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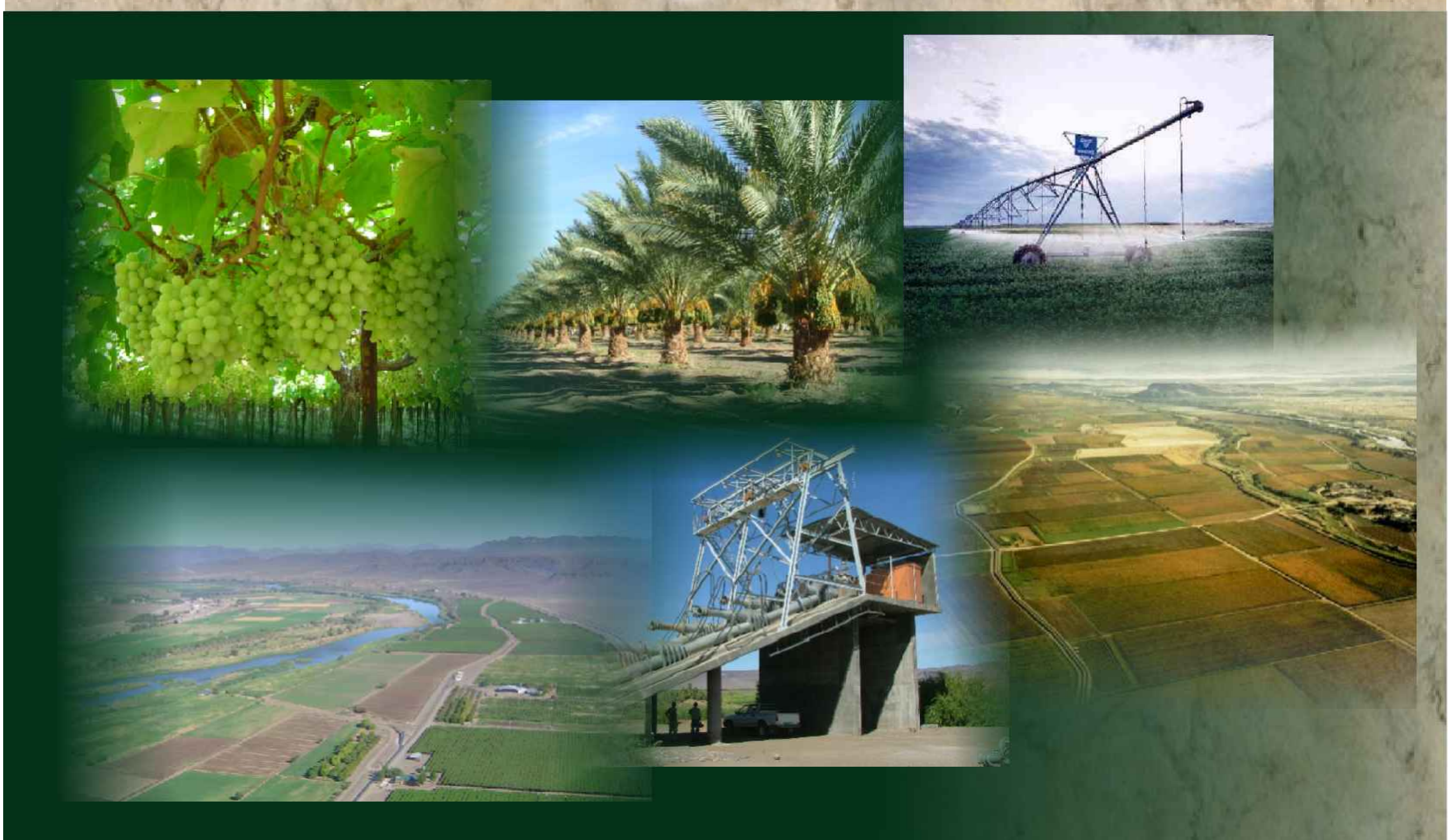
SUPPORT TO PHASE 2 OF THE ORASECOM BASIN-WIDE
INTEGRATED WATER RESOURCES MANAGEMENT PLAN
Work Package 6:
Water Conservation and Water Demand in the Irrigation Sector

Irrigation GIS Database, Interactive Database and Irrigation Scenario Tools



March 2011

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giz On behalf of Federal Republic of Germany The Federal Government UKaid from the Department for International Development Australian AID

Prepared by

wrp A Miya Group Company in association with DMM Golder Associates PTK RAMBØLL WCE

SUPPORT TO PHASE 2 OF THE ORASECOM BASIN-WIDE INTEGRATED WATER RESOURCES MANAGEMENT PLAN

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Study Name	Support to Phase 2 of the ORASECOM Basin-wide Integrated Water resources Management Plan
Report Title:	***Irrigation GIS Database, Interactive Database and Irrigation Scenario Tools***
Submitted by:	WRP Consulting Engineers in association with Golder Associates, DMM, PIK, RAMBOLL and WCE

REPORTS, WPS AND OTHER DELIVERABLES SUBMITTED	TYPE	No.
Overall Study		
Inception Report	Report	004/2010
Final Report	Report	013/2011
Work Package 1: WATER RESOURCES MODELLING OF THE ORANGE-SENQU BASIN		
Strengths and Weaknesses of Existing Models	WP	005/2010
Setting up and Testing of the Final Extended and Expanded Models; Changes in Catchment Yields and Review of Water Balance	Report & WP	001/2011
Modelling software and datasets	Software	None
Capacity Building and Setting up the Models in each Country; Process of Continuous Review	WP	003/2011
Work Package 2: EXTENSION AND EXPANSION OF HYDROLOGY OF ORANGE-SENQU BASIN		
Improvements to Gauging Network and Review of Existing Data Acquisition Systems	WP	005/2011
Extension of Hydrological Records	Report	006/2011
Hydrological Database	Database	None
Work Package 3: INTEGRATED WATER RESOURCES QUALITY MANAGEMENT PLAN		
Development of Water Quality Monitoring programme and Data Management Framework	Report	007/2011
Development of Specifications for the Water Quality Model	WP	006/2010
Work Package 4: CLIMATE CHANGE IN THE ORANGE-SENQU RIVER BASIN		
Downscaling Methodology and Ongoing Climate Modelling Initiatives	WP	007/2010
GCC Downscaling for the Orange-Senqu River Basin	Report	008/2011
Projection of impacts and Guidelines on Climate Change Adaptation Strategies	WP	009/2011
Work Package 5: ASSESSMENT OF ENVIRONMENTAL FLOW REQUIREMENTS		
Literature survey and Gap Analysis	WP	008/2010
Delineation of Management Resource Units	WP	009/2010
Desktop Eco Classification Assessment	Report	016/2010
Goods and Services Report	WP	010/2010
Environmental Flow Requirements	Report	010/2011
Work Package 6: WATER CONSERVATION AND WATER DEMAND IN THE IRRIGATION SECTOR		
The Promotion of WC WDM in the Irrigation Sector	Report	011/2011
Irrigation GIS Database, Interactive Database and Irrigation Scenario Tools	***WP***	***012/2011***
Irrigation GIS Database and Interactive Classification Tool	Software	None
Irrigation Scenario Generation Tool	Software	None

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1 INTRODUCTION

1.1 General Context

The Orange - Senqu River originates in the highlands of Lesotho some 3 300m above mean sea level, and it runs for over 2300km to its mouth on the Atlantic Ocean. The river system is one of the largest river basins in southern Africa with a total catchment area of more than 850,000km2 and includes the whole of Lesotho as well as portions of Botswana, Namibia and South Africa. The natural mean annual runoff at the mouth is estimated to be in the order of 11 500 million m3, but this has been significantly reduced by extensive water utilization for domestic, industrial and agricultural purposes to such an extent that the current flow reaching the river mouth is now in the order of half the natural flow. The basin is shown in **Figure 1-1.** The Orange-Senqu system is regulated by more than thirty-one major dams and is a highly complex and integrated water resource systems with numerous large inter and intra basin transfers.

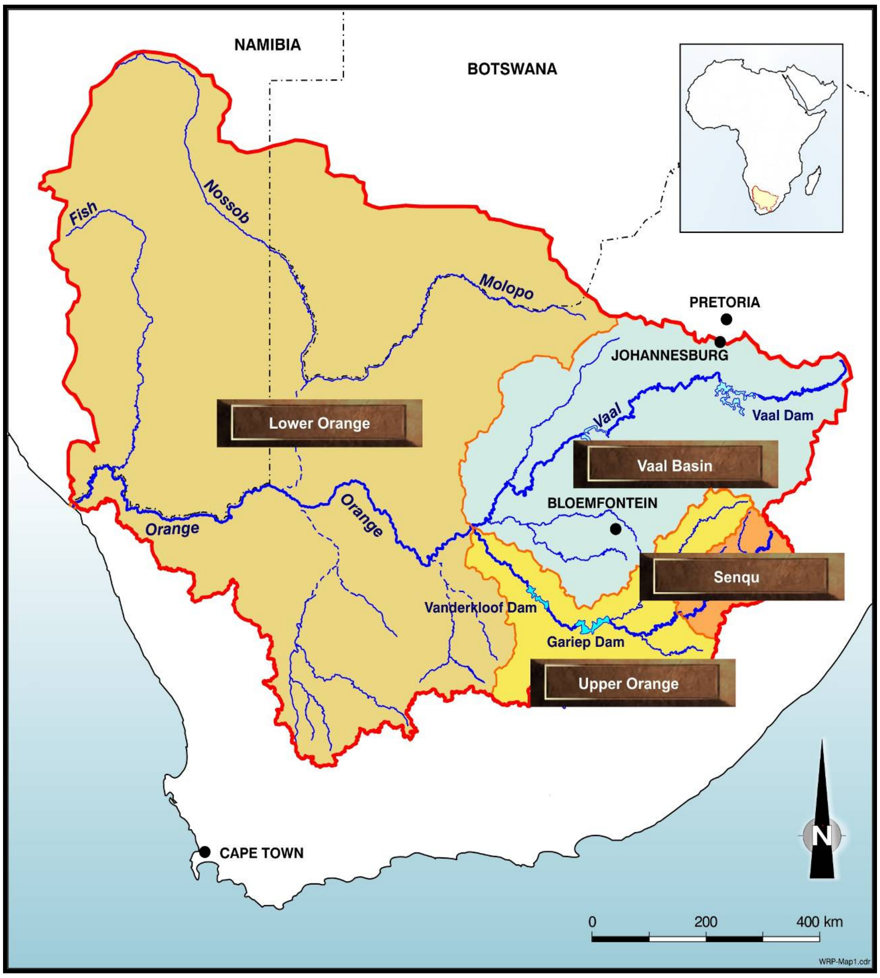

Figure 1-1: Orange–Senqu River Basin

1.2 Management and Environmental Context

1.2.1 General

Management issues, including environmental protection, conservation and sustainable development have to deal with problems relating to, both, water quantity and quality, potential conflicts between users, pollution sources from industry, mining, agriculture, watershed management practices and the need to protect ecologically fragile areas. The riparian countries have, for some time, recognized that a basin-wide integrated approach has to be applied in order to find sustainable solutions to these problems and that this approach must be anchored through strong political will. The development of this strong political will is one of the key initiatives of SADC, in particular the Revised Protocol on Shared Watercourses and the establishment of the Orange-Senqu River Basin Commission (ORASECOM). These initiatives are intended to facilitate the implementation of the complicated principles of equitable and beneficial uses of a shared watercourse system. It is accepted by all countries that the management of water resources should be carried out on a basin-wide scale with the full participation of all affected parties within the river basin.

Water supply in terms both of quantity and quality for basic human needs is being outstripped by the demands within and outside of the basin. Meeting the water supply needs of rapidly growing towns and cities and at the same time having sufficient water of an acceptable quality to meet existing and proposed irrigation and other demands (including environmental) further downstream, is a challenge for planners, decision makers and stakeholders in the Orange-Senqu river basin.

1.2.2 ORASECOM

Southern Africa has fifteen trans-boundary watercourse systems including the Orange–Senqu system. The Southern African Development Community (SADC) has adopted the principle of basin–wide management of the water resources for sustainable and integrated water resources development. In this regard, the region recognizes the United Nations Convention on the Law of Non-navigational Uses of International Watercourses, and has adopted the “Revised Protocol on Shared Watercourse Systems in the SADC Region”. Under this Revised Protocol, a further positive step has been the initiatives towards the establishment of river basin commissions in order to enhance the objectives of integrated water resources development and management in the region, while also strengthening the bilateral and multilateral arrangements that have been in existence for some time. The Orange–Senqu River Basin Commission (ORASECOM) was established on 3 November, 2000 in Windhoek, Namibia and is a legal entity in its own right.

The highest body of the ORASECOM is the Council consisting of three permanent members, including one leader, for each delegation from the four riparian states. Support from advisors and ad hoc working groups can be established by the Council. The main task of the Council is to “serve as technical advisor to the Parties on matters relating to the development, utilization and conservation of the water resources in the River System”, but the Council may also perform other functions pertaining to the development and utilization of water resources, as the parties may agree.

1.3 Context of the Study and this Working Paper

1.3.1 GIZ Support to SADC and ORASECOM

The overall goal of the GIZ-supported ‘Transboundary Water Management in SADC’ programme is to strengthen the human, institutional, and organisational capacities for sustainable management of shared water resources in accordance with SADC’s Regional

Strategic Action Plan (RSAP). The programme, which GIZ implements on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ), and in delegated cooperation with the UK Department for International Development (DFID) and the Australian Agency for International Development (AusAID), consists of the following components:

- Capacity development of the SADC Water Division;
- Capacity development of the river basin organizations (RBO); and
- Capacity development of local water governance and transboundary infrastructure.

The activities of this Consultancy, "Support to Phase II of the ORASECOM Basin-wide Integrated Water Resources Management Plan", being undertaken by WRP (Pty) Ltd and Associates, contributes to Component 2 above. The work of Phase 2 comprises six work packages, as briefly outlined in **Section 1.3.2.2** below

1.3.2 Support to Phase 2 of the ORASECOM Basin-wide Integrated Water Resources Management Plan

1.3.2.1 Objectives of the Overall Consultancy

The main objectives of this consultancy are to enlarge and improve the existing models for the Orange-Senqu Basin, so that they incorporate all of the essential components in the four Basin States and are accepted by each Basin State. These models must be capable of being used to meet the current and likely future information needs of ORASECOM. These needs will likely encompass additional options to achieve water security in each Basin State. The models should be able to simulate changing configurations for water supply and storage infrastructure to ensure that ORASECOM is able to demonstrate that its operations are aligned with the principles embodied in the SADC Water Protocol.

1.3.2.2 The Six Work Packages

In order to contribute to the realisation of the above-mentioned objectives, the project includes six work packages as outlined in **Table 1-1.** The first of these work packages is central to Phase 2 of the IWRM Plan and will also be at the core of the final plan to be developed in Phase 3. In work package 1, the WRYM water resources simulation model is being updated and expanded to cover the entire basin.

Table 1-1 Summary of Work Package Objectives and Main Activities

Work Package	Main Objectives	Main Activities
WP 1: Development of Integrated Orange-Senqu River Basin Model	To enlarge and improve existing models so that they incorporate all essential components in all four States and are accepted by each State	• Extension and expansion of existing models • Capacity building for experts and decision-makers • Review of water balance and yields • Design/initiation of continuous review process
WP 2: Updating and Extension of Orange-Senqu Hydrology	Updating of hydrological data, hands-on capacity building in each basin state for generation of reliable hydrological data including the evaluation of national databases,	• Assessment of Required Improvements to the Existing Gauging Networks. • Capacity Development • Extension of Naturalized Flow Data • Review of Existing Data Acquisition Systems, proposals on basin-wide data acquisition and display system.
WP 3: Preparation and development of integrated water resources quality management plan	Build on Phase 1 initial assessment to propose water quality management plan, based on monitoring of agreed water quality variables at selected key points	• Establishment of protocols, institutional requirements for a water quality monitoring programme, data management and reporting. • Development of specifications for a water quality model that interfaces with the systems models. • Capacity building to operate the water quality monitoring system and implement the water quality management plan.
WP 4: Assessment of global climate change	Several objectives leading to assessment of adaptation needs	• Identification of all possible sources of reliable climate data and Global Climate Model downscaling for the Orange-Senqu Basin • Scenario assessment of impacts on soil erosion, evapotranspiration, soil erosion, and livelihoods • Identification of water management adaptation requirements with respect to observed/expected impacts on water resources • Assessment of major vulnerabilities and identification of measures for enhancing adaptive capacities
WP 5: Assessment of Environmental Requirements	Several objectives leading to management and monitoring system responsive to environmental flow allocations	• A scoping level assessment of ecological and socio-cultural condition and importance • Delineation into Management Resource Units and selection of EFR sites. • One biophysical survey to collate the relevant data at each EFR site and two measurements at low and high flows for calibration. • Assessment of the Present Ecological State and other scenarios • Assessment of flow requirements, Goods and Services, and monitoring aspects.
WP 6: Water Demand management in irrigation sector	To arrive at recommendations on best management practices in irrigation sector and enhanced productive use of water	• Establish a standard methodology for collecting data on irrigation water applied to crops, water use by crops and crop yields; • Document best management practices for irrigation in the basin and finalise representative, best-practice demonstration sites through stakeholder consultation • Consider and assess various instruments that support water conservation/water demand management.

The other work packages are both self-standing and intended to provide inputs to an improved and more complete water resources simulation model for the whole basin. The model will be enhanced by a more complete hydrology (WP2), better and more complete water quality information (WP3), allowance for climate change impacts and adaptation (WP4), inclusion of environmental flow requirements at key points (WP5) and modelling of scenarios, with improved water demand management in the key irrigation sector (WP6).

1.3.3 Background to Work Package 6 and this Working Paper

1.3.3.1 Work Package Objectives

The overall objective of the work package is to attain an overall understanding of how better management practices could reduce water demand in the irrigation sector in the Orange-Senqu River Basin, and to make recommendations on improved water demand management in this sector in the future. In order to reach this goal, a number of sub-objectives were identified in the terms of reference:

- Building up of a GIS Database irrigation inventory through the collection and collation of information regarding irrigation areas, and the use of irrigation water by crops and crop yields;
- Assessment of various instruments for enhancing productive use of water, e.g. water markets and their operation in a local, as well as trans-boundary, context;
- Detailing the best management practices for irrigation in the basin; and
- Selection and evaluation of demonstration projects of best practices at suitable sites.

1.3.3.2 Work Package Activities

- Collect and collate previous studies on water conservation and demand management in the in the Orange-Senqu River basin;
- Identify caveats/pitfalls related to the practical implementation of results of these previous studies in the basin;
- Establish a standard methodology for collecting data on irrigation water applied to crops, water use by crops and crop yields;
- Building up of a GIS Database irrigation inventory through the collection and collation of reliable and detailed information about the use of irrigation water by crops and crop yields;
- Document best management practices for irrigation in the basin;
- Consider and assess various instruments that support water conservation and demand management;
- Hold stakeholder workshops; and
- Finalise and evaluate representative, best-practice demonstration sites; and make recommendations on how the generalisation of best management practices could improve water conservation and water demand management in the sector.

1.3.3.3 This Working Paper

This working paper reports on activities c) and d) and provides findings, conclusions and recommendations. Obtaining a clear picture of the irrigation sector is fundamental to optimising the management of the sector. The irrigation sector is, by far, the largest user of water in the basin with current use estimated to be 3,624 Mm^3/annum. Return flows are not accurately known for all schemes but are estimated at 13% on average for the main irrigation areas.

It is anticipated that areas under irrigation will continue to increase in some areas of the basin, most notably in the Lower Orange where the Namibian demand, mainly for high value export crops, may quadruple by 2025 to more than 300Mm^3. South African demand from the lower Orange is also predicted to increase albeit more slowly, but could rise from the current 1891 Mm^3 to more than 2,000 Mm^3 by 2025. In South Africa, between 2006-2008 the South African Department of Agriculture, Forestry and Fisheries (DAFF)-field crop boundary survey and the project 2009-2010 survey some 22,000 Ha of additional and/or “change of use to Centre Pivot” irrigation has been recorded.

This report describes the work undertaken on mapping the extent of land probably irrigated, or equipped for irrigation. The words “probably irrigated” or “equipped for irrigation” are used because it was apparent that some centre pivots showed up as fallow at all times, but nevertheless had the potential for use.

It is to be noted that one of the fundamental aims of this survey of crop water demands was to update the baseline (2009) crop water demands for the Water Resources System Simulation model. The most recent studies, using the Water Resources System Model, were apparently based on data provided in approximately 2001 and this data has been reviewed as part of the study.

In view of the fact that thousands of individual demands have been aggregated for modelling purposes there will be some discrepancies with respect to individual field crop boundary’s identified. The Water Resources System models can be used to explore many future possible scenarios for irrigation water demands. The precision for the baseline is only one factor in predicting impacts of changes in demand for water for agriculture over future planning periods. The project provides a tool to assist with predicting demands in future scenarios. The information available to generate scenarios includes:

- South African Department of Agriculture, Forestry and Fisheries (DAFF) field crop boundaries for 2006-2008;
- DAFF field crop boundaries updated by the project for 2009-10; and
- WARMS water use registration database for January 2010.

The DAFF 2006-08 study mainly identified irrigation as only “centre pivots”. The updating undertaken by the project attempts to identify: new centre pivots, new field crop boundaries and existing field crop boundaries under irrigation during 2009-10. The study also includes

Botswana, Namibia and Lesotho. A coarse qualitative inventory was prepared for Lesotho but the areas involved tend to be relatively small and, for the purposes of use in future scenarios, it is considered more appropriate to use the official plans and proposals for irrigation in Lesotho.

One of the most important scenarios is to assume that, over a period of time, all licensees take all of the water licensed, based on the crops actually licensed, and using the irrigation technologies specified. Taking this scenario as a baseline, it is possible to determine what changes in cropping pattern and irrigation technology might be possible using incentives (e.g. financial, technical – providing information to farmers using satellite technology to improve operational and economic efficiency), and regulations. This might also include speculation on market forces and ‘out of the box’ thinking – including relying on sourcing fodder and grain staples outside South Africa.

Given the above, the consultants are of the opinion that the cost effective approach used to update the DAFF field crop boundaries, and to map irrigated areas, has produced results of sufficient reliability to use in developing scenarios for irrigation planning

1.4 Implementation of Work Package 6

The work package 6 was executed primarily by a multi-disciplinary team supplied by WRP, Beuster Clark Associates and Golder Associates. Beuster, Clark Associates (BCA) was contacted by WRP to map all irrigation in the Orange River and Vaal River basins, using satellite imagery. The approach was two-pronged involving mapping the extent of areas either irrigated or equipped for irrigation; and, then producing an irrigation database containing information on crop patterns and Crop Water Requirements (CWRs). The latter to be used in estimating current and forecast (under alternative development scenarios) crop water requirements and summary economic values.

1.5 Approach Adopted

The approach adopted was first to establish the extent of irrigated areas and then to aggregate these areas, according to the water demand units used in the Water Yield and Allocation Model (WYAM). Once the aggregated irrigated area was established to each WYAM the current WARMS database was used to determine the proportions of irrigated land, for each aggregate unit licensed, for each crop.

The consultants proposed to use remotely sensed satellite imagery to map the extent of irrigation. This was supplemented by access to the DAFF Field Crop Boundaries (FCB) for South Africa GIS coverage for 2006 to 2008[1]. It was also proposed to consider the potential for extracting more than the official extent of irrigation, as a precursor for a follow-up study mapping crop extents using remote sensing. A proposal for such an activity has been

1 The Field Crop Boundaries mapped by DIA using SPOT 10 and 20 metre resolution satellite imagery for the period 2006 to2008, and manual digitizing.

prepared. The presentation of the results of the current mapping has been presented in such a way as to facilitate comprehensive crop mapping in the future. A key element of this would be the regular acquisition of 'ground truth'[2] for each satellite 'Tile' acquired (and to be acquired in the future).

The mapping of irrigated areas using remote sensing was accomplished using automatic (hard) classification procedures within the IDRISI image processing software This was supplemented by visual examination of the Standard False Colour Composite images[3] for each scene. Before deciding on the best approach to classification, a number of different classifiers were evaluated.

This report only deals with the estimation of areas believed to be irrigated or equipped for irrigation. The words 'believed to be irrigated' and 'equipped for irrigation' are used because, when using remote sensing methods, it is not all that easy to be absolutely sure that an area is being irrigated, and/or it is 'equipped for irrigation', and, as set out in the consultants' proposal, an evidence based approach was considered; with the possibility of combining the evidence from the multi-temporal imagery with other evidence, such as: the shape of the field crop boundary; proximity to water sources (farm dams, rivers); issuance of WARMS registrations (these have a point location); land slope; mean annual rainfall; and expert knowledge of the irrigated agriculture by team members. The automatic classification of the satellite imagery was only the first step in the process because, without extensive ground truth, it is difficult to distinguish always between irrigated, partially irrigated and non-irrigated land parcels, despite having multi-temporal imagery. To assist with separating out confusing classifications additional evidence was considered.

[2] Groundtruth is the obtaining of information on actual crops planted at various times and stages of growth in a representative sample of 'field crop boundaries –(FCBs).

[3] A standard false colour composite (FCC) image is constructed by placing an infrared band (usually band 4 of Landsat) into the red colour of a computer display, the red band (band 3) into the green colour of the display, and the green band (band 2) into the blue colour. In an FCC healthy vegetation shows as a red colour, bare soil as cyan. This is because healthy vegetation reflects the infrared light strongly.

2 SATELLITE IMAGERY USED AND ACQUIRED

2.1 Satellite Imagery Available

There is currently a wide range of satellite imagery available. Much of it, however, is beyond the budget available for this project. The satellite imagery considered included:

- Landsat imagery available from the USGS (through the GLOVIS viewer)
  - Landsat archive
    - Landsat 7 SLC-off 2003 to present
    - Landsat 7 SLC-on 1999-2003
    - Landsat 4-5 TM
    - Landsat 4-5 MSS
    - Landsat 1-3 MSS
    - Terralook ASTER 2000 to present
  - Landsat legacy Collections
  - ETM +Pan mosaics
  - TM – Mosaics
  - ETM –1999-2003
  - TM – 1987-1997
  - MSS 4-5 1982-97
  - MSS 1- 3 1972 - 83
- SPOT Image data
  - DAFF obtained 20metre resolution SPOT multi-spectral pan-sharpened (10metre) imagery for RSA for the period 2006 to 2008; this formed the basis for the DAFF Field Crop Boundary data used by the project. A request was made to obtain this imagery but it was not possible for it to be provided.
- Google Earth imagery
  - This was used to supplement the interpretation of the Landsat imagery
- ESAD MrSID
  - 1990 – see Appendix A
  - 2000 – see Appendix A

Since the main objective was to update the DAFF field crop boundary mapping with respect to irrigated areas, the main source of imagery used was the Landsat 7 – ETM+ for 2009 up to 2011. As far as possible, the whole USGS archive for this dataset was downloaded and is provided as an output to the project. It was, however, impracticable with the resources available for processing to process every scene downloaded.

2.2 Selection of Satellite Imagery

Landsat images were obtained from the United States Geological Survey (USGS) using the GLOVIS interface. These images are freely available at the USGS but the files are very large (200 to 300 Megabytes). Due to the large number of images that are required, downloading this volume of data can therefore be problematic. Approximately 550 Gigabytes of raw and processed imagery are located on an external hard drive in 3 folders, namely *\orange_river\2000* ; *\orange_river\2005* and *\orange_river\2009*. After examination of the imagery, it was decided that only the 2009 and 2010 images (both located in the 2009 folder) would be analysed in this study. The 2000 and 2005 images were also downloaded in the event they would be required to determine future growth in irrigated area. These data were used to obtain a time series of irrigated lands for a quaternary catchment. They are available on the external hard drive.

Note. Each image is compressed (in GZ format). This file must first be uncompressed to create a single .TAR file. A second stage of uncompression on the .TAR file will create 9 .TIF files. Each TIF file represents a separate band width that comprises the image. The format of each file is image location_date_band number. The 6 bands that were used in this analysis are band 1 (_B10), band 2 (B20), band 3 (B30), band 4 (B40), band 5 (B50) and band 7 (B70). The other bands are not appropriate to use when classifying vigorously growing vegetation.

It was decided to use data from the LANDSAT 7 with 'slcoff' as the basis for determination of irrigated areas. The implication of 'slcoff' is that sometime during 2003 the part of the sensor system that allowed for the effect of the movement of the satellite on the scanning process failed, and the resultant images have strips of image missing. Up to 30% of the image is missing. It was, however, possible to obtain a time series of scenes for most tiles. Since the project was supplied with the DAFF Field Crop Boundaries for the period 2006 to 2008, it was also possible to use these to fill in missing values for selected scenes. An overlap of approximately 30% exists. The extent of each satellite image (or scene) is referred to here as a 'TILE'.

Figure 2-1 indicates the location of each satellite image, only the path and row numbers are given that identify each tile. For each tile a number of different 'SCENES' have been acquired. Each scene represents a different time. Within each scene of Landsat, taken at different times, there are 9 images ('BANDS') representing different wavelengths of energies reflecting or radiating from the surface of the Earth. The file name given to each scene name includes the date of acquisition, path number, and row. The path number comprises the column and row number.

Satellite imagery was available at different times over the period 2009 to 2011 year at the same "tile" location. Up to 20 scenes for an individual tile were acquired, though not all of them were used. This enables classification of irrigated areas to take place at different times of the year. An attempt was made to use at least 4 'scenes' at each "tile" location so that irrigated crops grown during different seasons would be identified. This was not, however, always possible due to unavailability of specific images from the USGS (images containing missing data, and images also covered in cloud). The satellite images that were used are located in the folders coded as *orange_river\2009\"pathnumbers"\"dates"\"file.tif".*

Nine .tif' files make up a scene. A scene is located in a folder showing:

\project\year\path-row\and date.

An example would be:

\orange_river\2009\p170-r79\20090518\170079_07920090518_B10.tif.

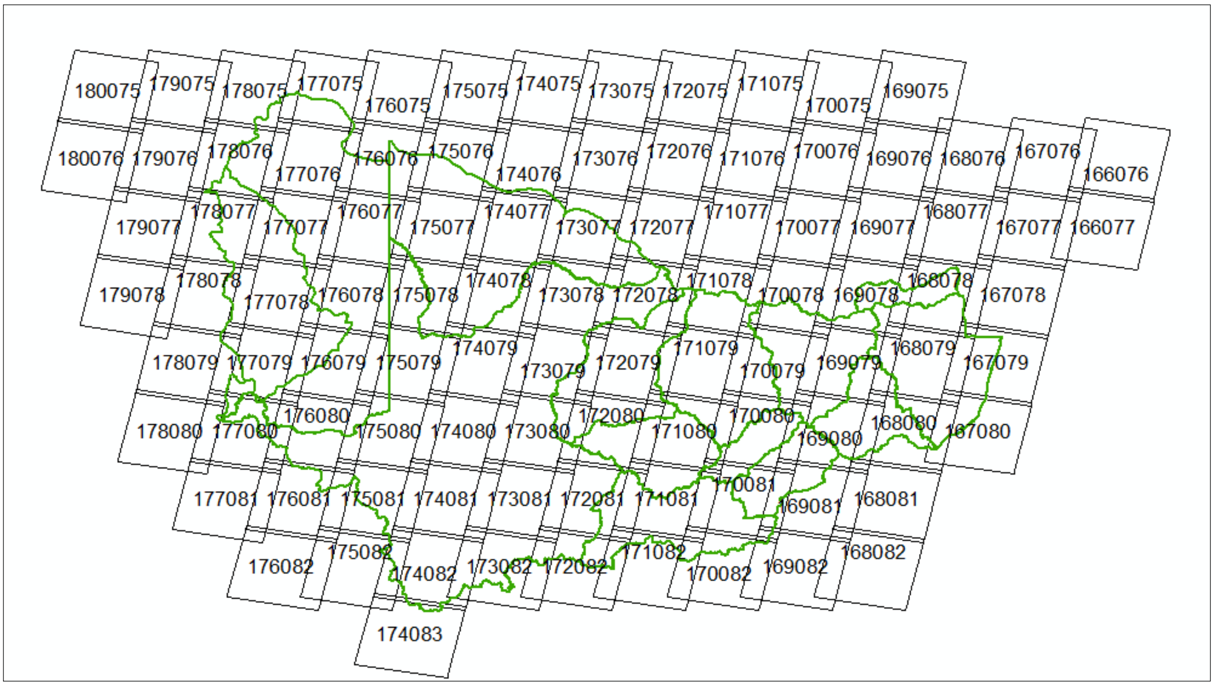

Figure 2-1: Location and Full Extent of Satellite Image Tiles that Cover the Orange-Senqu River Basin

3 IMAGE PROCESSING

The IDRISI Image processing and GIS software was used in the processing of satellite imagery.

The study area was divided into two parts - Paths 169 to 172 and paths 173 to 178. These represent the divide between where mixed rainfed and irrigated agriculture takes place, and where all crops have to be irrigated due to low annual rainfall (less than 400 mm annually).

3.1 Processing of Irrigated Agriculture (Western Portion)

3.1.1 South Africa

A combination of 'hard' classifiers and visual interpretation of the FCC, and the other imagery available, was used to map irrigated areas in the areas covered by paths 173 to 177. This area is almost entirely in the region where mean annual rainfall is less that 400 mm. Within South Africa, the DAFF field crop boundaries for the dry western part of the basin are assumed to correspond to the irrigated areas, since dry-land agriculture is not possible. This simplifies any automated classification procedures.

Some areas (mostly centre pivots) outside of the DAFF field crop boundaries were identified manually and these are summarized in **Table 3-2.**

Details of the approach are summarized in **Section 3.1.3.**

Table 3-1: Summary of Area of Irrigation in South Africa additional to that Falling Within DAFF Crop Field Boundaries (2006-2008)

Irr Zone	SubBasin	Description	AgroZone	AREA Ha
BO	Middle Orange	Ongers	G10	19
KU	Molopo Nossob	Kuruman	G6	624
O15	Middle Orange	Orange-Vaal confluence to Boegoeberg Dam	G8	1080
O16	Middle Orange	Boegoeberg Dam to Upington	G9	57
O17	Middle Orange	Upington to Neusberg	G9	60
O18	Lower Orange	Neusberg to Namibia border	G9	94
O19	Lower Orange	Namibia border to Onseepkans	G9	278
O4	Upper Orange	U/S Gariep, D/S Aliwal North	G3	12
O20	Lower Orange	Onseepkans to Vioolsdrift	G12	144
O22	Lower Orange	Orange-Fish confluence to river mouth	G12	392
O6	Upper Orange	U/S Van der Kloof, D/S Gariep	G3	75
O7	Upper Orange	Canals ex Van der Kloof Dam	G7	397
O9	Upper Orange	Van der Kloof Dam to Douglas	G7	907
V1	Upper Vaal	U/S Grootdraai Dam to Vaal Dam	G4	268
V10	Lower Vaal	Vaal and Riet U/S of confluence with Orange	G7	1976
V2	Upper Vaal	Wilge, Liebenbergsvlei Rivers	G2	53
V4	Middle Vaal	Barrage to Bloemhof Dam	G4	524
V5	Middle Vaal	Sand and Vet Rivers	G5	970
V6	Lower Vaal	Bloemhof Dam to Schmidtsdrift	G5	5496
V7	Lower Vaal	Harts River	G5	848
V8	Lower Vaal	Riet River	G7	466
V9	Lower Vaal	Modder River	G5	598
O2	Caledon	U/s Gariep, D/S Welbedacht Dam	G3	48
MU	Molopo Nossob	Molopo	G6	2356
CALR	Caledon	Lower Caledon tributaries (RSA)	G3	31
OUL	Upper Orange	Orange tributaries - Van der Kloof to Douglas	G7	28
OUU	Upper Orange	Orange tributaries U/S Van der Kloof	G3	630
OLU	Lower Orange	Lower Orange D/S Onseepkans	G12	158
CAU	Caledon	Upper Caledon tributaries	G2	16
18619				

* This includes conversion of previously irrigated irregular fields to center pivots

3.1.2 Namibia and Botswana

Field boundaries for irrigated areas in Namibia and Botswana were digitised manually and added to the database and are included in **Table 3-2**. Details of the approach are summarized in **Section 3.1.3.**

3.1.3 Manual Identification of Additional Field Crop Boundaries

The objective of the manual identification was to both update the South African DAFF field crop boundaries, and also to map irrigated areas in Namibia, Botswana and Lesotho (as of 2009-2011). It was decided here to use manual/visual interpretation of a combination of Landsat 7 images, ASTER[4] images and images found on Google Earth. All information found on Google Earth was updated using 2009-2011 Landsat images. The ASTER images gave a view of key parts of the land cover over the period 2006 to 2009 (at 4 times the resolution of the Landsat data). It is noted here that, although a request was made to obtain the SPOT 10-20 metre resolution images for 2006-2008 used by DAFF to map Field Crop Boundaries, it was not possible to obtain these data.

The Google Earth images at a resolution of from 2.5 to 0.6 metres in natural colour were dated from 2000 to the present. By using the “time slicer” it is possible in Google Earth to identify the date of the image being viewed and even to select a date from any image available at a given time and place. In general, the latest image date for any view was used. In any case, the information was updated using public domain Landsat 7 imagery for 2009 to 2011.

Each and every one of 54 Landsat FCC images (one per tile) was examined visually. The 2006-2008 DAFF field crop boundaries were overlaid, with a view to identifying any Centre Pivots not previously identified. In the case of Botswana and Namibia, an attempt was made to identify areas on the FCC and classified images that “looked” as if they may be cultivated and/or irrigated. It was assumed that if cultivated, then some form of irrigation may have been attempted. In any case, the areas mapped were extremely small in the context of the basin as a whole, but very important to the countries concerned. For Lesotho, the FAO global irrigation map was overlaid on the country, and the riparian areas scanned visually using Google Earth imagery. This did not produce much of value and it would appear that an “on the ground” survey, supplemented by any official irrigation mapping, is required if an accurate map of irrigation is to be obtained.

The areas were derived from manual identification and digitising from 2009 or 2010 False colour composites (FCC) supported by supplementary observations from Google Earth (for smaller areas). The original projections of the data were Geographic coordinates, WGS84. For computing areas, the data was projected onto UTM 34N using WGS84. The areas were aggregated for each irrigation zone identified for modelling, using the ARCGIS function “spatial join”, summing areas in Hectares. The “possibly irrigated” areas identified for Lesotho were not included (but are available). Some areas in Botswana are very hard to identify as being “possibly irrigated”.

[4] ASTER - (Advanced Spaceborne Thermal Emission and Reflection Radiometer)

The 18,619Ha in South Africa includes new Centre Pivots on 'unused' land in 2006-2008 and areas recorded as 'change of use'. This suggests that a field crop boundary identified by DAFF from 2006-2008 imagery had apparently been changed to 'Centre Pivot' by 2009-2010.

3.2 Processing Mixed Irrigation and Rainfed Agriculture

3.2.1 The Use of IDRISI Software to Classify the Satellite Imagery

Only 6 of the 10 '.TIF' files (spectral bands) that comprise each image were imported to the IDRISI format. These are the 6 bands that are useful for the classification of healthily growing vegetation. The data for each scene are downloaded as a nine geo-tiff format files and some metadata. Each image has been ortho-rectified/georeferenced (at source) using satellite information and a DEM. As a result, they have good locational properties and overlap with each other very well. For the purposes of classification, it was decided to use only the 30 metre resolution multi-spectral data (bands 1, 2, 3, 4, 5, and 7). These bands were imported into IDRISI (.RST) format. This process creates several files for each band. The most important files are the .RST files (a raster file where each pixel representing a 30 meter by 30 meter square on the ground contains a signature that describes the reflectivity of a band). This process was performed using a macro listed in the folder *\orange_river\macros\import_images* which converts the .tif files to 6 .rst files, namely bands 1,2,3,4,5 and 7. An example would be:

\orange_river\2009\p170-r79\20090518\170079_07920090518_B10.rst.

Once the 6 rasterised files are created the IDRISI software was used to firstly create a Standard False Colour Composite (FCC) image and then to create a "classified" image (a number of methods were used to perform this classification).

3.2.1.1 False Colour Composite (FCC)

A False Colour Composite is created using 3 bands with a "false" colour filter. Band 2 (green) is passed through a blue filter, Band 3 (red) is passed through a green filter and Band 4 (infra-red) is passed through a red filter. This composition is important as it provides a map which best shows all vigorously growing vegetation as pink and red. The FCC is therefore used as "ground truth" for the classification process.

Note. The FCC does not have signatures assigned to each pixel. It is simply a visual representation of green vegetation which shows as red on the FCC.

An example would be *\orange_river\2009\p170-r79\20090518\234_fcc.rst*. In order to see the FCC, the IDRISI software must be initiated and the correct project selected. Each tile is located in a separate project identified by date, in this case *20090518*.

3.2.1.2 Image Classification

The IDRISI software includes a number of image classification methods. Due to the lack of ground truth available, “hard classification methods” were chosen. The following methods for unsupervised and supervised classification were evaluated:

- Cluster - Histogram peak clustering technique;
- ISOCLUSTER – Iterative self organizing cluster analysis;
- ISODATA – iterative self organizing data analysis;
- KMEANS – K-means cluster analysis;
- MLP – Multi-layer perception (back propagation) neural network classifier (needs training area data – ground truth);
- SOM – Self organizing Map for neural network classification, (needs training area data – ground truth).

These methods use a process in which the IDRISI software combines any combination of bands chosen by the user and assigns a signature (derived from combining the reflectivity of each selected band) to each pixel. The software then groups pixels with similar pixel signatures into classes. Parameters define the number of classes to be included.

After evaluating a number of classification methods (see above), it was decided to concentrate on two of them, namely the Kmeans and Cluster methods. Kmeans is often cited in literature as providing a “satisfactory” classification, but is very slow compared to the Cluster method which is very fast. It should also be noted that the main aim was to basically find only two classes – under irrigation or not.

Kmeans

The Kmeans Method included a “fine” and “broad” classification. Using the “fine” classification creates a larger number of classes (approximately 40) while the “broad” classification provides approximately 10 to 16 classes. Problems are sometimes associated with smaller number of classes, as the software combines larger numbers of pixels with similar signatures, and this process can sometimes group irrigated and non-irrigated areas of healthy growing vegetation in the same class. For this reason, the cluster method was also used.

Cluster

The cluster method creates between 60 and 100 classes and clearly separates pixels from irrigated crops from pixels representing rain-fed crops or vigorously growing natural vegetation. This method therefore enables the user to have more control in selecting classes that define irrigated crops only.

Selection of the Best Method

The three methods (kmeans , clusters fine and clusters broad) were compared to the FCC, to select, firstly, the best method and secondly, to identify the classes that represent irrigation. This process involved grouping the classified images with the FCC image enabling the user to "zoom in" on the same field on all the images to undertake this comparison. This process is simplified by using the MAP COMPOSER facility in IDRISI to overlay the field crop boundary vector layer.

An example of a group file is found in the same folder i.e. *\orange_river\2009\p170-r79\20090518\fcc_km_clus.rgf.* The IDRISI software must first be initiated, the correct project selected (20090518) and the 3 raster files opened by first selecting the group file (fcc_km_clus). The field crop boundary vector layers are located in *orange_river\Vector_idrisi_vct_dia_dwaf_slc_utm* and the correctly transformed file is *DIA_FCB_UTM35N.vct*

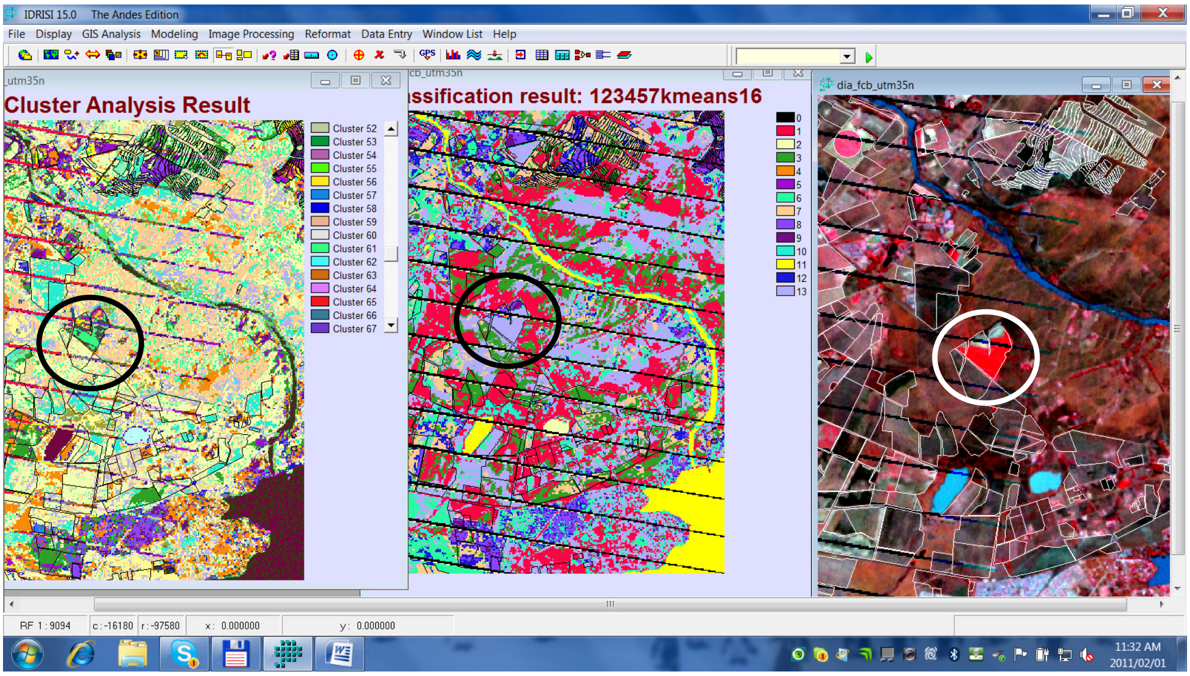

Figure 3-1: Comparison of the FCC, kmeans (broad) and Clusters Classification

Figure 3-1 shows a comparison of the FCC, kmeans (broad) and clusters classification. A bright red field is clearly visible in the centre of the FCC (the image to the right in **Figure 3-1.** This represents vigorously growing vegetation and since the image was taken in mid May (dry season) it is most likely an irrigated crop. The image in the centre of **Figure 3-1** is the kmeans classification and has classified the same field in class 13. However, class 13 also includes surrounding natural vegetation and crops so the kmeans classification is clearly too broad. The image on the left of **Figure 3-1** is the clusters classification and the same field has been placed in class 61, which is unique (class 61 only occurs in this field). In fact, the cluster analysis identifies 3 unique classes which are located in this field, namely class 33, 41 and 61.

3.2.1.3 Identification and Selection of the Correct Class

By zooming in to different locations across the image the user is able to select the classes that best represent irrigation. As mentioned in the previous section, classes 33, 41 and 61 from the clusters classification were chosen to best represent irrigated crops in that tile. These selected classes are then retained, and all other classes ignored, to create a new image that illustrates vigorously growing/irrigated crops only. **Figure 3-2** shows the selected pixels over the portion of the image displayed in **Figure 3-1**. All three classes (33, 41 and61) are now shown in the same colour: red. The FCC is included for comparison purposes. This new image, showing vigorously growing/irrigated crops, is located in all the tile folders, where image processing was undertaken and represents the last step using the IDRISI software. Using the same example, this file is located and named *\orange_river\2009\p170-r79\20090518\clus_class33_41_61.rst*.

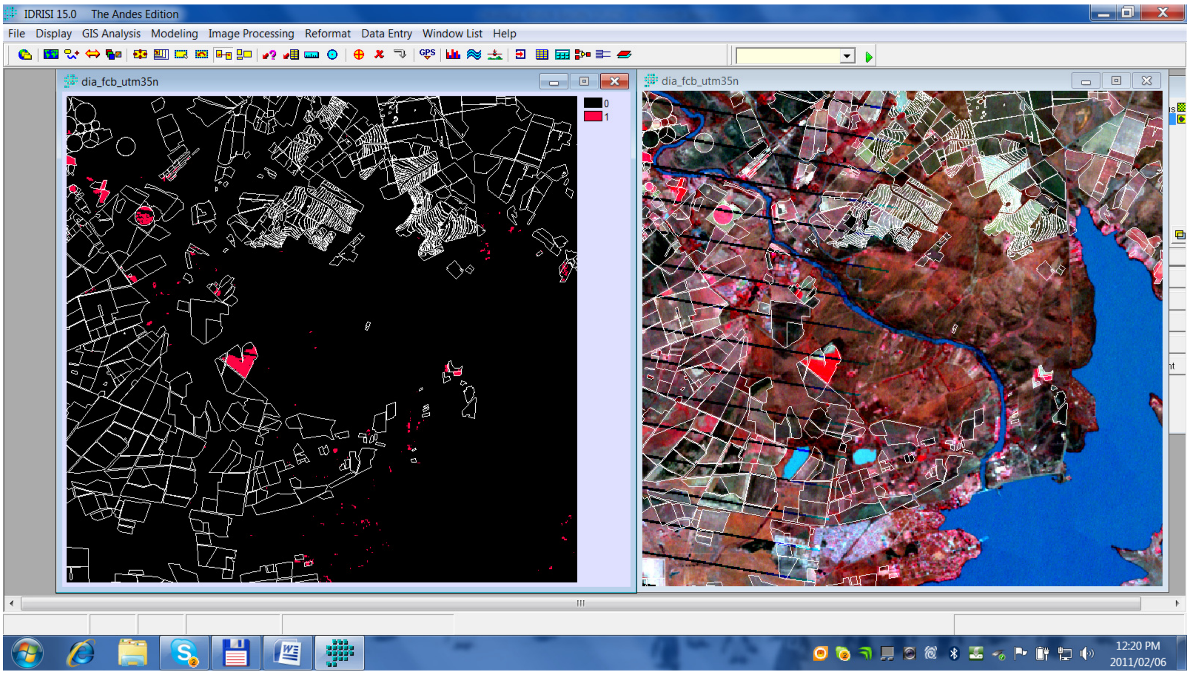

Figure 3-2: Selected Pixels showing Vigorously Growing/Irrigated Crops

The next step involved manipulating this classified image using ArcGIS. All classified images were immediately copied from their current location *\orange_river\2009\p170-r79\"date of image"\class number.rst* and all GIS manipulations of these classified images are located in the folder *\orange_river\classification\"tile number"\"date of image"\"filename"*.

It should be noted that a large number of files are located in some of the tile folders. This is due to methodology changes that took place before the current method was adopted. A great deal of experimentation took place in an effort to find the most effective classification method. These include a method initially explored where the image was firstly divided into four quadrants, then masked with the field crop boundaries, before interpolating to fill in missing data. An example for the top right quadrant would be *\orange_river\2009\p172-r77\20091124\172077_07720091124_B10_TR.rst* for the rasterised file,

\orange_river\2009\p172-r77\20091124\MASK_B10_TR.rst for the masked file and *\orange_river\2009\p172-r77\20091124\B10_TR_INT.rst* for the interpolated file. These files are for the top right quadrant only. In addition, there are corresponding .rdc files (a descriptive file) for each .rst file.

3.2.2 ARCGIS

The rasterised file showing pixels classified as vigorously growing/irrigated crops was imported to the ArcMAP module in ArcGIS. An attribute table is created where all classified irrigation is assigned a "1" and all non-irrigation is labelled "0" and overplayed with the field crop boundary in a process that determines the area of vigorously growing/irrigated crops in each field crop boundary This process involves the following steps:

- Convert the field crop boundary from a vector shapefile to a rasterised file. This speeds up the combining of the field crop boundaries and classified rasterised images.
- The Tabulate Area function in the Zonal option under Spatial Analyst Tools in ArcToolbox was used to create an attribute table that contains the area of vigorously growing/irrigated crops in each field crop boundary.
- This attribute table was exported as a DBASE ('.dbf') table.

All the classified images are located in *\orange_river\classification\"tile number"\"date of image"* and the field crop boundaries are located in *\orange_river\fld_crop_bnd_latest\"fcb with correct utm".* An example of the output is *\orange_river\classification\170_079\ 20090518\170079_20090518_class33-41-61.dbf*

3.2.3 Classification Process

The classified image presented in **Figure 3-3** clearly shows how the classification process often results in varying proportions of each field being classified as vigorously growing. The centre pivot located bottom right (circled in red) is approximately 70% classified as vigorously growing, while the centre pivot top centre (circled in yellow) is less than 10% vigorously growing. The '.dbf' file that defines each field with a unique ID also lists the actual area of vigorously growing vegetation (value_1) and non-vigorously growing vegetation (value_0) in each field. An example of this .dbf table (the information in the table is not related to the same fields shown in the diagram) is located to the left of **Figure 3-3**. It is noted that where there is missing data due to 'slcoff' the resultant classified area will be affected. This is evidenced in the centre pivot at the lower right of **Figure 3-3.**

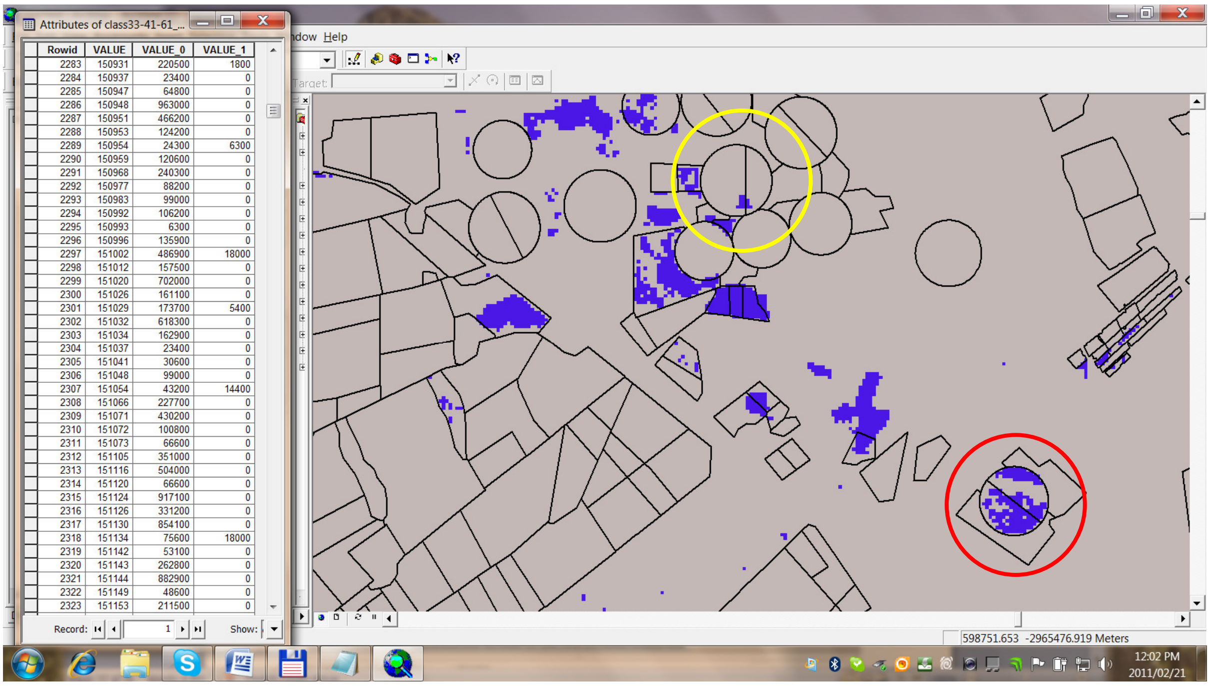

Figure 3-3 Extent of Vigorously Growing Vegetation Classified in each Field.

3.2.3.1 Strict classification versus less strict classification

During the class selection process, it became evident that it was necessary to define a variable percentage of cover to determine if a particular field would be classified as irrigated or not. The crops to the east of the Vaal Basin are often grown during the rainy summer months, so only complementary irrigation and sometimes no irrigation is required. In an attempt to separate the rain fed crops from those that are irrigated, a very strict classification was occasionally used. If the classification of a particular image was strict (i.e. only the most vigorously growing vegetation identified), then a low percentage of 30% was used. This implies that a field would be identified as irrigated if 30% or more of the field was classified as irrigated. If the classification was less strict, then a higher cut off percentage of (say 70%) was used.

3.2.3.2 Selection of images and variability within images

It also became apparent that certain images could be rejected, especially summer images which included significant areas of rain-fed crops. The effect of including/excluding summer images needed to take place in an iterative process, where the user is able to rapidly assess the results, necessitating a database type analysis.

In addition, it was necessary to identify the location of fields near rivers and/or within formal irrigation boards as they were more likely to be irrigated. Different criteria were therefore applied across a single image. Again, this was best achieved using a buffer system embedded in an ACCESS database that classified fields within these buffers more leniently than those outside the buffer.

3.2.4 Interactive Classification Tool

It became apparent that a tool was required which would enable all the above-mentioned requirements to be achieved. An Access database with an interactive tool, which allows a user to investigate the effects of remote sensing classification thresholds to distinguish between vigorously growing vegetation and irrigated crops, and location based screening rules which acknowledge:

- irrigation schemes;
- run-of-river abstractions along major tributaries; and
- known groundwater abstraction areas.

The tool will simplify future updating of estimates of irrigation areas as it encapsulates the methodology described above, provides a means to perform cross-checks against other sources of information (such as the WARMS), and to incorporate local knowledge about irrigation water sources.

The basic steps for using this tool are as follows.

- Import the '.dbf' file for each image;
- Define the cut-off percentage. The database calculates the percentage coverage of vigorously growing vegetation for each field, compares it to the cut-off percentage of that image scene to determine if a field was irrigated or not;
- Including the buffered areas which contain different decision criteria. All fields determined as irrigated from the remote sensing component were retained and fields other than centre pivots falling outside the buffers were assigned as "not irrigated";
- Identifying all centre pivot fields from the DAFF field crop boundary data and assigning them as "irrigated"; and
- Comparing the total irrigated area per irrigation zone with other sources of information such as the WARMS database and the reports on the Orange River (the *Orange River Development Project, Evaluation of Irrigation water use*) and Vaal River (the *Vaal River Basin Study, Evaluation of Irrigation*).

An example of this comparison is presented in **Figure 3-4.** The highlighted area shows irrigation zones in the Vaal catchment (V1 to V10). The summary also includes the total area of centre-pivots per irrigation zone (which is clearly the minimum area irrigated) and it is interesting to note that the area of centre pivots can differ significantly from the data sources (for example the area of centre pivots is 45.665 km^2 in V6 compared to a total irrigated area of 12.513 km^2 in WARMS).

6 - Compare Areas by Zones

ZONEID	COUNTRY	OSZONE	Description	Scheduled Area	WARMS Area	Centre Pivot Ar	OV Study Ar	RS Area	Screened Area
11	Lesotho	O1	Caledon U/S Welbedacht Dam			149		106	174
12	RSA	O15	Orange-Vaal confluence to Boegoeberg Dam	6 853	16 067	12 592	6 852	11 422	15 576
13	RSA	O16	Boegoeberg Dam to Upington	8 623	1 159	669	8 578	9 807	9 807
14	RSA	O17	Upington to Neusberg	13 163	13 723		13 163	11 536	11 536
15	RSA	O18	Neusberg to Namibia border	9 731	651		9 731	9 217	9 217
16	RSA	O19	Namibia border to Onseepkans	1 045	1 535		1 045	913	913
40	Namibia	O19	Namibia border to Onseepkans					273	273
36	RSA	O2	U/s Gariep, D/S Welbedacht Dam	4 775	3 280	2 239	3 482	1 359	2 979
18	RSA	O20	Onseepkans to Vioolsdrift	835	1 938		351	2 481	1 887
45	Namibia	O20	Onseepkans to Vioolsdrift					317	317
42	Namibia	O21	Vioolsdrift to Orange-Fish confluence	442			210	2 240	2 240
43	RSA	O21	Vioolsdrift to Orange-Fish confluence	442	316		210	324	324
41	Namibia	O22	Orange-Fish confluence to river mouth					181	181
19	RSA	O22	Orange-Fish confluence to river mouth	761	531	198	750	198	198
20	RSA	O3	U/S Aliwal North, D/S Oranjedraai	1 575	553	186	1 550	134	263
17	RSA	O4	U/S Gariep, D/S Aliwal North	2 560	2 970	911	1 940	854	1 465
21	RSA	O5	Kraai U/S Aliwal North	-999	970	450	-999	498	699
22	RSA	O6	U/S Van der Kloof, D/S Gariep	2 316	2 418	1 997	2 316	1 349	2 345
23	RSA	O7	Canals ex Van der Kloof Dam	17 378	322	4 420	17 378	3 454	4 474
24	RSA	O9	Van der Kloof Dam to Douglas	14 174	19 372	22 004	14 173	17 616	23 011
57	RSA	OLU	Lower Orange D/S Onseepkans		48			2 345	293
44	Namibia	OLU	Lower Orange D/S Onseepkans					392	6
46	RSA	OML	Middle Orange - D/S Boegoeberg		16 841	9		218	218
54	RSA	OMU	Middle Orange - U/S Boegoeberg		1 379			239	239
52	RSA	OUL	Orange tributaries - Van der Kloof to Douglas		311	889		891	889
999	Outside	OUTOFBASIN	Out of Basin					32	0
53	RSA	OUU	Orange tributaries U/S Van der Kloof		11 778	1 080		14 484	3 966
6	RSA	SER	Senqu (RSA)		509	24		993	52
25	RSA	SH	Sak River		16 451			16 071	11 758
26	RSA	V1	U/S Grootdraai Dam to Vaal Dam	7 279	20 674	14 899	7 279	7 667	15 202
27	RSA	V10	Vaal and Riet U/S of confluence with Orange	20 869	10 755	25 491	20 896	7 270	29 595
28	RSA	V2	Wilge, Liebenbergsvlei Rivers	5 517	24 006	15 262	5 517	9 229	16 232
29	RSA	V3	Vaal Dam to Barrage	9 008	14 150	8 640	9 008	8 679	15 671
30	RSA	V4	Barrage to Bloemhof Dam	16 586	43 120	28 585	15 646	21 818	33 981
31	RSA	V5	Sand and Vet Rivers	12 196	15 463	21 301	12 196	19 289	23 199
32	RSA	V6	Bloemhof Dam to Schmidtsdrift	50 277	12 513	45 665	47 392	17 540	69 523
33	RSA	V7	Harts River	1 783	16 526	18 120	1 763	6 073	20 406
34	RSA	V8	Riet River	4 234	6 793	4 714	8 391	1 737	5 303
35	RSA	V9	Modder River	3 564	22 824	22 527	6 371	9 770	27 470

Record: 41 of 50 No Filter Search

Figure 3-4 Comparison of Irrigated Areas per Irrigation Zone.

The Access database is located in the folder *\orange_river\database\Irrigation_v1.6.mdb* and the output is a shape file (*\orange_river\database\Irrigation_v1.6.shp*) showing all the classified irrigation areas. **Figure 3-5** indicates the irrigated areas differentiating between centre pivot and other irrigated areas, overlain on the irrigation and agro-economic zones. The dry land agriculture is also shown in a different colour.

Table 3-2 lists the final areas of irrigation (labelled screened areas in **Figure 3-4** for all the irrigation zones as derived from the remote sensing process. This includes only the areas falling within the field boundaries as defined by DAFF in South Africa, plus all the areas manually identified in the other three basin states. Once the additional areas as discussed in **Section 3.1**, and presented in **Table 3-1** are taken into account the figures increase slightly.

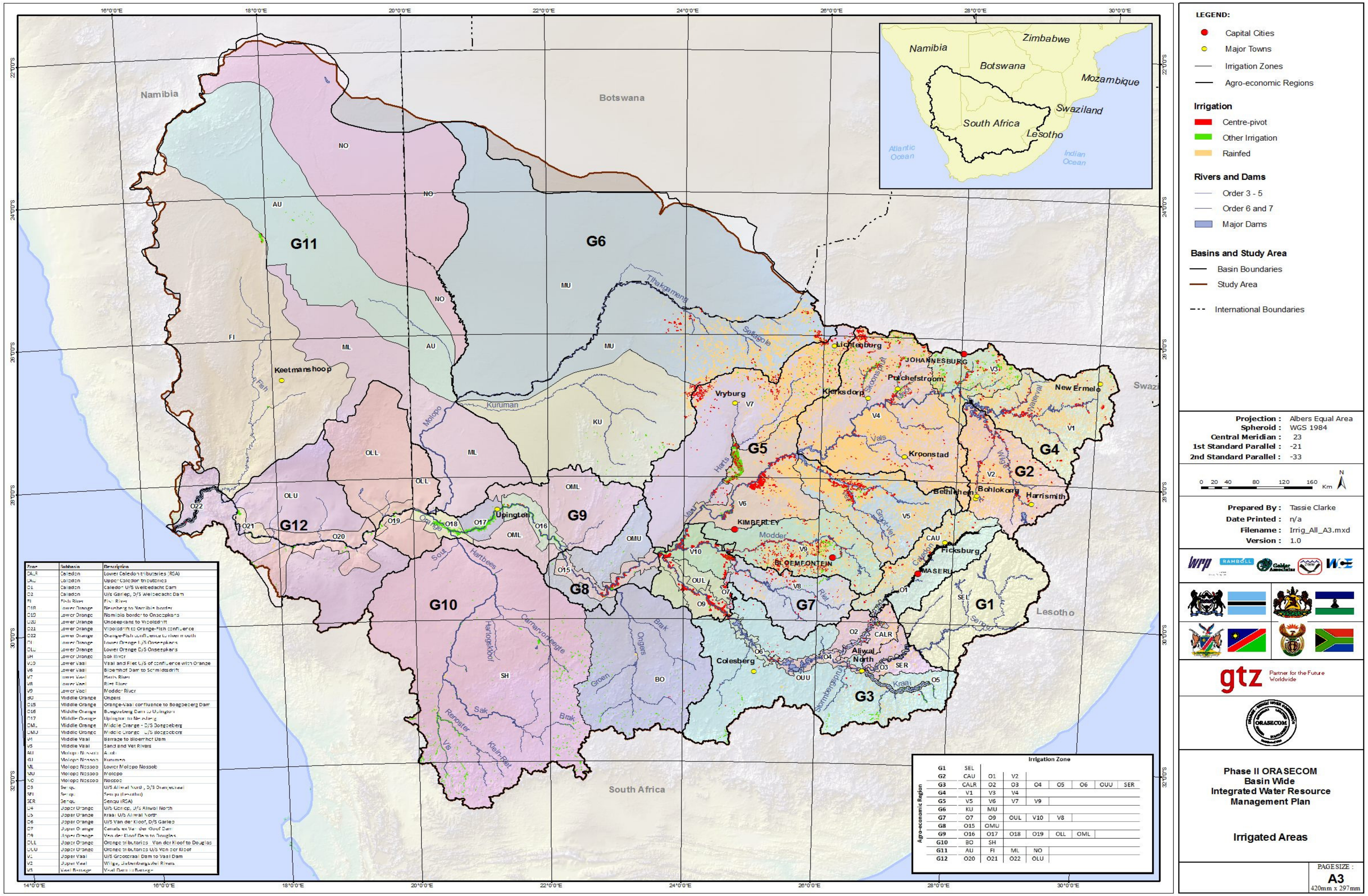

Figure 3-5: Areas of Irrigated (Centre pivot and other) and Rain-fed Agriculture

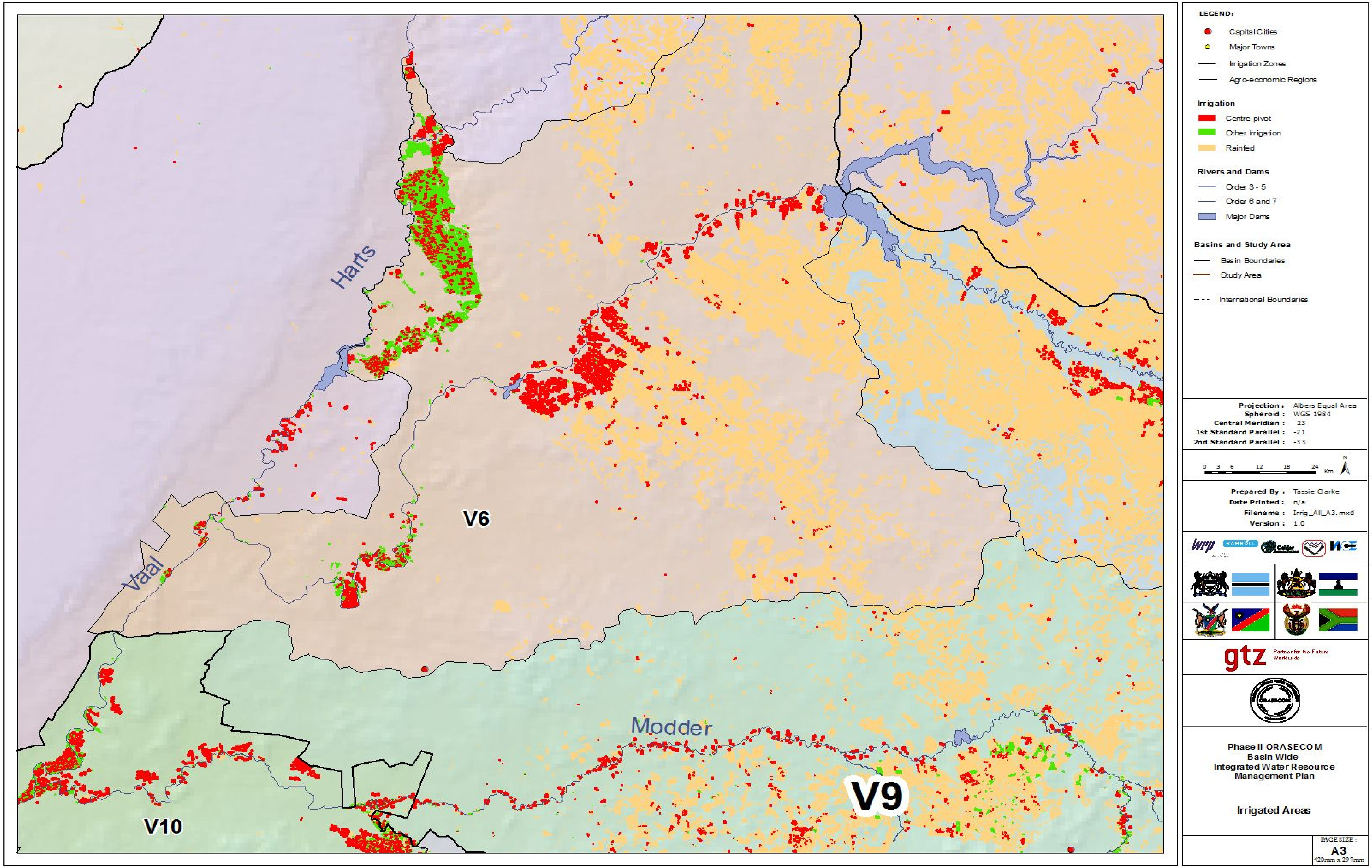

Figure 3-6: Close-up View of Areas of Irrigated and Rain-fed Agriculture along the Vaal, Harts and Modder Rivers

Table 3-2: Summary of Irrigation Area (ha) per Irrigation Zone

COUNTRY	ZONE	Description	Irrigated Area (ha)
RSA	BO	Ongers	1 456
Namibia	FI	Fish River	2 580
RSA	KU	Kuruman	3 635
RSA	SER	Senqu (RSA)	51
RSA	ML	Lower Molopo Nossob	7
Namibia	AU	Auob	582
Lesotho	O1	Caledon U/S Welbedacht Dam	174
RSA	O15	Orange-Vaal confluence to Boegoeberg Dam	15 576
RSA	O16	Boegoeberg Dam to Upington	9 806.
RSA	O17	Upington to Neusberg	11 535
RSA	O18	Neusberg to Namibia border	9 216
RSA	O19	Namibia border to Onseepkans	912
RSA	O4	U/S Gariep, D/S Aliwal North	1 465
RSA	O20	Onseepkans to Vioolsdrift	1 887
RSA	O22	Orange-Fish confluence to river mouth	198
RSA	O3	U/S Aliwal North, D/S Oranjedraai	262
RSA	O5	Kraai U/S Aliwal North	699
RSA	O6	U/S Van der Kloof, D/S Gariep	2 345
RSA	O7	Canals ex Van der Kloof Dam	4 474
RSA	O9	Van der Kloof Dam to Douglas	23 011
RSA	SH	Sak River	11 758
RSA	V1	U/S Grootdraai Dam to Vaal Dam	15 202
RSA	V10	Vaal and Riet U/S of confluence with Orange	29 594
RSA	V2	Wilge, Liebenbergsvlei Rivers	15 591
RSA	V3	Vaal Dam to Barrage	15 670
RSA	V4	Barrage to Bloemhof Dam	33 981
RSA	V5	Sand and Vet Rivers	23 198
RSA	V6	Bloemhof Dam to Schmidtsdrift	69 523
RSA	V7	Harts River	20 405
RSA	V8	Riet River	5 303
RSA	V9	Modder River	27 470
RSA	O2	U/s Gariep, D/S Welbedacht Dam	2 978
Botswana	MU	Molopo	92
RSA	MU	Molopo	11 508
Namibia	O19	Namibia border to Onseepkans	273
Namibia	O22	Orange-Fish confluence to river mouth	181
Namibia	O21	Vioolsdrift to Orange-Fish confluence	2 239
RSA	O21	Vioolsdrift to Orange-Fish confluence	324
Namibia	OLU	Lower Orange D/S Onseepkans	6

COUNTRY	ZONE	Description	Irrigated Area (ha)
Namibia	O20	Onseepkans to Vioolsdrift	316
RSA	OML	Middle Orange - D/S Boegoeberg	217
RSA	O1	Caledon U/S Welbedacht Dam	1 064
RSA	CAU	Upper Caledon tributaries	2 293
RSA	CALR	Lower Caledon tributaries (RSA)	220
RSA	OUL	Orange tributaries - Van der Kloof to Douglas	888
RSA	OUU	Orange tributaries U/S Van der Kloof	3 965
RSA	OMU	Middle Orange - U/S Boegoeberg	239
RSA	OLU	Lower Orange D/S Onseepkans	293
TOTAL			**385 321**

Table 3-3 provides a summary of the estimated areas under irrigation in each of the agro-economic zones. For the South African part of the basin the areas as given in the WARMS database have also been provided by way of comparison.

Table 3-3: Irrigated Areas by Agro-Economic Zone

AE Zone	Country(ies)	Area Measured in this Study (Ha)		Area from WARMS (Ha)
		Total	Centre Pivots	
G1	Lesotho	0	0	N/A
G2	Lesotho, South Africa	19 765	18 589	N/A
G3	South Africa, Lesotho	11 989	7 108	N/A
G4	South Africa	64 854	52 125	77 945
G5	South Africa	140 598	107 612	67 326
G6	South Africa, Botswana	15 236	13 523	N/A
G7	South Africa	63 272	57 517	37 553
G8	South Africa	15 815	12 592	17 446
G9	South Africa	31 963	678	34 617
G10	South Africa	13 215	132	19 570
G11	Namibia, South Africa, Botswana	3 169	0	N/A
G12	South Africa, Namibia	5 445	198	2 833
Totals (Zones entirely within South Africa)		**329 717**	**270 073**	**254 458**
Totals (Entire Basin)		**385 321**		**N/A**

It is interesting to note that the irrigated areas in the zones that fall entirely within South Africa is about 75 000 ha or 29% more than the registered areas in the WARMS database for the comparable zones. The differences are particularly evident in the G5 (Lower Vaal) and G7 (Modder-Riet) agro-economic zones. Areas under centre pivot irrigation (which were identified with high confidence) in zone G5 amount to about 107 600 ha, which by itself is about 60% more than the WARMS registered area for this zone. The total area, and the area under centre pivot irrigation in zone G7, both exceed the WARMS area by a large margin.

3.3 Testing of Crop Classification Techniques

Accurate, or even useful, crop classification depends on the availability of ground truth information on crops at a high resolution. This information was largely unavailable in most parts of the basin. It was possible, however, to make some useful progress with crop classification methods in selected parts of the basin (as described in **Section 2**)

3.3.1 Areas in Namibia

For Namibia it was possible to obtain quite detailed mapping based on ground truthing, for almost all of the irrigated areas. The results are illustrated in **Figure 3-7.** Even although detailed 'ground truth' was obtained, this is not always useful and can sometimes be confusing. For example, in the case of one area classified as 'vegetables', it happened to be bare soil on the day the image was captured because the vegetables had not yet been planted. This indicates the requirement for multi-temporal images and multi-temporal ground truthing, as set out in one of the recommendations for extension of the activity.

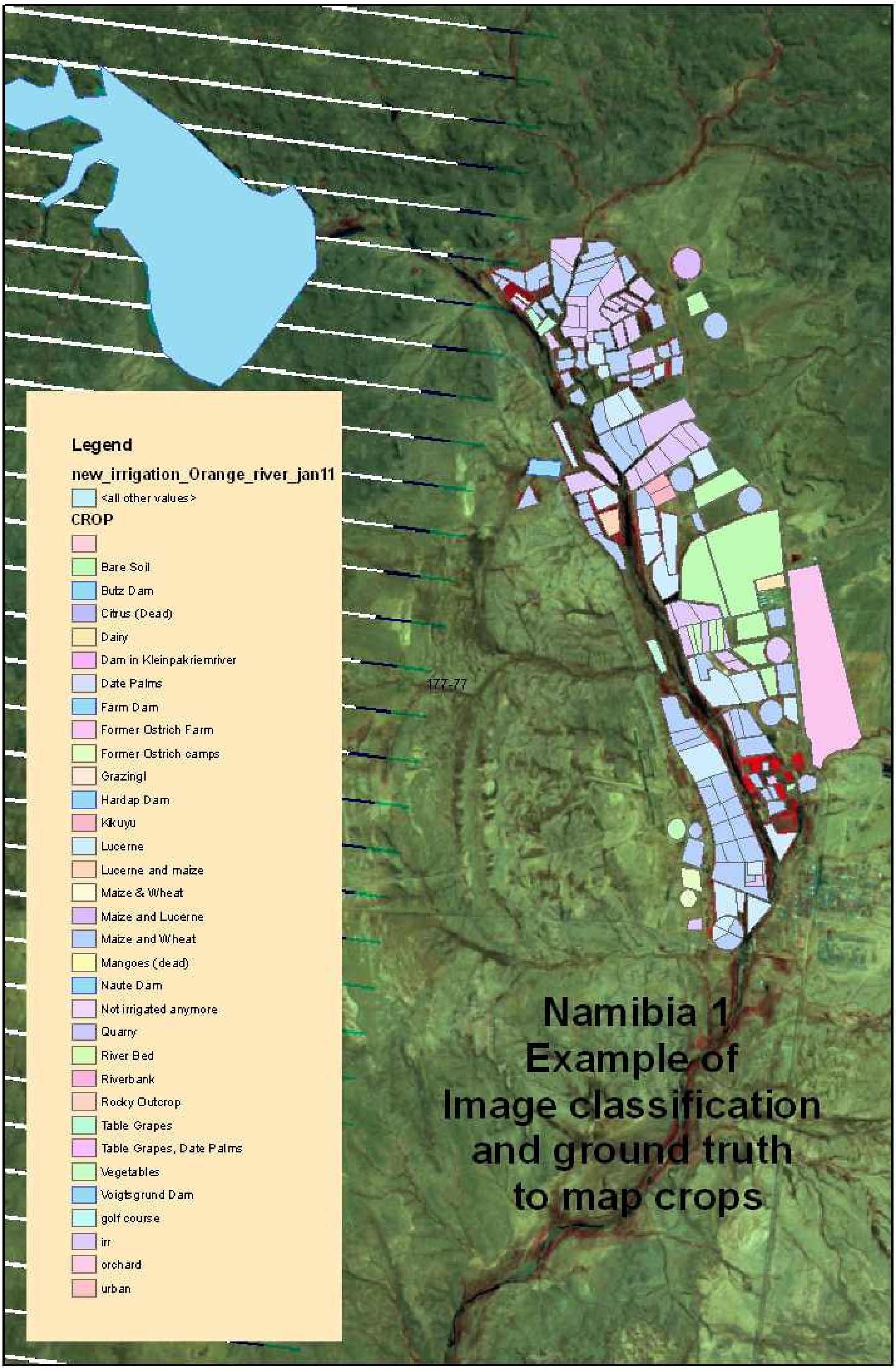

Figure 3-7: Image Classified Using Ground Truth -Namibia Mixed Crops

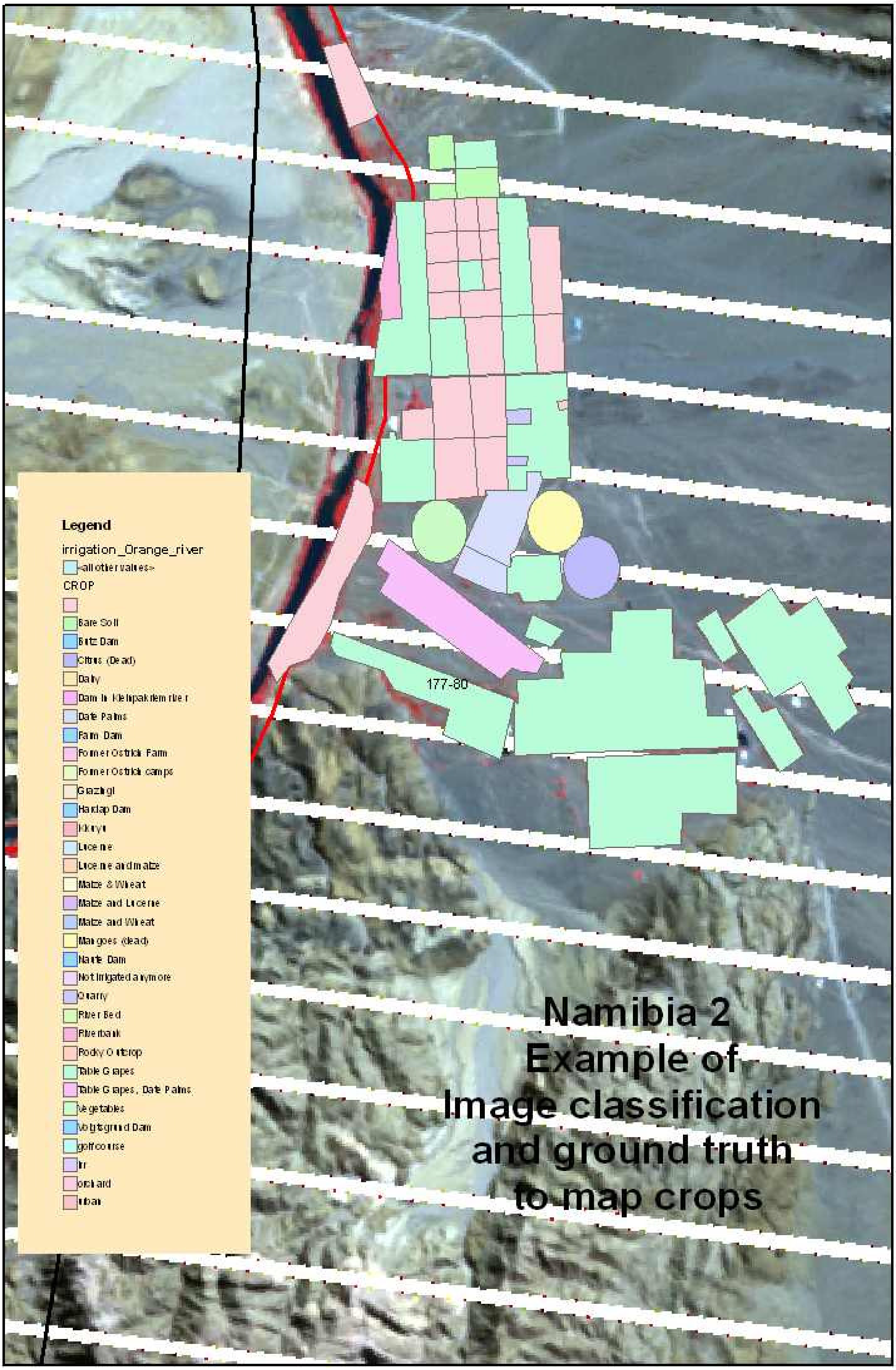

Figure 3-8: Image Classified Using Ground Truth – Namibia Mainly Grapes

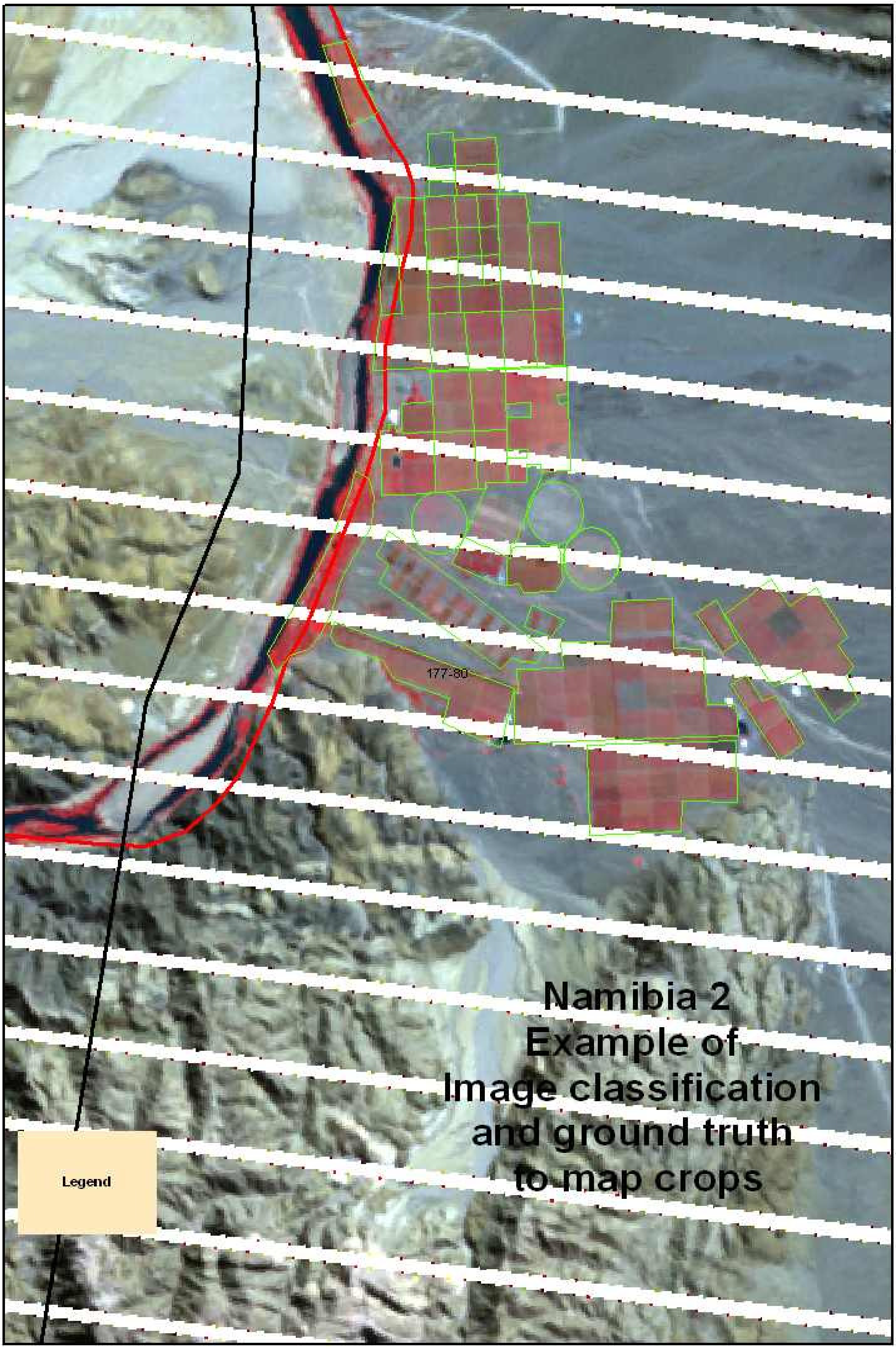

Figure 3-9 : False Colour Composite - Grape Crops Namibia

3.3.1.1 Crop Classification tile Path-174 – Row-80

This example is where the bands from two scenes, taken on two days, were mosaicked and then classified. The two dates were 17th July, and 3rd September, 2009.

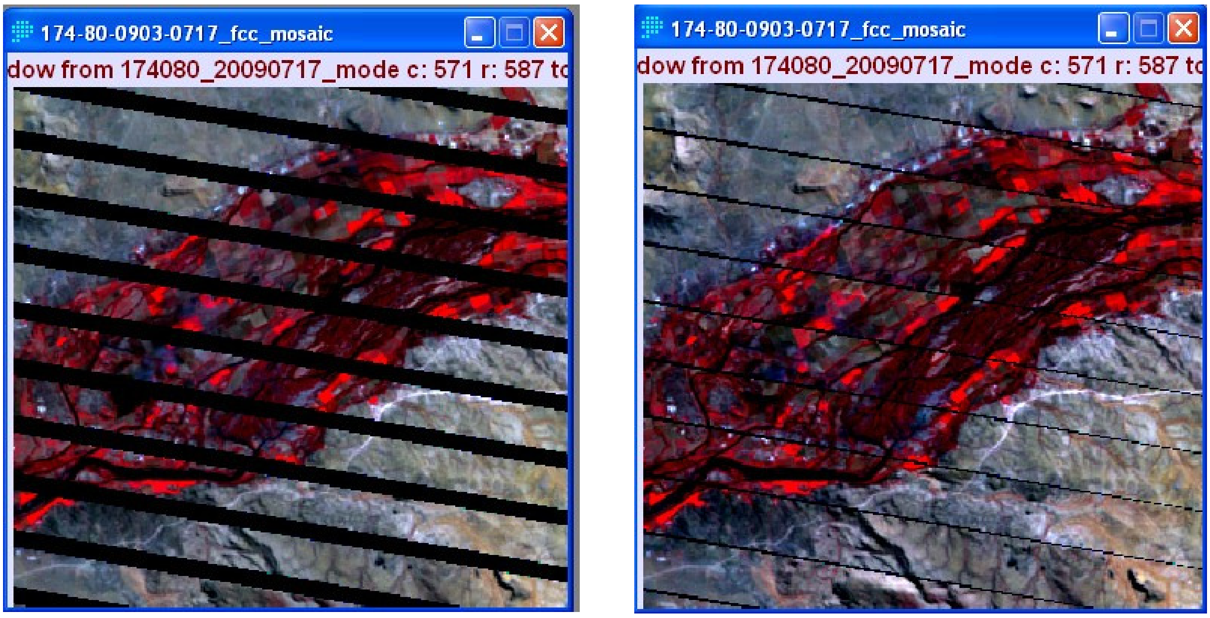

Figure 3-10: FCC Single Image (left and Mosaicked Image (right)

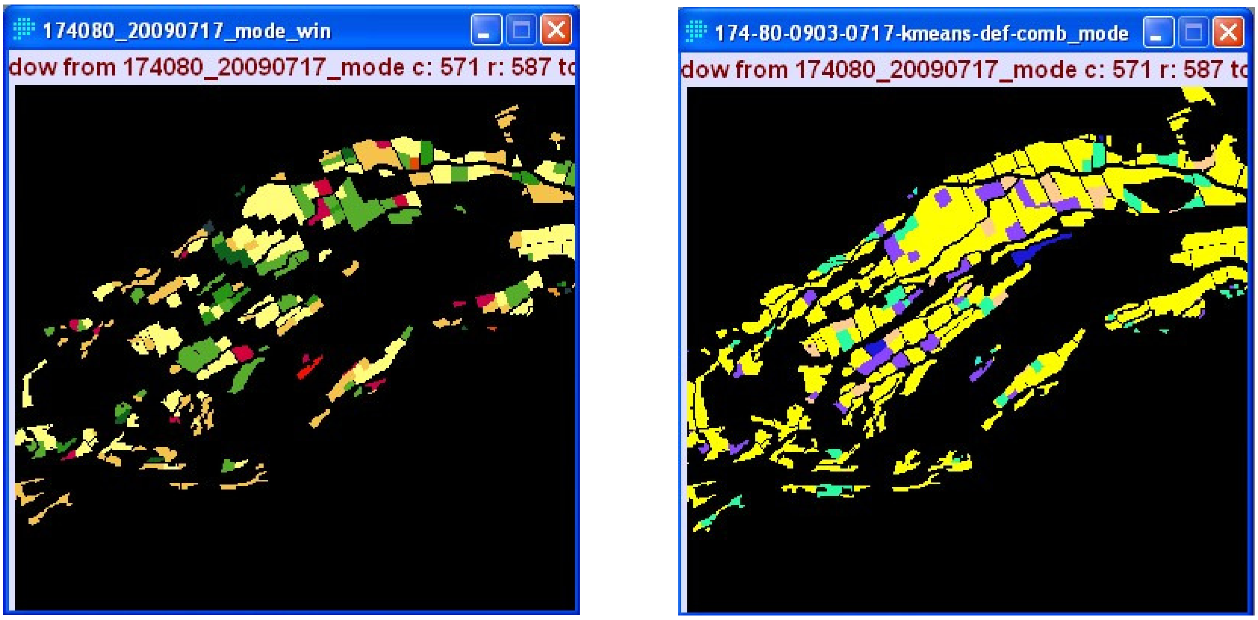

Figure 3-11: Classified Single Image (left) and Classified Mosaicked Image (right)

Figure 3-12: FCC Mosaicked Image and FCC Single Image

Figure 3-10 and **Figure 3-12** show two versions of a false colour composite, demonstrating that a) the slcoff gap can be all but filled; and b) that the result of mosaicking each band separately results in an FCC where the 'filled gap' is barely noticeable; except, as in the case of **Figure 3-12,** it is noticeable where the irrigated area has changed considerably between the two times.

Figure 3-11 shows the classified versions of the single and the mosaicked images/scenes. The small gaps evident in the mosaicked images have been filled by using the DAFF field crop boundaries and a 'MODE zonal statistics' filter in IDRISI. This takes each DAFF field crop boundary as a 'zone' and computes the modal value of all classified pixels within that field catchment boundary. The same procedure was used to obtain **Figure 3-12** but the gaps were so large and the field crop boundaries so small, that the modal class came up as zero (unclassified). This is not so marked in the case of the larger centre pivot field catchment boundaries that straddle across the gaps. In this case, the modal value will be the value related to the time period that covers the largest area within the field crop boundary.

Table 3-4 gives a summary of the kmeans classification of the image formed by mosaicking the July and September 2009 scenes, using bands 2, 3 and 4,of the Path-174 –Row-80 Tile. No less than 98.7 of the pixels are classified as one class, presumably including grapes in some state of growth. A finer breakdown can be obtained using a fixed number of clusters. The kmeans algorithm will, unless constrained, merge identifiable clusters on the basis of the closeness of their spectral signatures. This could lead to several kinds on 'healthy vegetation' being merged. This points once again for the need to use 'supervised classification' that requires 'ground truth'.

Table 3-4 Summary Classification Kmeans for Combined July-September Images

Class	Lower Limit	Upper Limit	Frequency	Proportion	Cumulative Frequency	Cumulative Proportion
10	11	12	172921	0.603	283138	0.987
5	6	7	66190	0.231	77153	0.269
7	8	9	23339	0.081	106033	0.37
6	7	8	5541	0.019	82694	0.288
4	5	6	4582	0.016	10963	0.038
11	12	13	3727	0.013	286865	1
1	2	3	2895	0.01	3893	0.014
9	10	11	2404	0.008	110217	0.384
2	3	4	2399	0.008	6292	0.022
8	9	10	1780	0.006	107813	0.376
0	1	2	998	0.003	998	0.003
3	4	5	89	0	6381	0.022

3.3.1.2 Crop Classification tile Path_173 - Row_80; Douglas Potato Area

A more detailed investigation was performed on scenes from the Tile - Path 173 – Row 80 (Note this study area has an overlap with Tile Path 172 - Row 80). This includes the area around Douglas and Berkeley West, where it is understood that significant areas of potato are grown. Information obtained indicates that it is a feature of potato growing that the planting regime is only once in every four or five seasons; where a season may be counted as one year or six months. If this is the case, one might expect to find fallow or an alternative crop being grown during the 'potato fallow' periods. Research on the Internet (Refer to: http://www.potatoes.co.za/) indicates that almost all potatoes grown (except Eastern Free State) are irrigated. This would indicate that there is a good chance of identifying all potatoes growing (95% irrigated) in South Africa using Remote Sensing. Spectral signatures would have to be developed using calibrated radiances and atmospheric correction. **Table 3-5** shows the potato growing conditions for the Tile referenced.

Table 3-5 Potato Production - Northern Cape

Item	Details
Irrigation / dry-land:	• All plantings are under irrigation. • Potatoes are mainly planted in the areas near the Vaal River such as Barkley West and Douglas and near the Orange River in Hope Town, Prieska and Douglas. (The confluence of the Vaal and Orange Rivers is about 10 km outside Douglas.)
Table and seed potatoes:	• 68% of the main crop area planted for the production of seed potatoes.

Planting time:	There are two table potato plantings, an early table potato crop, planted mainly in August and a main table crop planted from November to January. The seed potato crop is planted in January and early February.
Marketing period:	Table potatoes: The early crop is marketed from December to January and the main crop from April to October. The seed potato crop, of which over 60% are table potatoes, is marketed from June to October.
Processing:	Nearly 8% of the table crop is processed.
Cultivars:	The main cultivars are Up-to-Date, Darius and Mondial. The main seed potato cultivars are Darius, Up-to-Date, and BP1.

The cropping calendar would indicate that 'healthy vegetation' stage is to be found during October-November, and April-May.

The study acquired a time a time series of 20 scenes throughout 2009 and 2010 for the dates as follows:

- For year 2009: 0216, 0304, 0320, 0405, 0710, 0726,**1014, 1030, 1118**,
- For Year 2010: 0203, 0219, 0323, **0408, 0428, 0510**, 0915, 1001, 1220.

The highlighted dates were processed.

Another method for 'filling gaps' in the 'scloff' imagery was explored here. In this case, instead of mosaicking, two images were taken at a short interval. The two images were classified separately and the resultant classified images were merged. For this to work, it has to be assumed that the crop cover is not changed significantly over the time period. For example, the crop must not be harvested within the period. This method 'fills the gap' for the smaller fields.

Table 3-6 shows the results of a Kmeans classification, post processed by performing a modal filter using the DAFF fcb's as the method for grouping the data to be used in mode filtering (under this method the mode of the classified pixels is determined for all pixels found within each DAFF field crop boundary. For the larger fields this tends to remove the effect of the missing data due to 'slcoff'). Some 76% is classified under a single class. It is presumed that much of the class is potato. A visual examination of Google Earth imagery indicates that much of the area 'looks similar' - confirming the result. An interesting observation is that one would not expect so much of the area to be 'mono-cropped' as potato, given that it is said that cropping is only 1 in four or five seasons.

Table 3-6 Kmeans Classification With Mode Filter Path-173-Row-80, 30th October, 2009

Class	Lower Limit	Upper Limit	Frequency	Proportion	Cumulative Frequency	Cumulative Proportion
43	44	45	248459	0.758	327671	1
11	12	13	13943	0.043	41780	0.128
1	2	3	11157	0.034	12824	0.039
33	34	35	8848	0.027	71234	0.217
27	28	29	8574	0.026	59440	0.181
10	11	12	5079	0.016	27837	0.085
13	14	15	4787	0.015	46899	0.143
9	10	11	4020	0.012	22758	0.069
8	9	10	3317	0.01	18738	0.057
39	40	41	2451	0.007	77014	0.235
24	25	26	2411	0.007	50853	0.155
34	35	36	2188	0.007	73422	0.224
40	41	42	2039	0.006	79053	0.241
28	29	30	1772	0.005	61212	0.187
0	1	2	1667	0.005	1667	0.005
7	8	9	1290	0.004	15421	0.047
3	4	5	1138	0.003	13962	0.043
29	30	31	1026	0.003	62238	0.19
20	21	22	745	0.002	48358	0.148
17	18	19	498	0.002	47411	0.145
38	39	40	490	0.001	74563	0.228
35	36	37	450	0.001	73872	0.225
12	13	14	332	0.001	42112	0.129
41	42	43	159	0	79212	0.242
31	32	33	148	0	62386	0.19
19	20	21	134	0	47613	0.145
4	5	6	132	0	14094	0.043
37	38	39	114	0	74073	0.226
36	37	38	87	0	73959	0.226
23	24	25	84	0	48442	0.148
18	19	20	68	0	47479	0.145
5	6	7	37	0	14131	0.043
16	17	18	14	0	46913	0.143
25	26	27	13	0	50866	0.155
2	3	4	0	0	12824	0.039
6	7	8	0	0	14131	0.043
14	15	16	0	0	46899	0.143
15	16	17	0	0	46899	0.143

Class	Lower Limit	Upper Limit	Frequency	Proportion	Cumulative Frequency	Cumulative Proportion
21	22	23	0	0	48358	0.148
22	23	24	0	0	48358	0.148
26	27	28	0	0	50866	0.155
30	31	32	0	0	62238	0.19
32	33	34	0	0	62386	0.19
42	43	44	0	0	79212	0.242

3.3.1.3 Crop Classification tile Path_174 - Row_82

Special attention was paid to this tile because of its very different nature to most of the other tiles in paths 173 to 177. There were considerable differences between the DAFF field crop boundaries and what was apparently being irrigated in 2009-2010.

A trial of a procedure for filling in the missing data due to ‘slcoff’ was also performed on this tile. In this case two images, taken two weeks apart, were merged using a mosaicking technique. This can work if the missing strips are differently located in each of the images. This was undertaken using bands 2, 3,and 4 only. The resultant image was classified and irrigated areas were identified using the FCC for the three bands.

Table 3-7 shows the nature and extent of WARMS registrations issued within the tile.

Table 3-7 WARMS Licensing for Tile 174-82

tile 174-82			
WARMS Registrations			
IRRIGATION	**Count of registrations**	**Summary of CROP AREA (Ha)**	**Type**
61	6	88	Centre pivot
62	2	4	Drip
63	105	10116	Flood: Basin
64	139	2297	Flood: Border
65	39	870	Flood: Furrow
67	1	10	Micro spray
71	3	23	Sprinkler: Dragline
73	4	15	Sprinkler: Permanent
74	16	174	Sprinkler: Quick-coupling
75	1	5	Sprinkler: Side roll
77	3	15	Sprinkler: Travelling gun
	319	13620	Total
		13283	Flood
Proportion of 'flood irrigation'		0.9753	

- What is interesting in tile 174-82 is the presence of possibly opportunistic irrigation, in some cases supported by small dams.
- DWAF registrations have been issued; and over 97% of the area (highlighted) is registered for some form of 'flood irrigation'.
- The registered area in tile 174-82 is 13,620 Ha; the DAFF Field Crop Boundary identifies 21,293 ha.; the RS with the selection method proposed by the project identifies 6,453 Ha. The RS using filled 'slcoff' for July 2009 gives 4,122 Ha. (And one could possibly dismiss a patch of 400 Ha as being 'doubtfully irrigated); However, the location of the areas identified differs in each case, as does the definition of what is irrigated or 'apparently set up for irrigation'. It is speculated that while a large area is registered, the rainfall-runoff feeding any irrigation may be unreliable, leading to differences in the location and extent of actual irrigation from year to year.

Table 3-8 provides the alternative estimates for areas 'irrigated' in the Tile.

Table 3-8 Summary of Alternative Estimates of Irrigation for Tile 174-82

Type	Area ha	comment	Count
Registered as flood irrigation	13620	Approx	319
FCB_ALL_fin_yes[5]	6453	RS and selection	1154
FCB_ALL_in tile	21293	essentially DAFF FCB	4466
Classified as IRR withinOR jul 2009	10072	From DAFF FCB	1979
Irrigated jul7 2009 rs	4122		2346

3.3.1.4 Crop Classification Tile: Path_170 - Row_79

A detailed study was performed on Tile 170-79 following reports of a significant increase in irrigation in quaternary tertiary catchment C83 (Liebenbergsvlei and Wilge Rivers) due to diversion of additional water intended for transfer to Gauteng, outside the Orange-Senqu basin. This small study gives some indication as to the level it is possible to ‘drill down to’ with the imagery, GIS data and databases being provided. This study used the ESAD-MrSID (1990 and 2000) and Landsat (2009-10) images, together with the DAFF-field crop boundaries and took the quaternary catchment boundaries coverage and extracted and summarized the WARMS licensing data for the catchment C83.

The information available for this study was a detailed evaluation of water use in the period prior to about 1999; Landsat (ESAD-MrSID) images for 2001 and 1991. The date of the imagery used to update the 2006-2008 DAFF field crop boundaries was August 2009. There is in this sub-catchment some evidence (2009-2010) that additional areas are being irrigated in this catchment by using systems other than centre pivots (see **Table 3-10** and **Table 3-11).**

Table 3-9 Estimates of Centre Pivot Irrigation Quaternary Catchment C83

Date of Imagery	Area of Centre Pivot from Images Ha	No of CP	Notes
1990	834	52	date march to may 1991
2000	4,559	202	date march to may 2000-2001
2010	8,664	415	date of imagery 2009-2010
Estimate from Validation study 1999 (converting volume of water to Area)			
1996-99	3,228		date 1996-1999
Areas registered in WARMS within C83			
2010 Crops	18,400		Date as of January 2010
2010 Centre Pivot	11,000		

[5] FCB_ALL_fin_yes – area as determined by post processing of satellite imagery described in section 3.1.

Table 3-10 Crops - WARMS Registrations Quaternary C83 - 1010

CROP	AREA (ha)
MAIZE	5572
WHEAT	5070
POTATOES	1991
LUCERNE	908
VEGETABLES-SUMMER	882
FESCUE-GRAZING	809
PASTURES-SUMMER	686
PASTURES-PERENNIAL	587
RYE GRASS	432
APPLES	344
BEANS	265
GARDEN	173
MEALIES	126
VEGETABLES-WINTER	101
PASTURES SUMMER & WINTER	83
CHERRIES	71
GREEN FEED	60
SOY BEANS	43
OATS	40
GARLIC	37
GRAZING	35
BEANS-DRY	22
ASPARAGUS	20
CUT FLOWERS	19
STARFRUIT	10
KIKUYU	5
BERRIES	5
POMEGRANATE	3
NURSERY	1
NUTS	0.5
PEARS	0.5
Total	**18 412**

Table 3-11 Irrigation Technology - WARMS Registrations Quaternary C83 - 1010

IRRIGATION Technology	Name	Count	Cropped Area ha
61	Centre pivot	282	11002
62	Drip	65	2812
74	Sprinkler: Quick-coupling	128	2123
71	Sprinkler: Dragline	67	1183
69	Sprinkler: Big gun	16	284
67	Micro spray	28	279
77	Sprinkler: Travelling gun	5	259
73	Sprinkler: Permanent	8	165
75	Sprinkler: Side roll	5	125
68	Micro sprinkler	5	65
66	Linear	1	40
65	Flood: Furrow	2	30
72	Sprinkler: Hop-along	3	28
70	Sprinkler: Boom	2	17

4 THE IRRIGATION SCENARIO TOOL

The estimates of areas of irrigation, cropping patterns and irrigation technologies, that were derived as part of this study can be used as a baseline against which the economic impact of future trends can be measured. An irrigation scenario tool was developed to assist with the calculation of present day irrigation water demands and future irrigation scenarios, which could include crop and irrigation method changes to improve efficiency of water use and adaptation to climate changes in the region. These changes can be brought about through the use of technical and financial incentives and regulations. An example of a technical incentive is the provision of satellite monitoring information to farmers to assist them in improving operational and economic efficiency. Other scenarios could include speculation on market forces and 'out of the box' thinking – such as relying on sourcing fodder and grain staples outside South Africa. The irrigation scenario tool makes it possible to assess changes to irrigation water requirements and irrigation economics (gross crop margins) under these scenarios by allowing for:

- Calculation of monthly unit irrigation demands per crop type / agro-economic zone pairs. Water demands are calculated on the basis of long-term regional A-Pan evaporation, estimates of effective rainfall, crop coefficients and efficiencies associated with different irrigation technologies;
- Definition of crop mix / irrigation method change scenarios;
- Calculation of irrigation water demands per irrigation zone and per scenario; and
- Summarising of water demands and gross crop margins per area of interest (irrigation zone, agro-economic zone or country).

The relative economic value of existing crops and future scenarios where crop mixes are adjusted to adapt to climate change and/or to maximise annual return per unit of water used is defined in terms of:

- Crop gross margin (R/ha), a function of crop yield, producer price and direct costs of production;
- Crop gross margin per 1 000 m^3 water used in the crop's production, and
- Labour days per 1 000 m3, a function of total labour days required, divided by total water requirements.

Other features of the scenario tool include the "inheriting" of scenarios, i.e. a new scenario can be defined by copying a previously defined scenario and then specifying additional changes. An example of the scenario design screen is shown in **Figure 4-1.**

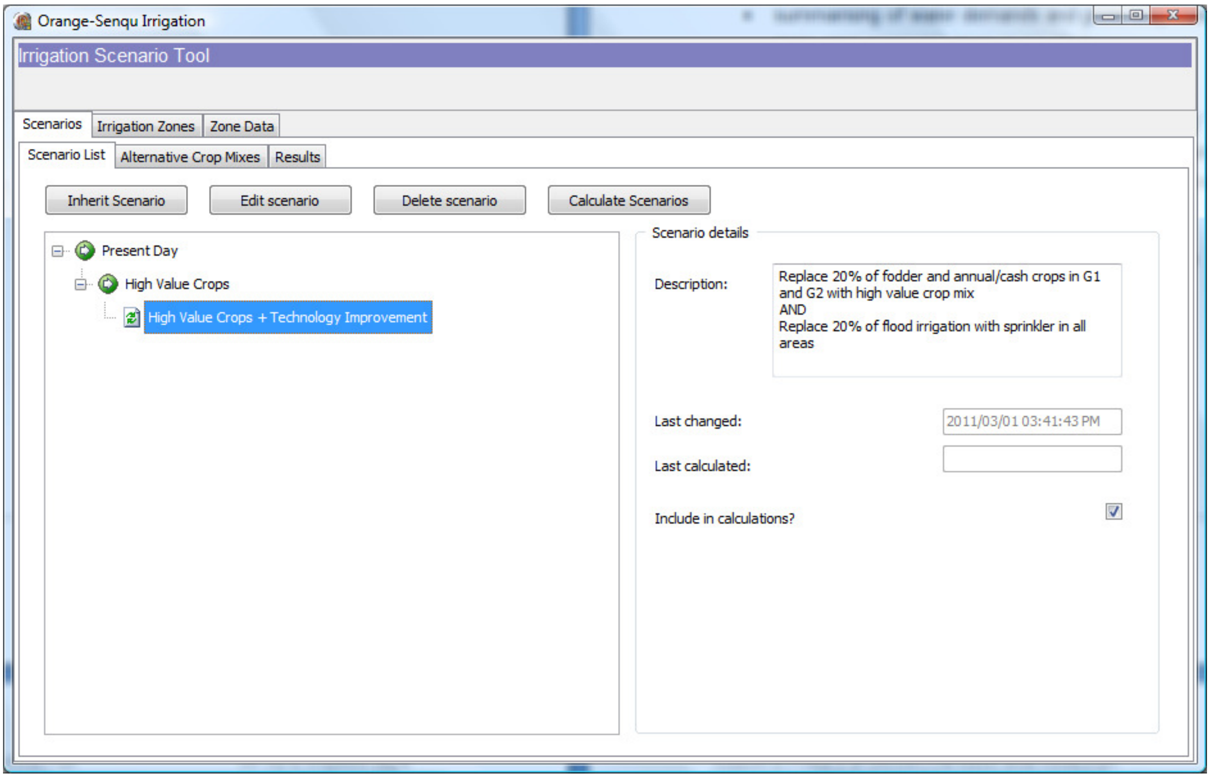

Figure 4-1 : Irrigation Scenario Tool - Scenario Design

The irrigation scenario tool has been populated with data for the entire basin, and the software and database can be downloaded from the project website at http://www.orangesenqu-iwrmplan-phase2.org/

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 General

The study has shown, at the country level, significant changes in irrigation practice are taking place, and that additional areas are being placed under irrigation. Of particular interest is the apparently large under-registration of irrigated areas in the Lower Vaal (G5) and Modder-Riet (G7) areas. It was also found that not all areas apparently equipped for irrigation (centre pivots) were being irrigated. This could be due to allowance for fallow periods, abandonment, and other reasons. One small study of the C83 quaternary catchment shows large increases in centre pivot irrigation over the period from approximately 1988 to the present. Another one for tile path-174 –row 82, shows changes (with respect to the DAFF-field crop boundary) over smaller periods, possibly due to different rainfall between years.

5.2 Ground Truthing

While the use of remote sensing has allowed the estimation of irrigation areas in the basin to be improved, the importance of ground truthing should not be underestimated. Ground truth information permits a more accurate estimate of irrigated areas, particularly in areas where rainfed agriculture is taking place. For crop classification, ground truthing is even more critical. As emphasized in the report on the *Promotion of Water Conservation and Water Demand Management in the Irrigation Sector*, the collection of information on areas under irrigation and which crops are being grown, should be carried out and recorded at the level of the water user association in the South African context, and by other equivalent organizations in the other basin states. These organizations have a need for this information and are also well-placed to collect it since they have a close relationship with farmers. Funding in the areas of GIS infrastructure and training for these organizations will result in much improved estimates of irrigated areas, cropping patterns and irrigation methods.

5.3 Further Development of systems developed under this Project

5.3.1 Annual Updating of the Database of Irrigated Areas

There is a need to supplement and link the South African Department of Agriculture's annual mapping of field crop boundaries with basin-wide long-term continuous mapping of irrigated areas in Namibia, Lesotho and Botswana. At present, crop type mapping is only available for isolated areas in the basin, and should be expanded to cover the entire basin. This should be based on regularly updated ground truth data from a sample of locations within each satellite image tile. The exercise could also be extended to non-irrigated field crop boundaries. It would require the continued acquisition of a time series of satellite images similar to that acquired under this project. This is regarded as a relatively low cost project which will make a large improvement to the confidence associated with estimates of irrigation water use.

5.3.2 Water Use Monitoring System

The development of a crop water use monitoring system based on near real-time satellite and ground based meteorological observations can potentially improve irrigation water scheduling and thus water use efficiency. This could be linked to the recommended continuous mapping of crop cover, which also requires crop type mapping. In this regard, the climate data acquired for the statistical downscaling could potentially be used for calibration of the approach and development of an operational system. This could also provide the basis for an agricultural extension system to farmers operated by the basin countries or contractors under contract to the governments.

5.3.3 Irrigation Scenario Tool

The Irrigation Scenario Tool (Section 4) developed for this study can be improved to include:

- Domestic and industrial demands;
- The introduction of optimisation based on economic returns;
- Introduction of risk based scenario generation; and
- Linking the Irrigation Scenario Tool (which provides estimates of field-edge irrigation water requirements) to the Water Resources Yield Model provided under this study.

5.3.4 System Development Proposals

Further details on the recommendations for further development of the systems provided under this study and first order cost estimates are provided in **Appendix B**.

APPENDIX A

ESAD MRSID IMAGERY

GEOCOVERTM

PRODUCT DESCRIPTION SHEET

ORTHORECTIFIED LANDSAT THEMATIC MAPPER MOSAICS

Mosaic Product Specifications:

- **Spectral Bands:** 3 - Landsat TM bands
  - Band 7 (mid-infrared light) is displayed as red
  - Band 4 (near-infrared light) is displayed as green
  - Band 2 (visible green light) is displayed as blue
- **Coverage:** The GeoCover Landsat mosaics are delivered in a Universal Transverse Mercator (UTM) / World Geodetic System 1984 (WGS84) projection. The mosaics generally extend north-south over 5 degrees of latitude, and span east-west for the full width of the UTM zone. For mosaics between 60 degrees north and 60 degrees south latitude, the width of the mosaic is the standard UTM zone width of 6 degrees of longitude. For mosaics above 60 degrees of latitude, the UTM zone is widened to 12 degrees, centered on the standard UTM meridian. To insure overlap between adjacent UTM zones, each mosaic extends for at least 50 kilometers to the east and west, and 1 kilometer to the north and south.
- **Pixel size: 28.5 meters,**
  - Contrast Enhancement: In order to maximize the information of each mosaic, EarthSat has applied a company proprietary contrast stretch known as LOCAL (Locally Optimized Continuously Adjusted Look-up-tables) stretch. This stretch uses multiple, locally collected histograms, to create a radiometrically seamless blend of contrast adjustment across areas of potentially extreme contrast ranges. The suffix __loc" is added to the mosaic name to signify the application of the LOCAL stretch.
- **Absolute Positional Accuracy:** 50 meters Root Mean Square Error.
- **File Naming Convention:** Within each UTM zone the "partitions" extend from the equator to the north and south (in the northern and southern hemisphere respectively) in 5 degree increments. The naming convention for the mosaics is three components, separated by hyphens; the first element is the hemisphere (either N or S), the second is the UTM zone number (1-60_, the last element is the latitude of the southern edge of the mosaic in the northern hemisphere and the northern edge of the mosaic in the southern hemisphere (there are some exceptions). For example:
  - N-13-25_loc: names a mosaic partition in the northern hemisphere, in UTM zone 13, extending between 25 and 30 degrees north latitude.
  - S-21-10_loc names a mosaic partition in the southern hemisphere, in UTM zone 21, extending between 10 and 15 degrees south latitude.

- **GeoCover Mosaic Image Product Delivery Format:** The GeoCover Landsat image mosaics are being delivered to NASA both as uncompressed color imagery in GeoTIFF format and as compressed color imagery in MrSIDTM file format. The data are delivered as 24-bit color uncompressed GeoTIFF files and as 24-bit color MrSID compressed files. The MrSID compressed file format is rapidly becoming accepted as the compression format of choice within a geodetic environment. More information on the compression format and viewing software can be found at http://www.lizardtech.com.
- **Non-standard UTM definition:** For the southern hemisphere, the GeoTiff files contain positive zone numbers with negative northing coordinates.

Source (Input) Data:

Imagery:

- Spectral Bands: All seven Landsat TM bands,
- Coverage: Single Landsat WRS Path/Row,
- Projection/Datum: SOM / WGS84,
- Pixel Size: Mixture of 28.5 and 30 meters,
- Interpolation Method: Cubic Convolution,
- Orientation: Path oriented,
- Coverage Date: Scene dependent (nominally 1990 +/- 3 years).

Control:

- Horizontal: Controlled scenes contained 6 to 12 photo-identifiable points with absolute positional accuracy not greater then 15.0 meters RMS.
- Vertical: DTM with 3-arc second postings, where available. Where 3-arc second data are not available, GTOPO30 (30-arc second) digital elevation models are used.

Digital Image Processing:

- Photogrammetric Block Adjustment:
  - Performed using Earth Satellite Corporation's proprietary photogrammetric software.
- Orthorectification:
  - Resampled to a UTM/WGS84 projection using nearest neighbor (i.e. no interpolation).
- Image Enhancements:
  - The data are spatially and spectrally unenhanced.

Modified (1/29/02) from Earth Satellite Corporation (April, 1999) www.earthsat.com

Enhanced Thematic Mapper

GEOCOVERTM

PRODUCT DESCRIPTION SHEET

ORTHORECTIFIED LANDSAT ENHANCED THEMATIC MAPPER

(ETM+) COMPRESSED MOSAICS

Mosaic Product Specifications:

- **Spectral Bands:** Three Landsat ETM+ bands, each sharpened with the panchromatic band.
  - Band 7 (mid-infrared light) is displayed as red
  - Band 4 (near-infrared light) is displayed as green
  - Band 2 (visible green light) is displayed as blue
- **Coverage:** The GeoCover Landsat mosaics are delivered in a Universal Transverse Mercator (UTM) / World Geodetic System 1984 (WGS84) projection. The mosaics extend north-south over 5 degrees of latitude, and span east-west for the full width of the UTM zone. For mosaics below 60 degrees north latitude, the width of the mosaic is the standard UTM zone width of 6 degrees of longitude. For mosaics above 60 degrees of latitude, the UTM zone is widened to 12 degrees, centered on the standard even-numbered UTM meridians. To insure overlap between adjacent UTM zones, each mosaic extends for at least 50 kilometers to the east and west, and 1 kilometer to the north and south.
- **Pixel size:** 14.25 meters,
  - Contrast Enhancement: In order to maximize the information of each mosaic, EarthSat has applied a company proprietary contrast stretch known as LOCAL (Locally Optimized Continuously Adjusted Look-up-tables) stretch. This stretch uses multiple, locally collected histograms, to create a radiometrically seamless blend of contrast adjustment across areas of potentially extreme contrast ranges. The suffix "__loc" is added to the mosaic name to signify the application of the LOCAL stretch.
  - Absolute Positional Accuracy: ±75 (ROSE: I am comfortable with a 50 meter RMSE, but wouldn't want to override your V&V folks) meters RMSEr.
  - File Naming Convention: Within each UTM zone the "partitions" extend from the equator to the north and south (in the northern and southern hemisphere respectively) in 5 degree increments. The naming convention for the mosaics is comprised of three components, separated by hyphens; the first element is the hemisphere (either N or S), the second is the UTM zone number (1-60), the last element is the latitude of the southern edge of the mosaic in the northern hemisphere and the northern edge of the mosaic in the southern hemisphere. For example:

- N-13-25_2000_loc: names a LOCAL stretched mosaic partition in the northern hemisphere, in UTM zone 13, extending between 25 and 30 degrees north latitude.
- S-21-10_2000_loc names a LOCAL stretched mosaic partition in the southern hemisphere, in UTM zone 21, extending between 10 and 15 degrees south latitude.
    - GeoCover Mosaic Image Product Delivery Format: The GeoCover Landsat image mosaics are being delivered to NASA both as uncompressed color imagery in GeoTIFF format and as compressed color imagery in MrSIDTM file format. The data are delivered in 24-bit color. More information on the MrSID compression format and viewing software can be found at http://www.lizardtech.com.
    - Non-standard UTM definition: For the southern hemisphere, the GeoTiff files contain positive zone numbers with negative northing coordinates.

Source (Input) Data:

Imagery:

- Spectral Bands: Landsat ETM+ bands 7, 4, and 2,
- Coverage: 5x6 degrees (south of 60 degrees North), and 5x12 degrees (north of 60 degrees North),
- Projection/Datum: UTM / WGS84,
- Pixel Size: Mixture of 14.25,
- Interpolation Method: Cubic Convolution,
- Orientation: North Up,
- Coverage Date: Scene dependent (nominally 2000 +/- 3 years).

Control:

- Horizontal: Image matching to 1990 GeoCover scenes where available, otherwise Landsat-7 ephemeris was used.
- Vertical: DTM with 3-arc second postings, where available. Where 3-arc second data not available, GTOPO30 (30-arc second) digital elevation models are used.

Digital Image Processing:

- Mosaicing:
- Radiometrically balanced across automatically collected seam lines.
- Image Enhancements:
- The data are spatially and spectrally unenhanced.

Earth Satellite Corporation July, 2004

www.earthsat.com

APPENDIX B

POSSIBLE DEVELOPMENTS OF THE GIS IRRIGATION DATABASE

1 CONTINUOUS MAPPING OF IRRIGATED CROP COVER

The work done on irrigation mapping in this project and the previous work of DIA in mapping field crop boundaries lends itself to extension into an institutionalized arrangement. This would provide a basin wide long term continuous mapping of crop cover and type of irrigation using regular ground truth from a sample of locations within each tile linked to an expanded GIS based coverage based on the one supplied by the project. This would provide improved landuse/crop mapping for irrigated areas that could also be extended to non-irrigated field crop boundaries). It would require the continued acquisition of a time series of satellite images similar to that acquired under this project. It is noted that the Landsat satellite may well fail in the near future but will be replaced by an improved satellite fairly soon thereafter. Studies are being conducted as to how to 'fill the gap' in the time series. It would require selected farmers to report on what crops had been planted in the sample of locations identified, in each growing season. This is regarded as a relatively low cost project.

This project may be regarded as being an essential precursor to the second proposed project in that a relatively accurate map of crops planted both for irrigation and rainfed agriculture is required.

The proposal here is for a commercial consulting company to provide the project management and for each country to identify appropriate institutions to implement the proposals within that country. The resources required are as follows:

Technical assistance 12 person months	300,000 euro
Equipment and software:	4 x 20,000 euro

Each country will provide office space, support and staff for the project, and undertake to maintain its operation.

2 CROP WATER USE MONITORING - IRRIGATION

The aim of such a project would be to develop a crop water use monitoring system based on near real-time satellite and ground based meteorological observations. This could be linked to the proposal for continuous mapping of crop cover, which also requires crop type mapping. With respect to this, the climate data acquired for the statistical downscaling could potentially be used for calibration of the approach and development of an operational system. This could also provide the basis for an agricultural extension system to farmers operated by the government or contractors under contract to the government. A possible future extension of such a system could look forward to providing a system for water balance estimation at the sub-catchment scale.

Such a project links naturally to a future wider project aimed at assisting with 'precision farming'. The basin-wide monitoring of water use, and the provision of information for 'precision farming' could be an important institutional action by a basin authority designed to persuade/induce farmers to adopt practices that are more efficient in use of water and other resource inputs to farming; thus making economic savings and reducing pollution due to agricultural inputs.

2.1 Current Situation

The items presented here are by no means a complete review of recent work on satellite hydrology both nationally and internationally. They do illustrate what seems to becoming a practical level of technology.

2.1.1 CSIR

The CSIR Satellite Applications Centre is a key component of the CSIR's efforts to maximise the benefit of information, communications and space technology for industry and society. The centre at Hartebeesthoek is located some 70 km west of Pretoria in the Magaliesberg mountain range and is ideally positioned to provide tracking, telemetry and command (TT&C) services for geo-synchronous and polar orbiting spacecraft to the manufacturers, operators and users of satellites and launch vehicles. It is also ideally situated for satellite data acquisition and as such, delivers earth observation data relayed from satellites to a range of stakeholders.

With respect to the application of satellite technology on monitoring evaporation, Keith Kennedy (EM KKennedy@csir.co.za) was contacted with the following response "….We'd enjoy the opportunity to discuss this Orange River opportunity with you and others….I met at some length with Wim (Basiaansen from WaterWatch) yesterday and this is the exact type of extension of data we are interested in evaluating beyond the activities we have started with WaterWatch here in ZA. This was followed up by a long telephone discussion with Keith Kennedy about SEBAL. Summarizing, It would appear that the application in irrigation water use monitoring is well advanced and full scale field trials are being held in 2010-11 for the grape areas in Western Cape (see section 2.1.3). Less success is reported in attempting catchment water balance applications and more research is regarded as necessary.

However, a study on the Olifants trans-boundary basin (Its catchment area spans over 54,672Km2) reports some success, quote1 "….. This paper describes a case study that uses

1 Estimating actual evapotranspiration through remote sensing techniques to improve agricultural water management: a case study in the Transboundary Olifants catchment in the Limpopo basin, South Africa

Mobin-ud-Din Ahmad, Thulani F. Magagula, David Love, Victor Kongo, Marloes L. Mul, and Jeniffer Kinoti

International Water Management Institute (IWMI), PO Box 2075, Colombo, Sri Lanka, 2 International Water Management Institute, 41 Creswell St, Weavind Park, 0184, Pretoria, South Africa, WaterNet, PO Box MP600, Mount Pleasant, Harare, Zimbabwe, ICRISAT Bulawayo, Matopos Research Station, PO Box 776 Bulawayo, Zimbabwe, School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, PB X01, Scottsville, 3209 Pietermaritzburg, South Africa, 6 Department of Civil Engineering, University of Zimbabwe, PO Box MP167, Mount Pleasant, Harare, Zimbabwe, UNESCO-IHE, Institute for Water Education, PO Box 3015, 2601 DA Delft, the Netherlands a remote sensing technique, the Surface Energy Balance Algorithm for Land (SEBAL) to assess actual evapotranspiration across a range of land uses in the middle part of the Olifants Basin in South Africa.. SEBAL enables the estimation of pixel scale ETa using red, near infrared and thermal bands from satellite sensors supported by ground-based measurements of wind speed, humidity, solar radiation and air temperature ………….. A Landsat7 ETM+ image, path 170 row 077, was acquired on 7 January 2002, during the rainy season and was used for this analysis. The target area contains diverse land uses, including rainfed agriculture, irrigated agriculture (centre pivot, sprinkler and drip irrigation systems), orchards and rangelands. Commercial farming (rainfed and irrigated agriculture) is one of the main economic activities in the area. SEBAL ETa estimates vary from 0 to 10 mm/day over the image. Lowest ETa was observed for barren/fallow fields and highest for open water bodies. ETa for vegetative areas ranges 3 to 9 mm/day but irrigated areas, using central pivot, drip and sprinkler systems, appear to evaporate with a higher rate: 6 and 9 mm/day. Penman-Monteith reference crop evapotranspiration ET0 on the same day was found to be 7 mm/day. This indicates that these irrigated areas have no water stress and potential yields can be achieved provided there is no nutrient deficiency. The major finding is that SEBAL results showed that 24% of ETa is from agricultural use, compared to 75% from non-agricultural land use classes(predominantly forest) and only 1% from water bodies. Although irrigation accounts for roughly half of diverted streamflow in the basin, it contributes only about 4% of basin-scale daily ETa at the time of assessment…."

Another study concluded, quote2 " …… Results of the district-wide water balance were compared to corresponding results from the remote sensing approach utilizing SEBAL for the 1998 water year (October 1997 to September 1998), resulting in a difference of less than one percent, providing a strong validation of SEBAL in arid, advective environments. The ET computed from the crop coefficient approach was 14 percent higher than the ET computed by the water balance approach. The following additional conclusions are evident:

- The 30-m by 30-m pixel spatial resolution of the remote sensing approach results allow for a more complete understanding of ET within and among fields.
- The remote sensing approach results allow for a more complete understanding of ET across time.

---

2 Comparison of Evapotranspiration Estimates from Remote Sensing (SEBAL), Water Balance, and Crop Coefficient Approaches

Bryan Thoreson, Ph.D., P.E., M.ASCE, Byron Clark, P.E., M.ASCE, Richard Soppe, Ph.D. Andy Keller, Ph.D., P.E., M.ASCE, Wim Bastiaanssen, Ph.D., , and John Eckhardt, Ph.D., P.E., M.ASCE.

World Environmental and Water Resources Congress 2009: Great Rivers © 2009 ASCE.

Davids Engineering, Inc., 1772 Picasso Avenue, Suite A, Davis, CA 95618, www.sebal.us, WaterWatch, Generaal Foulkesweg 28A, 6703 BS Wageningen, The Netherlands, www.waterwatch.nl. Keller-Bliesner Engineering, LLC, Vice President, 78 East Center, Logan, UT 84321, 435-753-5651; akeller@kelbli.com., Imperial Irrigation District, Executive Program Manager, QSA-IID/SDCWA Water Transfer, 333 East Barioni Boulevard, Imperial, CA 92251, 760-339-9736, JREckhardt@IID.com.

- Remote sensing of ET using thermal imagery plays an important role in the IID/SDCWA water transfer and, more broadly, water management in the West.
- Remote sensing of ET provides opportunities for improved agricultural water management at field, farm, district, basin, state, and regional scales……"

The literature suggests that the technique of using satellite observations for monitoring irrigation water usage is well advanced. Linked to this is the growing usage of satellite observations in the area of 'precision farming' for rainfed agriculture. The two techniques use very nearly the same satellite, agricultural and meteorological information. This provides for great synergy between the approaches and as a side benefit allows valuable information to be passed to farmers. The marginal cost of providing information for an additional 1000 farmers over say 10, is very small. So if a large area can be identified for a study the unit costs can be very small. The technique is further suited to monitoring trans-boundary resources because, up to a point, each country can observe independently what is happening in its neighbour's country's.

2.1.2 Satellite Applications and Hydrology Group (University of Kwa-Zulu Natal)

Current Projects

HYLARSMET

HYLARSMET: A HYdrologically consistent Land Surface Model for Soil Moisture and EvapoTranspiration modelling over Southern Africa using Remote Sensing and METeorological data. This project is a follow on to "Soil Moisture from Satellites - Daily maps over RSA" and aims to share, improve and validate the methodology, products and software developed in the earlier project.

Modelling daily rain-gauge network measurement responses under changing climate scenarios

The purpose of this Water Research Commission solicited project is to establish a link between expected rainfall, as measured by multiple rain-gauge networks, hydrological responses and climate change. The approach might include disaggregation of mesoscale scenarios that are typically generated by GCMs, into small spatial and temporal scales using a combination of downscaling methods to explore the human induced change in the context of natural variability, and develop probabilistic projections of the envelope of possible change, inclusive of quantified uncertainty.

SHARE

SHARE is one of the European Space Agency's DUE Tiger projects. SHARE aims at enabling an operational soil moisture monitoring service for the region of the Southern African Development Community (SADC). With this service SHARE will address one of today's most severe obstacles in water resource management which is the lack of availability of reliable soil moisture information on a dynamic basis at a frequency of a week and less. The original project was completed in 2009 but has been extended for 2 years starting January 2010.

Soil Moisture from Satellites - Daily maps over RSA

The goal of this project, funded by the Water Research Commission, completed March 2010, is to provide the best available estimate of Soil Moisture over the entire country, in near real time, in as much detail as feasible, freely accessible on the web. Users of this information are expected to include Researchers, Agriculturalists, Flood Forecasters and Drought and Catchment Managers.

2.1.3 Grapelook

South Africa is well advanced in the area of using satellite information in water use monitoring for irrigation. Grapelook[3] is set in the summer of 2010-11 to demonstrate, to all farmers, irrigation advisors, water user associations and irrigation boards the possible benefits of such a system. It will provide quote "….free online access to weekly updated semi-real-time information on their production, irrigation water demands and crop nitrogen status. Information will be available for vineyards in De Doorns, Worcester, Stellenbosch, Somerset West, Paarl, Wellington, Citrusdal and Vredendal….."

Quote "……. Recently the Western Cape Department of Agriculture started a new project focusing on operationally monitoring efficient crop water and nitrogen use of grapes in the Western Cape. The objective of the project is to assist grape farmers with the daily management of irrigation water resources and on-farm nitrogen by means of satellite remote sensing technologies.

The project aims at:

- increasing the water use efficiency in vineyards;
- promoting sustainable optimal resource utilization;
- reducing input costs (e.g. fertilizers); and
- protecting the environment.

For a limited number of "demonstration farmers" the project produces regular irrigation advice. As a demonstration farmer you are requested to provide inputs on your field boundaries and irrigation management. At some of the demonstration farms soil moisture status and surface temperature will be monitored throughout the growing season……"

[3] http://www.grapelook.co.za/ A project is funded by the Department of Agriculture: Western Cape (supported by the Department of Agriculture, Forestry and Fisheries) and the European Space Agency (ESA). The project is executed by WaterWatch BV, the Netherlands, and the University of KwaZulu-Natal (UKZN), South Africa.

2.1.4 Earth Observation and Water Resource Management: Supporting the Measurement of Evapotranspiration for water resource management in South Africa

This is an extract from a research proposal to ESA. – No ID 2801

Title Earth Observation and Water Resource management: Supporting the measurement of evapotranspiration for water resource management in South Africa

Type Tiger AO

Class Peer Review

Cost Free of Charge

Primary Application Domain Hydrology

Secondary Application Domain Land Environment

Location Africa

Status accepted

Principal Investigator

Last name (Family name) Jarmain, Name (Given name) Caren, Title Dr.

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University of KwaZulu-Natal, School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, Pietermaritzburg, P/Bag X01, Scottsville, South Africa, +27 33 260 5678 (t)

Others:

WaterWatch, Generaal Foulkesweg 28A, 6703 BS, Wageningen, The Netherlands, +31 317 423 401 (t), +31 344 693 827 (f), www.waterwatch.nl

Team Composition, Experience, Innovation and Contribution

Team Dr. Caren Jarmain (CSIR), Dr. Colin Everson (CSIR), Mrs. Marilyn Govender (CSIR), Assistant (CSIR)

Prof. Graham Jewitt (UKZN), Student (Mr. Luke Wiles) (UKZN), Prof. Geoff Pegram (UKZN), Mr. Dirk Boon (WaterWatch), Dr. Wim Bastiaanssen (WaterWatch), Representative from Wageningen Agricultural University (e.g. Wouter Meijninger or Henk de Bruin)

Experience CSIR Land use hydrology group:

The CSIRs Land use hydrology group has extensive experience (> 15 years) in land use hydrology, both at a catchment and field scale. Extensive experience exists in modelling and measuring components of the water balance. Very specific expertise also resides within this group in the use of state of the art micrometeorological methods (e.g. Eddy covariance, Bowen ratio, Scintillometry techniques) to estimate total evaporation.

WaterWatch group:

WaterWatch is the original developer of the SEBAL model, which has grown out to become a cutting edge technology in the field of evapotranspiration and water resources management. The team holds more than 100 papers related to the theories and applications of surface energy balance modelling. WaterWatch collaborates with research institutes and universities in US, Mexico, Brazil, Egypt, Pakistan, Sri Lanka, Vietnam and China. SEBAL has been applied in more than 30 countries worldwide, and the WaterWatch science team has been involved as advisor in most of these studies. Waterwatch is the original developer and intellectual owner of Surface Energy Balance Algorithm for Land (SEBAL). SEBAL computes actual, potential and reference evapotranspiration, root zone soil moisture and biomass growth from low resolution (1 km) and high resolution (30 m) satellite images with minimum inputs.

Innovation Enable the validation of the SEBAL model with ESA data for South African circumstances.

Develop products relevant to water resource management (e.g. evapotranspiration maps for complete years over extensive areas (see also list above in 2.2), identify SFRAs.

Future innovation:

Further develop SEBAL to use high resolution imagery (hyperspectral imagery) for small scale applications like slimes dames, riparian strips, etc.

Contribution Water, the blue gold of the 21st century, can be monitored from space at several different stages of the hydrological cycle, using Earth observing satellites (from TIGER website).

SEBAL is an excellent illustration of monitoring water from space.

Following the 2002 Johannesburg World Summit on Sustainable Development, the European Space Agency has launched the TIGER Initiative - focusing on the use of space technology for water resource management in Africa and providing concrete actions to match the Resolutions. (from TIGER website)

South Africa has its own water problems on large, medium and small scales. Evapotranspiration is a process that is part of the water balance on all these levels. Management of evapotranspiration can lead to enormous savings on water use. Monitoring

ET with SEBAL can be done on all levels and is an excellent tool in water resources management.

The proposed work could also compliment projects like SMOS and others.

Executive Summary OBJECTIVE:

Calculating the water balance (including ET) for selected sites with SEBAL, under both current and historic conditions, and cross-checking it with available ET data. Eventually parameter fine tuning to typical environmental conditions encountered in South Africa.

METHODS:

SEBAL model will be used to calculate the water balance (and ET) whereas historic (and current) data collected with the Bowen ratio energy balance, eddy covariance and catchment water balance techniques will be used to cross-check the water balance estimates.

SEBAL will be applied to three research catchment, ranging in size and climatic conditions experienced. These include the Cathedral peak catchment with moist upland grassland, close to the Drakensberg (Everson, 2001); the Two streams catchment with forestry and sugarcane and in close proximity to Greytown (Jarmain and Everson, 2002 and Everson et al., 2005); and the Jonkershoek catchment, Stellenbosch with forestry and fynbos (Scott et al., 2005). All three study sites are situated in South Africa. In both the Two streams and Jonkershoek catchments historic and current data is available, where as 5 year historical data set is available for the Drakensberg catchment.

DELIVERABLES:

Publication on the validation of SEBAL under varying climatic conditions within SA (and for different vegetation types)

Report/Publication on the proposed use of SEBAL for Water resource management in SA, specifically in terms of CMAs, and illustrated by SFRA and ET maps.

Others

Schedule PLANNING/PREPERATION, 1 September 2005 to 30 March 2006

DATA ACQUISITION, 1 April 2006 to 30 September 2006

DATA ANALYSIS 1 October 2006 to 30 March 2007

REPOPRTING (including work on new proposal/s) 1 April 2007 to 30 March 2008

Natural environment

http://www.csir.co.za/enews/2010_mar/15.html

They take a scientific approach not a practical engineering approach where calibration against measured rainfall runoff is always used.

Working for Water Programme is working, CSIR study finds

Pines and hakeas are nearly impossible to eradicate because they are so widespread and form dense and impenetrable stands. They also produce enormous quantities of winged seeds, especially after a fire, which are then spread over great distances

Australian wattles are extremely difficult and expensive to control. Most species are able to sprout after felling, while the seeds, buried in the soil, germinate by the hundreds and thousands after a fire

Caren Jarmain is an agrometereologist with CSIR Natural Resources and the Environment

The Working for Water Programme is having a significant impact on the availability of water resources, especially in those provinces heavily invaded by aggressive invaders such as Black wattle, Eucalypt, Port Jackson, Pine, Lantana and Solanum.

Results from a recent CSIR study in the Western Cape and KwaZulu-Natal showed an annual decrease in water use of 13% and 6% respectively following clearing of invasive alien plants by the Working for Water Programme (WfW) in the areas investigated in this study.

Combining remote sensing data with the Surface Energy Balance Algorithm for Land (SEBAL) model, CSIR agrometeorologist Caren Jarmain and Wouter Meijninger from WaterWatch in the Netherlands were able, for the first time, to estimate the water use of invasive alien plants spatially for three climatically different years over entire provinces.

According to Jarmain and Meijninger, invasive aliens have a major impact on the water resources and biodiversity of South Africa and their spread is controlled through legislation: "An invasive alien plant has the tendency to spread out of control. They have frequently been introduced from elsewhere in the world and do not have the native pests and diseases to plague them in their new environment, which allow them to grow vigorously and spread rapidly. In South Africa, most of the invasive aliens are declared weeds or invaders and are controlled by the Conservation of Agricultural Resources Act," she explains.

Previous studies done by the CSIR showed that about 10 million ha (8.28%) of the country has been invaded to some extent, at an average density of 17%. The top ten invaders are Syringa, Pine, Black wattle, Lantana, Rooikrans, Port Jackson, Mesquite, Bugweed, Hakea and Opuntia sp. (small round-leaved prickly pear). Multiple studies have shown the increased water use of these aliens compared to the native vegetation.

According to Jarmain this study is unique in that it could integrate the impact of multiple invasions on water resources over space (entire provinces) and time (multiple years), thereby assessing the impact of the WfW programme in attempting to lessen this impact.

"In this study we were able to quantify the actual water use of several invasive plants over space and time, and contrast it to the water use of native vegetation and forestry species. We also assessed the impact of the WfW programme by contrasting plant water use prior to and following clearing of an area," she explains.

The average water use of the five dominant invasive alien plants in the Western Cape was 897 mm - significantly higher than the water use of most of the native vegetation (thicket 576 mm, fynbos 517 mm and Karoo 117 mm). On average, the annual water use decreased by 13% (781 mm) following clearing by the WfW programme.

In KwaZulu-Natal, the average annual water use of the five dominant invasive alien plants was 876 mm, with exotic non-woody invasive species found to use more than 940 mm of water per year - this includes Chromolaena, Lantana and Solanum.

The Working for Water programme was initiated in 1995 as a joint project between the then Department of Water Affairs and the CSIR. It currently spends R600 million each year on providing over 20 000 jobs aimed at clearing invasive alien plants. It has received international acclaim as one of the world's biggest programmes on invasive species and their impact on biodiversity and water resources.

According to Jarmain this is the first study to demonstrate the impact the Working for Water programme has on South Africa's scarce water resources using remote sensing technology. Since this study focused on quantifying the impact of clearing lower density invasions, the potential impact of clearing higher density invasions is likely to be more than the 13 and 6%.

2.2 Proposed Project On Monitoring of Irrigation Water Use

Two approaches are proposed:

- A purely commercial approach using consultants;
- and, a hybrid approach using a mix of consultants and academics.

The rationale for the hybrid approach is that it is still a relatively new area, and that it is an opportunity to build capacity in the four countries. In other respects the aims are the same as the commercial approach.

This is not a project preparation document, but it sets out aims and objectives, and outline costs.

The proposal is made with the knowledge of what has been achieved by the present Orange River Project in the way of setting up and collating various datasets.

2.2.1 Aims and Objectives

The aims and objectives of the investment are to provide a basin wide system for monitoring crop water usage by irrigated agriculture, based upon a mixture of satellite and ground observations and measurements. It is dependent on establishing, in parallel, the project described in section 1 which would provide an essential input to the activity.

A possible extension to the project that could be undertaken separately by commercial initiatives using the basic information gathered, would include a system for provision of information to support ‘precision farming’ for both rainfed and irrigated agriculture. The basic earth observation and climate data are essentially the same. ‘Precision farming’ is increasingly applied to rainfed agriculture. Ideally it requires more detailed soil information. This extension could be a part of the project or considered separately.

One objective would be to provide all computer software required as 'in the public domain'. This would allow the cost to be kept low to the four client states in achieving the objective of crop water monitoring at inter-government level, while allowing the opportunity later, for competition in delivering outputs to individual farmers on a purely commercial basis. Much of the basic knowledge for such a system is in the public domain already.

The approach would offer the possibility for monitoring 'off irrigation scheme' usage and linkage to licensing.

In order to keep costs down, the system would aim at estimation of water usage at a monthly level but not necessarily in near real-time since the inter-governmental objective would be annual assessment for the purposes of monitoring agreements. Producing near real-time information for operational purposes in water and farm management and would be a development best left to commercial enterprises, or national water authorities (e.g. DWAF).

2.2.2 Activities

Review of current technologies and Risks to Development

This review would consider previous work in Southern Africa and Globally to ensure the latest ideas and concepts were introduced in the areas of software and hardware. A risk assessment would be made as to the future viability of such a project (this could be conducted at the project preparation stage). The risk assessment would consider the probable reliability and precision for both inter-governmental purposes and irrigation scheme and farmer level usage.

Identification of Data Requirements and Sources

The different data types both necessary and ideally required include:

- medium and high resolution earth observation data;
- meteorological data
- Topographic data
- hydrogeologic data;
- hydrologic data;
- irrigation scheme measurements,
- agronomic data;
- soil data;

The identification should include evaluation of frequency and timeliness of data for different purposes.

Evaluation and Cost of Technologies to Provide Required Information at Different Time Scales

In respect of this aspect the earth observation data is mostly provided by sensors and platforms of governments other than in Southern Africa, even though Southern African government institutions may be able to receive or otherwise obtain these data. There are also several current initiatives, national and international in the provision of such data (e.g. AMESD).

Public domain software linking satellite receivers is available (e.g. 52North, ILWIS and ESA GeoNetcast system). High bandwidth internet connections also serve a purpose in this respect.

An important local input would be meteorological data. As explained since the main purpose is ‘annual level’ evaluation this should be available at relatively low cost. It is the real-time and near-real time data that gets expensive and has great protection for uses, which is one reason for targeting the system at the annual evaluation level.

Development of a System for Annual Estimation of Crop Water Usage by Irrigation in the Orange-Senqu River Basin.

The estimation would be targeted at determination of a monthly breakdown. However, this may require the use of daily data. This is why there is a need for ground measurements of meteorological data to assist with interpolating the earth observation data in time

We would propose to use ‘desk top’ super computers for the project complete with solid state disks. The computer code would be written in a language compatible with such ‘super computers’ and with modern desk-top machines, in order to widen the scope for commercial and other applications.

The existing data collated by the present Orange-Senqu River Basin project will form the basis for model development and calibration. The target would be to evaluate any proposed system against an up to 10 year period from 2000 to 2010.

The only additional data required (assuming that we can still use the meteorological data acquired for the project), are some medium resolution satellite data, e.g. Modis, AVHRR, ENVISAT etc.

2.2.3 Commercial Approach

In the commercial approach a commercial company or consortium would be invited to tender to the work in the usual way

The project period would be18 to 24 months.

We estimate the resource requirements for such an approach are:

Technical Assistance 36 person months: 750,000 euro

Equipment –Software: 200,000 euro

Purchase of data (provisional sum): 5,000 euro per year

2.2.4 Hybrid Approach

In this approach academic institutions in each of the four countries would become involved. They would provide institutional support and the project would provide project research fellowships to graduate and/or post-doctoral fellows. The project management would be provided by a commercial organization. The project period would extend over 36 months and the cost would be essentially the same as the purely commercial project.

The project period would be 24 to 36 months.

We estimate the resource requirements for such an approach are:

Technical Assistance 18 person months: 450,000 euro

Fellowships, University support etc: 300,000 euro

Equipment –Software: 200,000 euro

Purchase of data (provisional sum): 5,000 euro per year

It is assume that satellite information is free to collector, but this may change as existing satellites come to the ends of their lives.

Satellite Data (provisional sum): ???

2.2.5 Risks

It is dependent on the appropriate Earth Observation Data becoming available at an affordable cost.

3 DECISION SUPPORT SYSTEM FOR ORANGE RIVER PLANNING

An important component of any natural resource planning system is a 'scenario generation tool'. This proposed project would expand the scope of the 'crop water requirements scenario generation tool' provided by the consultants to include:

- Additional economic sectors: water, agriculture, energy, tourism, water quality, environment, commercial, domestic, etc;
- introducing optimizing;
- and, introducing risk based scenario generation.

This extension is regarded as a key requirement in the provision of an effective decision support and planning system for the Orange-Senqu Basin. An extension to this would be the provision for linking any proposed scenario generation tool to the Water Yield and Allocation Model being provided under this study.

The scenario generation tool provided under the current project does not include optimization using multi-criteria and multiple objective optimization. Given the extremely large number of options available for regulation and control of irrigation, and the risk and uncertainty in making future projections there is a need to provide a system that does allow for optimization and evaluation of risk and uncertainty. Furthermore the existing system is deterministic and only covers irrigation. It is necessary to include all water uses and water quality into decision making.

3.1 Activities:

- Review of current practice, and resource gathering for 'scenario generation' for natural resource projects, in particular water related.
- Review of macro level planning in each of the four riparian countries of the Orange-Senqu basin.
- Identification of key stakeholders and interested parties, and discussions with them as a 'focus group' to identify economic and social policy trends.
- Selection of appropriate model building tools.
- Assembly of relevant data sets.
- Model building and calibration
- Preparation of training materials.
- Provision of training to stakeholders.

3.2 Resources

The team would comprise a Resource Economist, a water resources planner and a modeler

The task would be spread over a period of 12 months to allow access to key stakeholders who are already overworked.

Some 18 months of technical assistance is proposed, with a provisional sum of 30,000 euro for software and computers. The total cost is estimated to be 480,000 Euro.

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