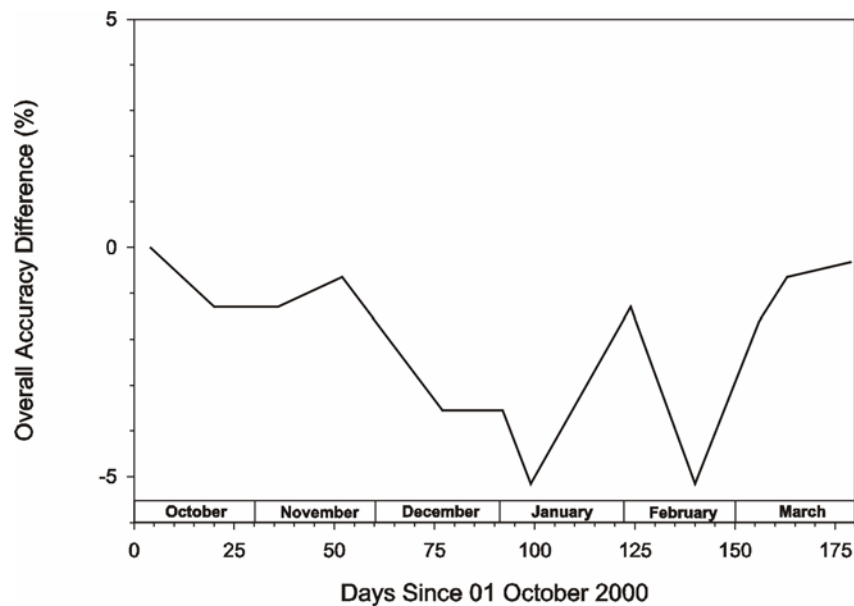
Figure 4. One of the most complicated image processing procedures, atmospheric correction, was shown to decrease rice classification accuracy consistently throughout the 2000-01 summer growing season (i.e., a negative value in the figure above is the degree to which performing atmospheric correction reduced the per-field rice classification accuracy). This analysis justified removing this complicated step from the rice identification methods.

5.3 <u>*Tech Transfer:*</u> The rice-based classification system was transferred as an operational system to the CIA. A detailed Client Report (publication 10.9 below) formed the basis of our technology transfer to CICL with respect to rice field identification. Valuable input from the GIS staff from CICL was incorporated into earlier drafts of the document as we wanted this document to be directly relevant to those performing the rice compliance mapping. Reuben Robinson, David Klienert, and Tracey Singh (all of CICL) have all implemented the approach over the 2002-03, 2003-04, and 2004-05 growing seasons. With the skills and knowledge transferred to CICL's GIS staff, they are able to continue using this method in the future. However, it should be noted that if rice become an intermittently flood irrigated crop, or is grown on raised beds; the method developed may need to be revised, as the current method assumes rice is flood irrigated permanently during the growing season. See Figure 5 below which shows the accuracy results for the 2004-05 growing season when classifying rice vs. non-rice based on a simple density slice of a single ETM+ band. An accuracy of *>98%* was achieved estimated from 68 paddocks of known crop types.
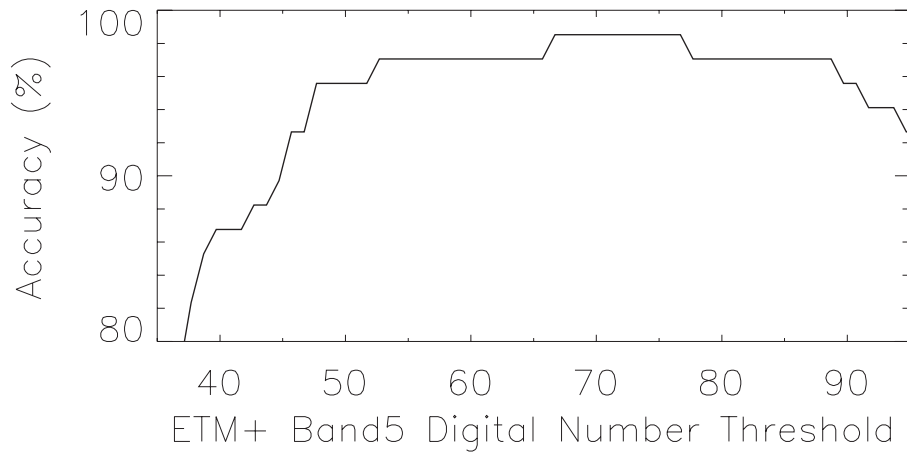
Figure5. Overall rice identification accuracy *vs*. ETM+ band 5 digital number threshold used. Based on this single band taken from a late November 2004 image, >98% accuracy was achieved.

5.4 *Other Crops:* A characterisation of the best time in the growing season was performed (Figure 6 – see publication 10.1). Results showed that maize was best discriminated from mid-February to mid-March, the maximum sorghum separability occurred from early April till at least early May, and the soybean temporal window extended from early January to mid-March, with late-February to early March being best.
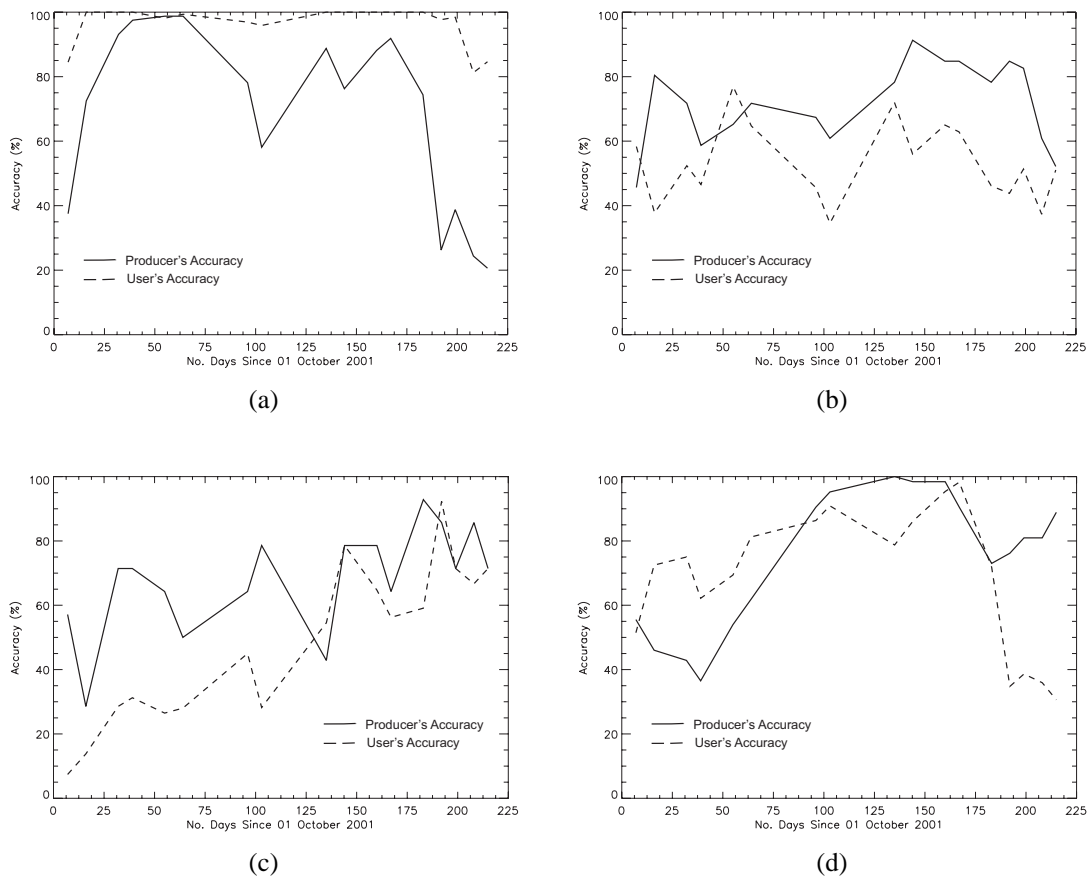

(a)

(b)

(c)

(d)

Figure 6. Per-field producer's and user's accuracies for the major crops are shown through the entire 2001-02 summer growing season. Number of fields used for validation was 160 for rice (a), 46 for maize (b), 14 for sorghum (c), and 63 for soybeans (d).

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5.5 *Hyperspectral:* The research has to date been summarised in two international peer-reviewed journal papers (10.5 and 10.6) and a series of conference papers (10.13 to 10.19). For satellite hyperspectral data, the processing required to achieve a product ready for analyses relevant for agricultural management seem to be quite intensive (see Figure 7) and currently beyond the scope of the remote sensing capabilities within the 3 main irrigation companies. However, these skills, if determined to be important, could be sought from private consultants or added as a technical position, possibly shared amongst the 3 companies.
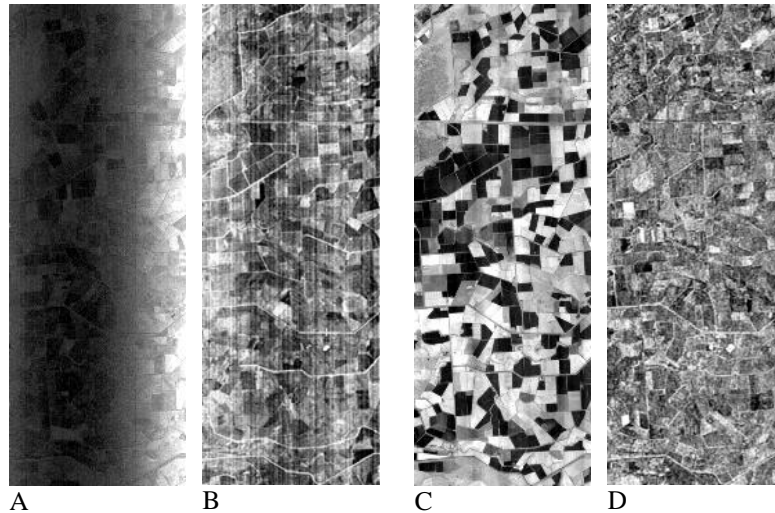

A   B   C   D

Figure 7. MNF Bands 1 and 15 before (A and B) and after (C and D) global de-striping. The 176 band selection from Hyperion was used for the MNF (see article for detailed description [10.6]). Contrast the 'on-the-ground' information content in image C (after global de-striping) with image A (before global de-striping).

It was also determined that appropriate field data was critical for relating hyperspectral data to agronomic metrics. Initial analyses of hyperspectral data show strong correlations with certain soil properties (see Figure 8), but correlating indirect soil variables (i.e., those soil properties that do not have corresponding reflectance or absorbance features in the hyperspectral spectra, e.g., soil electro-conductivity) may not be robust as it is strongly influenced by the field data and possibly residual noise after atmospheric correction and it is unlikely to provide a relationship that is able to be applied to other sites or even the same site in a different year.
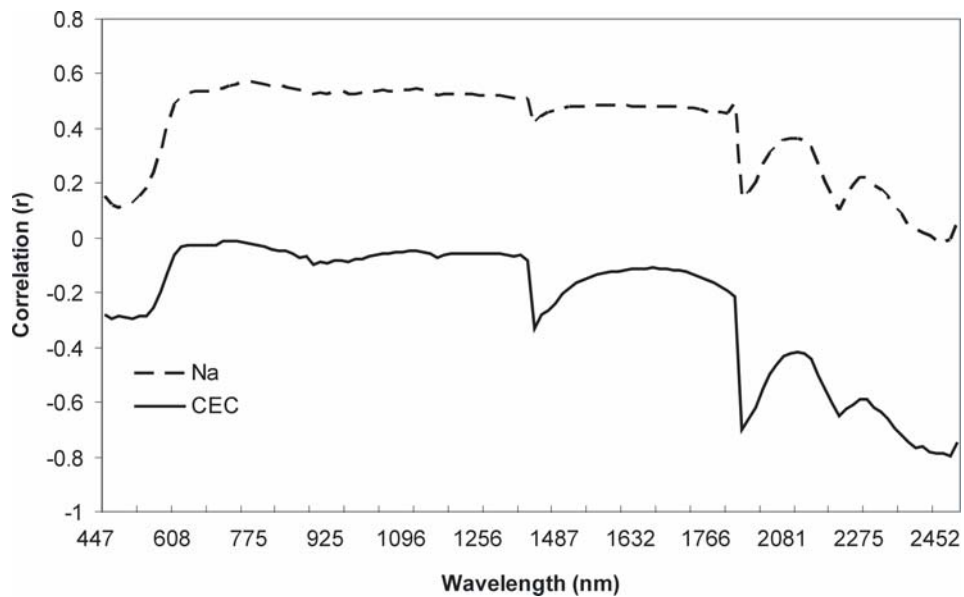
Figure 8. Correlograms of Na and CEC between 38 soil sites (0-2cm depth) and the 125 HyMap bands acquired on 8th December 2000.

6.   Discussion of results

6.1 *Literature Review:* The remote sensing/rice literature was thoroughly examined and summarised in the form of a technical report (publication 10.10) and an international peer-reviewed journal paper (publication 10.2). These documents assessed the past and current worth and future potential of regional remote sensing for monitoring the irrigated farming systems of southern NSW and highlighted the research that was currently being done well (currently influencing management) and that research that still needs more work before it will be able to influence management. Estimates of costs to develop suitable monitoring systems was inspected and reported early in the project (March 2000) – this summary provided individual irrigation companies with the information they needed to decide whether remote sensing was feasible as a data source for the management of each irrigation area.

6.2 *Rice Admin:* The spatial aspects of yearly rice administration were assessed and considerable improvements were made to the procedure. The methods used to map rice using satellite remote sensing were optimised based on accuracy, simplicity, and cost (publications 10.3 and 10.4). This is demonstrated by the financial savings attained in collection of the base data alone every year (discussed below), while maintaining very high attribute accuracy (e.g., 98%) and high spatial accuracy (e.g., GPS or high resolution aerial photograph-based). Also the errors within this product were assessed in detail in order to understand what the sources of error were and how they interacted with the phenological response and management of rice. These techniques were successfully made "user-friendly" and operational as proven by the implementation by CICL GIS staff of the methods for 3 years running.

6.3 *Tech Transfer:* Technology transfer of the improved and simple rice identification methods was successful. A local irrigation company (CICL) was provided with a 'user's guide' for performing rice administration using satellite

remote sensing, which provided a step-by-step description of the entire process (publication 10.9). These improved techniques have been used by CICL for the 2002-2003, 2003-04, and 2004-05 growing seasons. This demonstrates an impact on the Australian rice industry. Previously CICL paid approximately $20,000 for high resolution air photos each summer growing season, whereas the satellite data (ETM) cost $700.

6.4 *Other Crops:* The best practice use of satellite remote sensing for identification of other irrigated summer crops was determined. Results identified the best times to purchase satellite imagery when attempting to discriminate between maize, sorghum, soybeans (and rice). It also showed the best simple method for combining classification results from different acquisition dates in order to improve accuracy of the product (publication 10.1). This research is potentially very important as an initial characterisation study and may provide critical information if the rice industry moves towards planting lower water using crops.

6.5 *Hyperspectral:* The extra value added from hyperspectral remote sensing (*e.g.*, > 100 spectral bands per image) over current coarse remote sensing (e.g. ETM has 6 bands) for rice-based irrigation farming systems was inspected (publications 10.13 to 10.19). This preliminary study showed that there is great potential for hyperspectral remote sensing in the rice industry of Australia, but currently satellite-based data was slow in coming and was difficult to process. The research performed in project 1105 describes a processing pathway, which makes the procedure from image acquisition to analysis easier (publication 10.6). Airborne hyperspectral data also proved to be somewhat time-consuming in its processing as many images needed to be geometrically and atmospherically corrected before mosaicking, even for the smallest irrigation area CIA – for MIA and MV this issue would be more problematic given their larger areas. Preliminary results show that improved agronomic metrics should be attainable from hyperspectral remote sensing. Hyperspectral remote sensing has a great deal to offer the rice industry in both research and development aspects, but is yet just out of the realm of influencing operational management (due to increased time to process). It is expected that this will be less of a limiting factor with the launch of new satellite missions; however before optimistically using any new technology we advise conducting some applied research to assess the utility of new technologies for the specific cases where they are to be applied. Within the Australia's rice industries it will be important to stay abreast of future developments in satellite technology; ideally areas such as CIA could be a calibration test site for future missions – hence gaining access to such datasets before they are routine.

7.   Implications and recommendations

7.1 *Literature Review:* This work has provided the Australian industry with specific recommendations regarding the current and potential use of remote sensing in irrigated rice systems. These include concentrating on water and crop production in the future; plant establishment and early stages of plant reproduction were two critical timeframes that were suggested as times when better relationships might be attained. It was also highlighted that water use

was an area that was largely ignored, but should be considered in the future. The worth of such a summary of the Australian industry is almost impossible to quantify; it is expected to have provided context for many of the GIS staff working in the rice-based industries to greater understand how remote sensing data can be used in their operational management. Additionally, the expected impact of this summary in the national and international literature is high.

7.2 *Rice Admin:* *Issue1 – accurate spatial data:* Our research has assessed and improved the accuracy of aerial photography used to digitise GIS paddock boundaries (publication 10.8 below) and has advanced theoretical spatial error and uncertainty methodologies concerning the GIS roads network at the CIA (publication 10.7). This research provided a scientific justification for certain management decisions made by CICL, which shows that this research has been adopted by industry. Recommendations were also provided regarding the impact of spatial error on areal estimates from high-resolution aerial photographs. ***Issue 2 – increase accuracy while simplifying the methods:*** A new method using low-cost Landsat imagery was developed in project 1105 (publication 10.4), from which the classification of rice was over 97% accurate at the CIA. The main achievement of this work was a better understanding of spatio-temporal patterns of the NSW rice systems. This research identified rice for a fraction of the cost to the irrigation company ($700 instead of >$20,000 annually for the base data) 3 months earlier than using previous methods. This work has been adopted by industry. Specific recommendations were made to the rice industry to change the timing of image acquisition dates and the type of imagery required. Rice administration using satellite remote sensing data is only operational if the methods used are simple to understand and repeat and inexpensive to incorporate (publication 10.3). The simplified rice identification methods were designed to be fully processed in a generic GIS software package (ArcView); this was already being used by the irrigation companies in the region (and is also inexpensive to purchase and maintain). Also, several staff at the test site (CIA) was proficient in the use of ArcView. This avoided the expenses of purchasing expensive image processing software and the cost of hiring a remote sensing specialist or training an existing staff member on any new software.

7.3 *Tech Transfer:* The technology transfer of project 1105 is embodied in the rice administration user's guide (publication 10.9). This document provided specific recommendation and a step-by-step guide to performing rice administration using satellite imagery. As mentioned above, this provides cost savings in the data purchased every year, but there is also an unquantified savings provided by this report, which allows CICL staff members to perform this task unaided every year (previous satellite remote sensing consultation has been provided in the past for >$10,000). It is reasonable to assume that this document saves these sorts of consultation fees every year in which it is used (so far, 3 years).

7.4 *Other Crops:* The implications for this work are great. As the pressures on irrigation companies' increase due to lower water allocations, the importance of non-rice (lower water using) crops increases. This research provided the first characterisation of the 'best' times in order to purchase satellite images for

classification of these non-rice crops (i.e., corn, sorghum and soybeans – see publication 10.1). The benefit to the Australian industry, again, is not quantified. However, a feasibility study of this kind could easily be worth > $50,000, all of which was leveraged against the satellite images acquired and processed for the other related studies listed above.

7.5 *Hyperspectral:* The research performed in project 1105 has indicated that Hyperion (satellite hyperspectral remote sensing) data requires substantial pre-processing, with our research (conducted in collaboration with staff from CSIRO Earth Observation Centre and NASA – see publication 10.6 below) defining the pre-processing pathway, the system is closer to operational. The long turn-around times in acquiring the data was a problem for our project, this is possibly rectified now that the production of the data is handled by a more operational US government agency (US Geological Survey), rather than a more research focused US government agency (NASA). For our project, airborne hyperspectral data also required processing time (e.g., geometric and atmospheric correction) such that providing a product in time to influence management was difficult. The implication of our research is that hyperspectral remote sensing is still more in the realm of research and development than for operational management for the rice industry in Australia. Given time, or a targeted effort, the two could easily be bridged. There are 3 current research aims being conducted, they are: (1) assessing the stability of hyperspectral data for mapping soil properties by performing a time-for-space transfer where empirical relationships from HyMap and field data acquired on 8th December 2000 are applied to HyMap data acquired on 12th January 2002 (and vice versa in situ soil sampled were also collected and processed to support the 12th January HyMap data acquisition); (2) assessing the ability of hyperspectral data based indices to monitor vegetation moisture by relating field samples of moisture to Hyperion data acquired on 13th February 2002; and (3) assessing the utility of hyperspectral over broadband remote sensing to be able to map crop yields – the validation data set are fields where d-GPS yield data were recorded.

8. A description of the Project Intellectual Property and of any commercially significant developments arising from the Project

There are no commercial significant developments arising from the project; all material has been published in the public domain and training of relevant CICL staff is currently still being performed to ensure that the methods developed in 1105 can continue after the project is completed.

9. Recommendations

As a result of the research described in this final report, remote sensing has been used more efficiently in the Australian rice industry. It has provided justification for management decisions, provided a metric of certainty in measurements made from baseline GIS data, and allowed management decisions to be made, earlier, with less expense, and with greater ease than previously was the case. Recommendations to further develop this research include further analyses into the benefits of

hyperspectral remote sensing (and even time-series hyperspectral analysis), particularly into the relationship driving crop yield as well as the indirect and direct modeling of water use (efficiency). These two important issues are cutting edge, not only in the rice industry of Australia, but internationally.

10. References

The references generated from 1105 are listing under the following headings. It is likely that there will be several journal papers published after the completion date of the project (30th June 2005) from the hyperspectral research (the topics are identified in 7.5 above).

Peer Review Journal Papers:

10.1 **Van Niel TG**, **McVicar TR** (*2004*) Determining temporal windows for crop discrimination with remote sensing: a case study in south-eastern Australia. *Computers and Electronics in Agriculture* **45**, 91-108.

10.2 **Van Niel TG**, **McVicar TR** (*2004*) Current and potential uses of optical remote sensing in rice-based irrigation systems: a review. *Australian Journal of Agricultural Research* **55**, 155-185.

10.3 **Van Niel TG**, **McVicar TR** (*2003*) A simple method to improve field-level rice identification: Toward operational monitoring with satellite remote sensing. *Australian Journal of Experimental Agriculture* **43**, 379-387. *[Imagery from CIA shown on cover of journal]*

10.4 **Van Niel TG**, **McVicar TR**, Fang H, Liang S (*2003*) Calculating environmental moisture for per-field discrimination of rice crops. *International Journal of Remote Sensing* **24**, 885-890.

10.5 Liang S, Fang H, Thorp L, Kaul M, **Van Niel TG**, **McVicar TR**, Pearlman JS, Walthall CL, Craig S, Daughtery T, Huemmrich F (*2003*) Estimation of land surface broadband albedos and leaf area index from EO-1 ALI data and validation. *IEEE Transactions of Geosciences and Remote Sensing* **41**, 1260-1267. *[Imagery from CIA shown on cover of journal]*

10.6 Datt B, **McVicar TR**, **Van Niel TG**, Jupp DLB, Pearlman JS (*2003*) Pre-processing EO-1 Hyperion hyperspectral data to support the application of agricultural indices. *IEEE Transactions of Geosciences and Remote Sensing* **41**, 1246-1259 *[Imagery from CIA shown on cover of journal]*

10.7 **Van Niel TG**, **McVicar TR** (*2002*) Experimental evaluation of positional accuracy estimates from a linear network using point- and line-based testing methods. *International Journal of Geographical Information Science* **16**, 455-473.

10.8 **Van Niel TG**, **McVicar TR** (*2001*) Assessing positional accuracy and its effects on rice crop area measurement: an application at Coleambally Irrigation Area. *Australian Journal of Experimental Agriculture* **41**, 557-566.

Technical Reports:

10.9 **Van Niel TG**, **McVicar TR** (*2004*) A user's guide for identifying rice paddocks using GIS and remote sensing at Coleambally Irrigation Area, NSW, CSIRO Land and Water Client Report, Perth, WA, Australia, 53 p.

10.10 **Van Niel TG**, **McVicar TR** (*2001*) Remote sensing of rice-based irrigated agriculture: A review.' Cooperative Research Centre for Sustainable Rice

Production, P1105-01/01, Yanco, NSW, Australia, http://www.ricecrc.org/reader/P1105TR01-01.pdf.

10.11 **McVicar TR**, **Van Niel TG**, Jupp DLB. (*2001*) Geometric Validation of Hyperion Data acquired by Earth Observing 1 Satellite at Coleambally Irrigation Area. CSIRO Land and Water Technical Report 46/01, Canberra, Australia, pp. 70.

10.12 **Van Niel TG**, **McVicar TR** (*2000*) 'Assessing and improving positional accuracy and its effects on areal estimation at Coleambally Irrigation Area.' Cooperative Research Centre for Sustainable Rice Production, P1-01/00, Yanco, NSW, Australia, http://www.ricecrc.org/reader/project1105.pdf.

Conference Papers:

10.13 Jupp, D.L.B., Pearlman, J.S., Datt, B., **Van Niel, T.G.** and **McVicar, T.R.** (2003) Scale Comparisons between Landsat, EO-1, SAC-C for local and regional crop assessments. *Proceedings of the International Conference,* Buneios Arerias, Argentinia, 21-25 July 2003.

10.14 Datt, B., Jupp, D.L.B., **McVicar, T.R.**, **Van Niel, T.G.** and Pearlman, J.S. (2003) Time Series Analysis of EO-1 Hyperion data for Yield Estimation at an Agricultural Site. *Proceedings of the International Geoscience and Remote Sensing Symposium*, Toulouse, France, 21-25 July 2003.

10.15 Datt B, Jupp DLB, **McVicar TR**, **Van Niel TG**, Lovell J, Campbell SK (*2002*) Spectral Feature Analysis of Crop, Soil and Stubble Using Hyperion and Hymap Data. *Proceedings of the 11th Australasian Remote Sensing and Photogrammetry Conference*, Brisbane, Australia, 2-6 September, 657-658.

10.16 Pearlman J, **McVicar TR**, **Van Niel TG**, Jupp DLB, Datt B, Campbell SK, Lovell JL, Mitchell RM, Barry P, Liang S (*2002*). Assessing the Value of a Time Series of EO-1 Data for Coleambally Irrigation Area. *Proceedings of the International Geoscience and Remote Sensing Symposium*, Toronto, July 2002.

10.17 Jupp DLB, Datt B, **McVicar TR**, **Van Niel TG**, Pearlman JS, Lovell J, King EG (*2002*) Improving the Analysis of Hyperion Red Edge Index from an Agricultural area. In *'Proceedings of the SPIE's Third International Asia-Pacific Symposium on Remote Sensing of the Atmosphere, Ocean, Environment, and Space'*. Hangzhou, China.

10.18 **Van Niel TG**, **McVicar TR**, Campbell SK, Liang S, Kaul M, Pearlman J, Clancy P, Segal C (*2001*) The Coleambally Agricultural Component of Hyperion Instrument Validation. *Proceedings of the International Geoscience and Remote Sensing Symposium*, Sydney, July 2001

10.19 Liang S, Fang H, Kaul,M, **Van Niel TG**, **McVicar TR**, Campbell SK, Walthall C, Daughtry C, Pearlman J (*2001*) Land Surface Bio/Geophysical Variable Estimation for EO-1 Data and Validation. *Proceedings of the International Geoscience and Remote Sensing Symposium*, Sydney, July 2001

Posters:

10.20 **McVicar, T.R.**, **Van Niel, T.G.** and Campbell, S.K. (2002) Coleambally Irrigation Area: A Time Series Remote Sensing Site. *Presented at the 11th Australasian Remote Sensing and Photogrammetry Conference*, 2-6 September, Brisbane. A-0 poster.

10.21 **Van Niel, T.G.**, **McVicar, T.R.** and Edge, F. (2002) Coleambally Irrigation Area, Riverina District, New South Wales. *ACRES Update, Geoscience Australia*. Issue 26, September 2002, A-3 poster.

Media Interactions:

10.22 ABC Radio Wagga Wagga NSW "NASA and Coleambally Irrigation Area" September 5, 2001.

10.23 The Weekend Australian "NASA helps beat salinity" September 1-2, 2001, pp 22.

Invited Presentations:

10.24 **McVicar T.R.**, and **Van Niel T.G.** (2004) 'Recent activities in the Rice CRC project at Coleambally Irrigation Area (CIA): (1) assessing positional accuracy; and (2) determining temporal windows for summer crop classification'. CSIRO Earth Observing Seminar Series, 9th July, Canberra, ACT, Australia.

10.25 **McVicar T.R.**, and **Van Niel T.G.** (2004) 'Determining temporal windows of summer crop discrimination using time series remote sensing at Coleambally Irrigation Area (CIA)'. Integrated Catchment Management Research Directorate Seminar Series, 20th January, Canberra, Australia.

10.26 **McVicar T.R.**, and **Van Niel T.G.** (2003) 'Remote sensing of irrigated crop types and its application to regional water balance estimation'. CRC for Sustainable Rice Production, Annual Program 1 Science Meeting. 27th and 28th November, Griffith, NSW, Australia.

10.27 **McVicar T.R.**, **Van Niel T.G.**, Jupp D.L.B., Datt B., and Pearlman J.S. (2002) 'Coleambally Irrigation Area (CIA) and EO-1: A time series agricultural site'. CSIRO Earth Observation Centre Annual Science Meeting. 27th to 29th August, Canberra, ACT, Australia.

10.28 **McVicar T.R.**, **Van Niel T.G.**, Jupp D.L.B., Datt B., and Pearlman J.S. (2002) 'Coleambally Irrigation Area (CIA) and EO-1: A time series agricultural site'. Australian Centre for Remote Sensing (ACRES) EO-1 workshop, 15th March, Canberra, ACT, Australia.

10.29 **McVicar T.R.**, and **Van Niel T.G.** (2002) 'Implications of Rice CRC remote sensing research'. CRC for Sustainable Rice Production, Annual Science Meeting. 12th February, Yanco, NSW, Australia.

10.30 **Van Niel T.G.** and **McVicar T.R.** (2001) 'Assessing positional and areal accuracy for environmental compliance monitoring of rice farmers using high resolution digital aerial photography'. Department of Geography and Earth Resources Divisional Seminar, Utah State University. 8th September, Logan Utah, USA.

10.31 **Van Niel T.G.** and **McVicar T.R.** (2001) 'Assessing positional and areal accuracy for environmental compliance monitoring at Coleambally Irrigation Area'. CRC for Sustainable Rice Production Annual Science Meeting. 15th February, Yanco, NSW, Australia.

10.32 **McVicar T.R.** (1999) 'Possible roles for time-series remote sensing to support decision making in a rice-based irrigation system'. CRC for Sustainable Rice Production Annual Science Meeting. 9th February, Yanco, NSW, Australia.

11.   Acknowledgements