ACRU
WAS
SAPWAT
RISKMAN
SWB
GIS

Technology Transfer and Integrated Implementation of Water Management Models in Commercial Farming

TT 267/08

Water Research Commission

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Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

Introduction

This project relates to the transfer of technology and integrated implementation of the following models:

Agricultural Catchments Research Unit - ACRU

ACRU is an integrated agrohydrological modelling system capable of being used for, amongst others, water resource assessments, design flood estimations, crop yield assessments and irrigation water demand and supply evaluations. However, ACRU is not yet capable of easily representing complex catchment operating rules and thus for the purposes of this project it has been used primarily as a catchment-scale daily time-step hydrological rainfall-runoff model. ACRU was used to determine the streamflow from non-irrigated (i.e. dryland) lands in a catchment. The streamflow was used as input into the MIKE BASIN model (developed by the Danish Hydraulic Institute). The MIKE BASIN model was used to simulate the supply and demand interactions in catchments for given operating rules. The irrigated lands are dealt with by MIKE BASIN, and not ACRU, as the irrigated lands are subject to operating rules (which dryland land-uses are not) which are easily represented in MIKE BASIN. The ACRU model was developed by Prof R E Schulze at the School of Bioresources Engineering and Environmental Hydrology from the University of KwaZulu-Natal – Pietermaritzburg.

Water Administration System - WAS

WAS is a modelling system that promotes efficient operational management of water. WAS consists of four main modules that are integrated into a single program that can be used on a single PC or over a network. These modules can be implemented partially or as a whole, depending on the requirements of the specific irrigation scheme or water office. The four modules are summarized as follows:

- The **Administration** module administers the details of all water users of a scheme or water office. Information including addresses (owners, tenants and postal), scheduled areas, water quota allocations, household and livestock pipes installed, list of rateable areas (LRA), crops planted, planted areas and crop yields are managed in this module. All information can be printed.
- The **Water orders** module administers water usage through pressure-regulated sluice gates, water meters and measuring structures. Water orders can be captured using a water order form based on a flow rate and time or using meter readings based on a start and end reading. Conversion factors can be captured in WAS to convert meter readings automatically if necessary. A range of reports is available for printing that includes water allocations and water balances per user, water balance sheets per user and a water usage summary.
- The **Water accounts** links with the water orders module and administers all water accounts for a scheme or water management office. The user can choose between two major accounting systems. The first is the current Department of Water Affairs accounting system

and the second a full debit system, from which monthly reports can be printed, including accounts on pre-printed stationery, reconciliation reports, age analysis and audit trail reports.

- The **Water release** module links with the water orders module and calculates water releases for the main canal or river and all its branches and tributaries allowing for lag times and any water losses and accruals. A schematic layout of the total canal network or river system is captured with detail such as the cross-sectional properties, positioning of sluices or pumps, canal or river slope, structures and canal or river capacities. Discharges are converted to the corresponding measuring plate readings where needed. Water distribution sheets and water loss analysis reports can be printed for canal or river systems.

Dr Nico Benadé initially developed WAS to capture water orders which were needed for an open channel simulation model. The model was further developed through Water Research Commission projects done at the Rand Afrikaans University and subsequently further developed by NB Systems. Dr Nico Benadé was responsible for the technology transfer of WAS.

Crop Water Use Model -SAPWAT

SAPWAT is a crop water use planning model that can be applied at field or scheme scales. SAPWAT was developed by Mr C Crosby at Murray Biesenbach and Badenhorst and subsequently further developed by Mr P S van Heerden of PICWAT consultants. The SAPWAT model is used for planning purposes, and is used to estimate the crop water use requirements of different crops under different irrigation systems and different irrigation management regimes throughout South Africa and neighbouring countries.

Soil Water Balance model - SWB

SWB is a generic, mechanistic model for real time irrigation scheduling at field scale (i.e. for operational purposes). SWB has been developed by Prof John Allandale of the University of Pretoria. The model has been further developed in the course of this research project, and is now also able to be used for planning purposes. The model has been renamed to SWB-Pro to differentiate it from the previous version.

Risk Manager - **RISKMAN**

RISKMAN is a simulation model of net cash-flow for water use and crop combinations at specified risk levels at a farming scale. The model was originally developed by Prof A Meiring at the University of the Free State. The model is generally applied at farm scale.

All the models share a common thread in that they can all be used to promote the improved management of water resources. Each of the models listed above has been developed over a number of years with funding from the Water Research Commission. For all the models independent technology transfer projects have been undertaken. This project relates to the integrated implementation of the models, targeting five Water User Associations and two Irrigation Boards across South Africa. The rationale for the integrated transfer of technology for the suite of models relates to the following fact: many of the models were developed prior to the promulgation of the 1998 National Water Act. The models were developed for very specific purposes. The 1998 National Water Act calls for water to be used in an equitable, efficient and sustainable manner. Water users in South Africa require decision support to meet the objectives of the Act. As the models listed above cater for specific aspects of water resource management, and at specific spatial scales, it makes sense to technology transfer the suite of models to water users, so that a holistic optimal solution to challenging management situations can be found.

All models are driven by some form of input data, which is then transformed into information via computational processes housed through the models. A central approach of this integrated technology transfer (TT) project was to capture high quality data of the targeted participant Water User Associations and Irrigation boards in a Geographical Information System (GIS). It was clear from earlier WRC projects that stakeholders showed a strong interest in GIS packages, largely due to the understanding that the use of GIS promotes for spatial and temporal information. This is due to the graphical (visual) nature of GIS which enables features to be viewed in a spatial context. In order to promote the buy-in from potential WUA and IB participants, a key feature of the project was the collection of data pertinent to the WUAs and IBs which would then be captured in a GIS. The data incorporated in the GIS could then be used (with other input data) to drive the models associated with the TT project. The original thinking was to develop a unified database, from which all the models would draw their input-data, and write their output data. This thinking was revised in the course of the project, as a development of this nature would be very complex in terms of the additional computer programming involved, and would not necessarily add much value to the project. Instead, the data housed in the GIS can be exported for use by the respective models.

This integrated transfer of technology project targeted the commercial irrigation sector in particular since, according to the National Water Resources Strategy (NWRS, first edition, 2004), this sector is responsible for over 62% of South Africa's total water use. The terms of reference required the research team to (i) identify, (ii) negotiate with and (iii) select 5 – 7 Water User Associations or Irrigation Boards to participate in the technology transfer project. A key objective of the project was for the models to be used sustainably after the completion of the project to increase the efficiency of water use. As such, the potential participant WUAs / IBs were evaluated in terms of (i) their user needs for the respective models, (ii) the level of commitment shown and (iii) the level of infrastructure of the respective schemes. The participants were ranked in terms of these criteria, and short-listed. It is hoped that the WUAs / IBs which were selected will act as centres of excellence, from which other WUAs / IBs can learn over time.

At the first reference group meeting of the project, it was pointed out that the term "technology transfer" is possibly not the most appropriate option available, with the term "technology exchange" being a preferable option. The reason for this stems from the fact that both the research team and the representatives from the participating Water User Associations, Irrigation Boards and associated farming circles would benefit from a mutual exchange of knowledge. The research team did in fact learn a tremendous amount from the participating WUAs and IBs, as well as from farmers, which in some cases resulted in the models associated with the technology transfer project being modified to better suite the needs of the WUAs and IBs. It is thus requested that throughout this document, the term "technology exchange" is inferred where the words "technology transfer" are used.

Project objectives and the progress made against the objectives

The project had 13 clearly defined objectives. These are detailed below. Comments related to the objectives are included in italics.

1. The research team was to undertake an exploratory overview of potential target irrigation scheme options, and to provisionally select 5 to 7 irrigation schemes as study areas in consultation with WRC and DWAF.

   The irrigation scheme options include Water User Associations, or Irrigation Boards which have not yet converted to WUAs.

2. The research team was to forge an improved understanding of the minimum data requirements common to all the models associated with the Technology Transfer project, as well as the intricacies of configuring and operating the respective models.

   It became clear that a central database, capable of driving all the models associated with the TT project was not viable in the course of the project. The models all have very unique data requirements, and operate at different scales. A unified database suitable of housing data inputs for all the models, as well as the outputs generated from the models would be very complex, and would not yield any significant value to the project. The research team did however realise the importance of the data captured in the GIS. In effect the GIS data (captured in the GIS database), could be exported (manually) to the databases of the respective models.

3. The research team was to consult with end-users (staff of Water User Associations (WUA) and farmer representatives) of the 5 to 7 provisionally selected irrigation schemes to:
   - Explain the purpose of the Technology Transfer project,
   - Present different models for water management decision support,
   - Identify water management requirements on irrigation schemes,
   - Identify potential users and capture associated user need requirements, and
   - Determine which data are available for the identified schemes.

   The research team made contact with numerous candidate participant Irrigation Boards and WUAs. Consideration was given to the user needs of the candidates (i.e. the potential need for the models being technology transferred), as well as the interest shown by the candidates to participate in the study, as well as the resources available (e.g. staff, computers, etc.) to the candidates. One of the key objectives of the project was for the models to be used sustainably after the completion of the project. Therefore only those WUAs and IBs which displayed a high user need for some or all of the models, while exhibiting a high degree of interest combined with an acceptable level of resource availability, were short-listed as potential candidates for the project.

4. With a better understanding of each irrigation scheme, the research team was to revisit the schemes with the appropriate team members. The objective of the "revisit" was to:
   - Highlight to the participant stakeholders the integrated modelling approach within the context of the water supply system and to demonstrate the integrated application of these models in water management, and
   - For stakeholder participants to share local knowledge with the research team.

5. With the information gleaned from objective 4, the research team was to reassess the user need requirements.

6. Following on from objective 5, the research team was to decide which schemes were to be addressed within available funding constraints and the combination of models that needed to be used for each selected scheme.

   The following WUAs and IBs were selected to participate in the study:

- The Loskop Irrigation Board
- The Nkwaleni WUA and Mfuli and Heatonville Irrigation Boards in the Mhlathuze Catchment
- The Vaalharts Water WUA
- The Oranje-Riet WUA
- The Lower Sundays River WUA
- The Gamtoos Irrigation Board, and
- The Lower Olifants River WUA.

A map of South Africa is shown below in Figure 1 which illustrates the geographical location of the respective participant WUAs/IBs. The seven participating WUAs/IBs are spread throughout South Africa and thus have different climatic conditions.

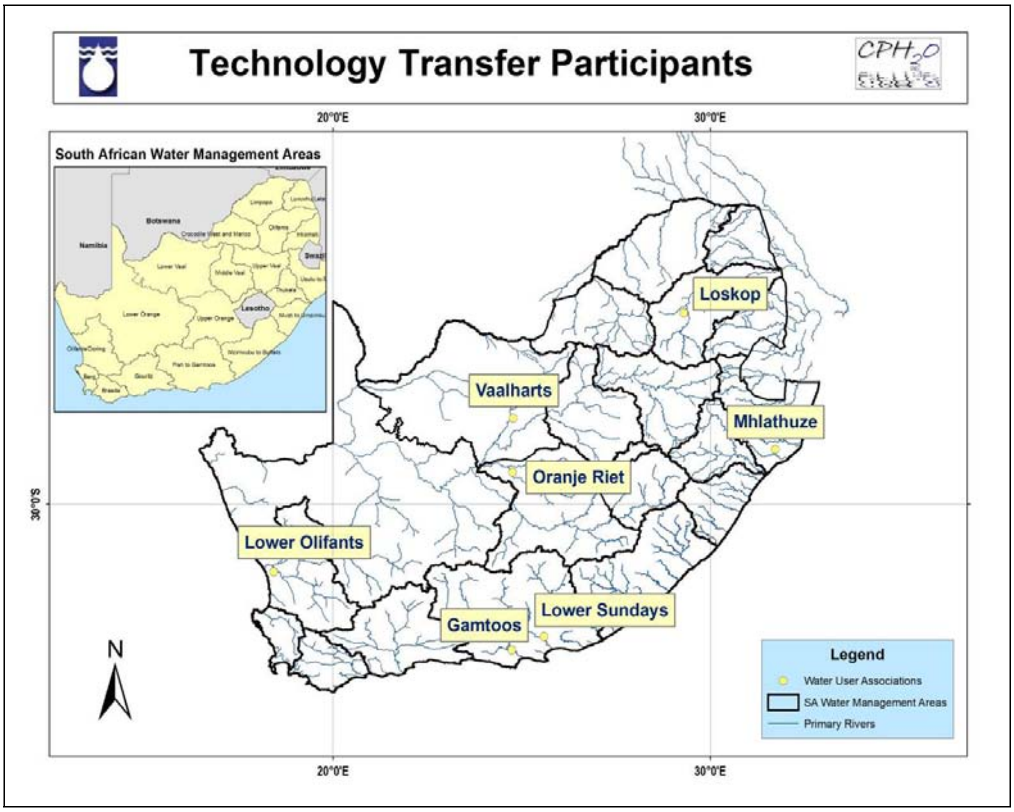

Figure 1 A map illustrating the location of the participant WUAs / IBs

Table 1 below details the needs of the participant WUAs / IBs for the models (or model modules) forming part of the TT project.

Table 1 User Needs of the Water User Associations and Irrigation Boards

					WAS			
IB / WUA	ACRU MIKE BASIN	SWB	RISKMAN	SAPWAT	Admin module	Accounts Module	Request Module	Release Module
Mhlathuze	High interest							
Loskop	High interest	High interest	High interest		Already using	Already using	Already using	High interest
Vaalharts			High interest	High interest	Already using	Already using	Already using	High interest
Oranje Riet			High interest	High interest	Already using	Already using	Already using	Already using
Lower Olifants					Already using	Already using	Already using	High interest
Lower Sundays River		High interest			High interest	High interest	High interest	High interest
Gamtoos		High interest	High interest		Already using		Already using	

HIGH INTEREST SHOWN IN MODEL / SYSTEM
ALREADY USING THE MODEL / SYSTEM

7. Within the research team, test, evaluate and adapt the integrated GIS and modelling system for the successful implementation of the models to the targeted research areas.

8. Collect spatial information and install an appropriate GIS.

   Very detailed GIS information was captured in the course of the project. As the costs of capturing detailed imagery of the WUAs / IBs and subsequent annotation in GIS is high, WUAs / IBs interested in the GIS component were asked to co-fund this component. The table below details the WUAs for which GIS information was captured. Co-funding equal to half the cost was received from the relevant WUA / IB for which the GIS tasks (i.e. imagery acquisition and/or GIS annotation) was undertaken.

   Table 2 below illustrates the WUAs / IBs which opted for GIS tasks to be undertaken.

Table 2 GIS Needs of the Project Participants

IB/WMA	Imagery	Annotation
Mhlathuze	Available	Available
Gamtoos	Available	Required
Loskop	Required	Required
Lower Olifants		
Lower Sundays River	Required	Required
Oranje Riet	Available	Available
Vaalharts Water	Required	Required

(green)	Available
(red)	Required
(blank)	Not interested

9. Populate database (collect/collate/verify data)

   A single unifying database was not created. The data captured in the GIS database was exported (manually) to the databases of the respective models.

10. Install the appropriate combination of models for the selected target groups e.g. WUA staff, farmer study groups and advisors/extension officers

    The models or modules with a high user need were configured and technology transferred to the relevant participant WUAs / IBs.

11. Develop and present training courses for end-users (WUA staff, extension officers/advisors/farm leaders, etc.)

    User manuals were prepared for the various models. In addition to this training courses were held for the respective models and GIS.

12. Interact with end-users through workshops or information sessions to evaluate acceptance and effectiveness of the technology transfer.

    In general, the research team visited the respective WUAs / IBs to give effect to the transfer of technology associated with the models the WUA / IB showed a high interest in. In addition to this, a 3-day workshop was held, to which all WUA / IBs and individual farmers were invited. An open GIS training course was also offered to interested participants.

13. Put in place a process for hand over and continuation, i.e. formulate an exit strategy.

    A significant amount of work was done to either further develop the respective models, or the relationship between the researchers amongst themselves and/or between the researchers and the participating WUA / IBs to ensure that the models would be used sustainably over time. The current demand for some of the TT models is very clear, and the models (or modules) are either currently being used, or will soon be used. However, for other models, the demand is still growing. For example, the use of SWB for real-time irrigation scheduling is anticipated to become utilised to a far greater degree in the future, particularly after the Compulsory Licensing process has been undertaken in over-allocated catchments. The focus has been to develop the models to be used by consultants, who can then service the growing needs for this type of service in the future. It must be borne in mind that the models have generally been developed by academic organisations, and hence the focus of the models has often been on scientific correctness, and not necessarily on packaging the software to be used by consultants in a cost-effective manner. The objective for the models to be used sustainably over time had a large bearing on the actions and developments initiated in the course of the project. Further details in this regard are provided in the sections below. User manuals have been developed for the models, which are downloadable of the World Wide Web.

Project results

The project goals have been achieved in adapting, combining and implementing the models to the selected WUAs/IBs for which a high user need was shown. The project has resulted in the research team members being more aware of the integrated user needs of irrigation schemes. This has resulted in some of the models being further developed during the course of the project to with better integrate with one another. The sections below detail the progress made with respect to the various models and GIS component of the project.

- The GIS component of the project

The participant WUAs / IBs were given the option of having detailed data relevant to the schemes captured in a GIS. This option was more favourably received than originally anticipated. Not only did the vast majority of the participating WUAs / IBs opt for the GIS to be undertaken for their management areas, they also agreed to co-fund the GIS component (paying for half the costs associated with the GIS tasks). Participants also, in general, opted for more detailed GIS tasks to be undertaken than the research team anticipated they would. The GIS tasks included (i) the capture of imagery at a fine scale of resolution, and (ii) the use of the imagery to annotate features such as fields, canals, roads, weirs, etc. The option was given to the WUAs / IBs to have the imagery flown at different options of resolution, (i.e. 0.5 m, 0.75 m and 1 m pixel resolution). The cost of flying at a higher level of resolution becomes higher in a non-linear manner. It was anticipated that most WUAs / IBs would opt for the 1m pixel resolution option, as this would be the cheapest option. A few of the WUAs / IBs, bearing in mind that they were responsible for half the bill, opted for the 0.75 m pixel resolution option even though it was more expensive.

There were some delays in the acquisition of the GIS imagery, largely due to poor weather conditions. The detailed imagery has enabled very detailed annotation of features such as farm fields, canals, waste-canals, weirs, dams, etc. This information is valuable not only to the participating WUA / IBs, but will also be valuable to other research projects. The WUAs / IBs make use of the GIS imagery and annotation in various ways. However, it appears that the GIS has on its own provided the WUAs / IBs with better information to help plan and operate their areas of management. For example, the GIS enables the WUAs / IBs to independently verify crop types and areas with certainty without having to request this information from the water users. The GIS imagery provides an effective medium to identify where canals are in a poor state of disrepair, or where waste-canals are required. The GIS component of the project has significantly contributed to the success of the project.

- *ACRU-MIKE BASIN*

In the course of the project developments were undertaken to link ACRU with MIKE BASIN via a GIS interface. Although MIKE BASIN has not been developed with funding from the WRC, the WRC has funded some projects where MIKE BASIN has been used. ACRU is a rainfall-runoff model, whereas MIKE BASIN is a node-and-channel network model. The relevance is that a node-and-channel network model makes use of streamflow (which is output from ACRU) as one of its inputs. Given the fact that a number of the catchments in the country are considered to be over-allocated, linking ACRU with MIKE BASIN has enabled a methodology to quantify the extent of over-allocation. Water resource planners in South Africa currently make use of the Water Resources Yield Model (WRYM), a node-and-channel-network model, which is fed with streamflow generated from the Pitman model. The ACRU-MIKE BASIN linkage provides an alternative to the Pitman-WRYM combination, and has some advantages over the Pitman-WRYM, which relate to (i) the time-step that the models operate on (i.e. daily as opposed to monthly), and due to the fact that ACRU is a process based hydrological model, which allows various landuse and management practice scenarios to be considered which are not suited to the Pitman modelling framework since it is a regression model.

As part of the TT project, developments were undertaken that enable ACRU be easily set-up from within a GIS environment, using GIS data available at a national scale. The ACRU-MIKE BASIN models were then configured for the Loskop Catchment area, as well the Mhlathuze Catchment, as both of these catchments are deemed to be over-allocated according to the National Water Resources Strategy. It is not plausible that the members of the WUAs and IBs will themselves directly use the ACRU-MIKE BASIN software, as the models need to be operated by experienced hydrologists or water engineers. What is plausible though is that the WUAs and IBs make use of consultants who have access to ACRU-MIKE BASIN, particularly in over-allocated catchments.

- *WAS*

The Water Administration System (WAS) consists of four main modules, which include the administration module, the accounts module, the water order module, and the water release module. The software can be utilised by a CMA or by a WUA. Many of the participating WUAs / IBs were already using some of the WAS modules. In general, the one module that was not being used was the release module. The reason for this is that of all the modules, the release module is the most expensive to configure and most difficult to operate. Another reason is that many of the water control officers make use of their own rules (some computer aided) to aid them with water release decisions.

In the course of the TT project the release module has been configured for most of the WUAs / IBs, and the water control officers have been trained in the use of the release module software. The feedback from the water control officers has been very favourable, and it is probable that the release module will continue to be used sustainably by the water control officers participating in the research. In addition to this, the Department of Water Affairs and Forestry has shown an interest in the WAS model and may request that all WUAs use the WAS software to generate their water disposal reports.

A GIS based script has been developed which enables the WAS database to be queried from within the GIS environment. It is unclear at this stage if this development will be of great value to the WUAs / IBs. If it is, the recommendation will be put forward to more formally integrate WAS with a GIS environment.

- *SAPWAT*

SAPWAT is a crop water use model which is generally used for planning purposes at various spatial scales (e.g. WUA scale to field scale). The model has been very successful over time, and the research team explored the reasons behind this. Some of the key reasons for SAPWAT's success include the following:

- ❑ The model was pre-packaged with key input data (weather, soils & crop data), which were used to drive the model. The implication is that potential users did not have to spend time and effort to find, format and capture this data,
- ❑ The model was structured in a manner that is relatively easy to understand. It is quite easy to configure a scenario in SAPWAT, to run the model and then to output and display the results. The turn-around time to simulate the water use of a crop for a given scenario is thus very quick, and the results are accurate within acceptable levels of confidence. The result is that many consultants and DWAF personnel make use of the model.
- ❑ The model is scientifically based, and finds a sound balance between keeping the model practically operable and scientifically sound.
- ❑ The model is well supported by its developers, who are able to respond to queries and/or requests very quickly.

As the SAPWAT model was already being used by many of the participant WUAs / IBs, there was not much scope to further technology transfer SAPWAT. SAPWAT was however used to simulate the crop water use requirements for the dominant crops and management practices for each of the participant WUAs. This allows a quick comparison to be made of the impact of spatial location and management practice of given crops for different areas in South Africa.

- *SWB*

The SWB is a field-scale crop growth model, which is able to accommodate different crops, as well as different irrigation system and management options. In response to feedback received from the participant WUAs / IBs, a number of developments were undertaken on the SWB-model. Some of the key developments include:

- ❑ The SWB-model was pre-packed with weather and soil data for South Africa. This enables it to be used for planning purposes, as use is made of long time series of historical weather data.

- The Graphic User Interface to SWB was modified, to make it more user-friendly.
- An initial conditions scenario is generated by utilising the pre-populated database, which the user can then adjust. The implication is that the turn-around time to get a base run initiated is significantly improved.
- A scenario generator option has been developed, which allows multiple crop and irrigation scenarios to be configured with ease.
- The model has been developed to provide model outputs which can be readily fed into the RISKMAN model, thereby allowing hydro-economic scenarios to be considered.
- A number of software upgrades were undertaken. For example the database was migrated from a paradox database to that of Firebird SQL database.

The developments listed above were deemed to be very important to enable the sustained use of the model after the completion of the project. In addition, much effort was expended to promote the use of the model by end users. The SWB model has been renamed to the SWB-Pro version, in order to distinguish it now from the previous version. The TT project team believes that the demand for the SWB-Pro software will continually increase over time, as the cost of water increases and the opportunity cost of water is recognised by the water users.

- *RISKMAN*

RISKMAN is a software package that enables water users to assess the risks of certain water use and land use (i.e. crop) options. SWB-Pro has been developed to generate outputs which are then used as inputs into the RISKMAN model. The SWB-Pro & RISKMAN models combined offer WUAs and water resource managers in general a tool to help assess the hydro-economic implications of various water management decisions.

The demand shown for RISKMAN in the course of the TT project was not very high, but as with the SWB-Pro model, it is anticipated that this demand will soon grow, particularly following the completion of the Compulsory Licensing process in over-allocated catchments. The SWB-Pro / RISKMAN combination may even be used to help guide licensing decisions during the Compulsory Licensing process, as the combined set of models enables the hydro-economic impact of various landuse and management scenarios to be simulated.

It can be said that the objectives of the contract have been achieved for two main reasons. Firstly, the models have been successfully technology transferred to the WUAs / IBs which illustrates a high interest for the respective models. Secondly, the models have been further updated in response to valuable feedback received from the participant WUAs and IBs, which will promote the sustained use of the models after the completion of the project.

Capacity building

The capacity of the research team has been built in response to the integrated nature of the technology transfer. The interaction with persons from the participant WUAs and IBs has further developed the understanding held by the research team members regarding the practicalities faced by the WUAs / IBs. This is very important, as the research team members are in effect developers of solutions, which are translated into algorithms in software, for application by the WUAs / IBs, either directly or indirectly. An appreciation of the realities faced by the WUAs / IBs enabled the research team to either develop more appropriate solutions, or to package the solutions in a manner that is useful to the end-users.

The capacity of the participant WUAs and IBs has been increased, in that they have been exposed to the models associated with the TT project. They have also been exposed to GIS, and have had training in the use of GIS.

In the course of the project the research team presented the various models to persons in the Department of Water Affairs and Forestry (Pretoria office). In general, the models used for the TT project are of a higher spatial and/or temporal resolution than the models currently used in DWAF. Although DWAF has not formally requested the models (other than WAS), they are, as a result of the project, more familiar the details and functionality of the models forming part of the TT project.

Conclusions

The technology transfer project has in effect been a technology exchange project, the goals of which have been achieved. The WUAs / IBs have shown a very high interest in the use of GIS, which is very encouraging, as the GIS data, if kept current over time, will provide valuable input data for the various models forming part of the TT project. The current user needs for some of the models is very high, resulting in the models either being used now, or the intention to use the model in the near future (e.g. WAS & SAPWAT). For some of the other models the user need is growing, and is anticipated to grow significantly once the compulsory licensing process has been completed in many of the over-allocated catchments in the country. Models like SWB and RISKMAN will be very useful to test the hydro-economic impact of various water-use and land-use scenarios. Like-wise, the ACRU-MIKE BASIN model combination is well placed to assist water resource managers and stakeholders evaluate water management scenarios.

Recommendations

1. To further develop the ACRU – MIKE BASIN model combination to also include RISKMAN. The reasons for this are:
    - The SWB-Pro is currently unable to simulate catchment operating rules (which will have an impact on the quantity of water available to water user, particularly when restrictions are imposed), and
    - The SWB-Pro is unable to simulate return-flows.

    As many of our catchments are over-allocated, water resource managers will want to assess the hydro-economic impacts of various operating rules, and license allocation decisions on water users. The ACRU-MIKE BASIN linkage is a useful platform to work from. What is missing is the economic component, which is the RISKMAN model. The alternative will be to further develop the SWB-Pro model, but this may be significantly more complex than the option being tabled.

2. The SWB-Pro model should ideally be further developed to also make use of short term rainfall forecasts, which may influence the scheduling advice generated from the model. The SWB-Pro currently does not give any consideration to short-term rainfall forecasts.

3. It is recommended that the WRC and/or DWAF provide funding to support a technical user support unit, which continues supporting the use of the models associated in the Technology Transfer project. Although the Technology Transfer project was successful, it targeted only 7 WUAs / IBs, which is a very small percentage of the total number of WUAs and IBs in the country. At some stage all water users will require assistance in the management of their water, be it a catchment scale, scheme scale, or field scale. An organisation such as the former Computing Centre for Water Research (CCWR) would be a suitable organisation to provide support and assistance for this purpose.

4. GIS based software should be developed to help WUAs / IBs with the planning and administration of canal maintenance. The GIS is very visual facilitating an improved understanding of the issues to users.

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The project Reference Group Members included:

Dr GR Backeberg	:	Water Research Commission (Chairperson)
Dr AJ Sanewe	:	Water Research Commission
Mr PJ Strumpher	:	Department of Agriculture
Mr C Chunda	:	Department of Water Affairs and Forestry
Mr HJJ van Stryp	:	Loskop Irrigation Board
Mr NE Knoetze	:	Orange-Riet Water User Association
Mr WF Bruwer	:	OranjeVaal Water User Association
Mr CT Crosby	:	PICWAT consultants
Dr NL Lecler	:	South African Sugarcane Research Institute (SASRI)
Mr JJ Momberg	:	Vaalharts Water User Association

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- Mr Kevin Meier for his assistance with the linkage of ACRU and MIKE BASIN,
- The Danish Hydraulic Institute for their assistance with the linkage of ACRU with MIKE BASIN,
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- Persons who have been involved in assisting with the management of the project, and associated functions. In particular Mr Richard van der Merwe of Clear Pure Water for assisting with the final editing of the document.

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ABBREVIATIONS

AAMG	Amalgamation of Agro-Hydrological Groups
ACRU	Agricultural Catchment Research Unit
DOA	Department of Agriculture
DWAF	Department of Water Affairs and Forestry
GIS	Geographic Information Systems
IBS	Irrigation Boards
LORWUA	Lower Orange River Water User Association
SWB	Soil Water Balance
TT	Technology Transfer
WAS	Water Administration System
WRC	Water Research Commission
WUAS	Water User Associations

1. INTRODUCTION

In April 2004 a three year Water Research Commission (WRC) funded Technology Transfer Project was initiated. Co-funding from the Department of Agriculture (DOA) and the Department of Water Affairs and Forestry (DWAF) was also received. The aim of the project was to effectively transfer the integrated implementation of computer models to a number of participant Water User Associations (WUAs) and Irrigation Boards (IBs) spread across South Africa. The models were:

- ACRU
- WAS
- SAPWAT
- SWB
- RISKMAN

Each of the above-mentioned decision support models has been developed independently from each other over a number of years at different locations in South Africa and by different researchers. The models all relate to the management of water from catchment to field scale, although the purpose of the models is often quite unique and the outputs are thus project specific. A short description of each of the models forming part of the integrated technology transfer project is outlined in Table 1.1 below. The table indicates the details of the person responsible for the technology transfer of the particular model.

Table 1 Description of the Models Forming Part of the Technology Transfer Project

Agricultural Catchments Research Unit - ACRU	ACRU is an integrated agrohydrological modelling system capable of being used for, amongst others, water resource assessments, design flood estimations, crop yield assessments and irrigation water demand and supply evaluations. However, ACRU is not yet capable of easily representing complex catchment operating rules and thus for the purposes of this project it has been used primarily as a catchment-scale daily time-step hydrological rainfall-runoff model. ACRU was used to determine the streamflow from non-irrigated (i.e. dryland) lands in a catchment. The streamflow was used as input into the MIKE BASIN model (developed by the Danish Hydraulic Institute). The MIKE BASIN model was used to simulate the supply and demand interactions in catchments for given operating rules. The irrigated lands are dealt with by MIKE BASIN, and not ACRU, as the irrigated lands are subject to operating rules (which dryland land-uses are not) which are easily represented in MIKE BASIN. The ACRU model was developed by the School of Bioresources Engineering and Environmental Hydrology from the University of KwaZulu-Natal - Pietermaritzburg. The project research member responsible for the TT of ACRU was Mr Andrew Pott and his colleagues from Clear Pure Water CC, with assistance from the School of Bioresources Engineering and Environmental Hydrology at the University of KwaZulu-Natal – Pietermaritzburg.
Water Administration System - WAS	WAS is a modelling system that promotes efficient operational management of water. WAS consists of four main modules that are integrated into a single program that can be used on a single PC or over a network. These modules can be implemented partially or as a whole, depending on the requirements of the specific irrigation scheme or water office. The four modules are summarized as follows:

	• The **Administration** module administers the details of all water users of a scheme or water office. Information including addresses (owners, tenants and postal), scheduled areas, water quota allocations, household and livestock, pipes installed, list of rateable areas (LRA), crops planted, planted areas and crop yields are managed in this module. All information can be printed. • The **Water orders** module administers water usage through pressure-regulated sluice gates, water meters and measuring structures. Water orders can be captured using a water order form based on a flow rate and time or using meter readings based on a start and end reading. Conversion factors can be captured in WAS to convert meter readings automatically if necessary. A range of reports is available for printing that includes water allocations and water balances per user, water balance sheets per user and a water usage summary. • The **Water accounts** links with the water orders module and administers all water accounts for a scheme or water management office. The user can choose between two major accounting systems. The first is the current Department of Water Affairs accounting system and the second a full debit system, from which monthly reports can be printed, including accounts on pre-printed stationery, reconciliation reports, age analysis and audit trail reports. • The **Water release** module links with the water orders module and calculates water releases for the main canal or river and all its branches and tributaries allowing for lag times and any water losses and accruals. A schematic layout of the total canal network or river system is captured with detail such as the cross-sectional properties, positioning of sluices or pumps, canal or river slope, structures and canal or river capacities. Discharges are converted to the corresponding measuring plate readings where needed. Water distribution sheets and water loss analysis reports can be printed for canal or river systems. Dr Nico Benadé initially developed WAS to capture water orders which were needed for an open channel simulation model. The model was further developed through Water Research Commission projects done at the Rand Afrikaans University and subsequently further developed by NB Systems. Dr Nico Benadé was responsible for the technology transfer of WAS.
SAPWAT	SAPWAT is a crop water use planning model that can be applied at field or scheme scales. SAPWAT was originally developed by Mr Charles Crosby while working for MBB Consulting Engineers with funding from the Water Research Commission. SAPWAT has subsequently been further developed by PICWAT consultants. A recent project to further develop SAPWAT has been initiated with funding from the WRC, which will translate into a new version of the model, referred to as SAPWAT 3. The SAPWAT model is used for planning purposes, and is used to estimate the crop water use requirements of different crops under different irrigation systems and different irrigation management regimes throughout South Africa and neighbouring countries. The research team member responsible for the technology transfer of SAPWAT was Mr

	Pieter van Heerden who is a member of the PICWAT consulting team.
Soil Water Balance - SWB	SWB is a generic, mechanistic model for real time irrigation scheduling at field scale (i.e. for operational purposes). SWB has been developed by the University of Pretoria. The model has been further developed in the course of this research project, and is now also able to be used for planning purposes. The model has been renamed to SWB-Pro to differentiate it from the previous version. The research team member responsible for the technology transfer of SAPWAT was Dr Martin Steyn from the University of Pretoria.
Risk Manager - RISKMAN	RISKMAN is a simulation model of net cash-flow for water use and crop combinations at specified risk levels at a farming scale. The model has been developed by the University of the Free State. The model is generally applied at farm scale. The research team member responsible for the technology transfer of RISKMAN was Mr Bennie Grové from the University of the Free-State.

Each of the models listed above has already been technology transferred as part of previous projects, independently of one another, and at different points in time, and often to different end users. The purpose of this project was to technology transfer the models in an integrated manner. This meant is that the developers of the respective models formed part of one research team. The objective of the research team was to work closely with managers on 5 to 7 commercial irrigation schemes i.e. Water User Associations (WUAs) or large Irrigation Boards (IBs) with the objective of technology transferring some or all of the models to the participant WUAs and IBs. The rationale for undertaking the integrated transfer of technology associated with the models stems from the fact that the (i) the models cater for specific aspects associated with the management of water, and (ii) the National Water Act (Act 36 of 1998) calls for water resources to be managed in a more integrated manner. The time has thus dawned for a few, if not all, of the models to be used in conjunction with one another to find improved solutions to challenges that relate to the more efficient and effective management of water from catchment to field scale.

The integrated technology transfer project targets the commercial irrigation sector in particular, given the fact that the commercial irrigation sector is the dominant water user in South Africa, utilising approximately 62% of the water used in the country (National Water Resources Strategy, first edition, 2004). There are literally hundreds of irrigation boards and Government Water Schemes in the country which will over time be transformed into Water User Associations. A number of these have already transformed to WUAs. Realising that it would be impossible to technology transfer the models to all the WUAs and IBs in the country, the objective was set to identify 5 to 7 suitable WUA and IB candidates, and to work with these candidates in the course of the project.

A list of WUAs and IBs and their telephone contact details was obtained from the offices of the Department of Water Affairs and Forestry (DWAF). During the telephonic conversation particulars of the project were discussed with the members of the WUAs and IBs, and the contacted persons were asked (i) if a potential need for some or all of the models existed, (ii) if the IB/WUA would be interested in participating in the project, and (iii) what types of resources were available to the IB / WUA (in terms of man-power, and computing power). Given the fact that key objective of the project was to promote the use of the models after the completion of the project, the responses from the telephonic interview were used to do a first-round short-listing of potential candidates to participate in the research.

The first-round short-listed candidate WUAs / IBs were then visited by a member of the research team, at which meeting more comprehensive details of the project were shared with members of the respective WUA or IB. At the same time the researcher ascertained the potential need for and interest in the respective project models. A table summarising the user needs of the models was then drawn up, which also captured the interest shown by the respective WUA / IB to participate in the project (subjectively ranked on a scale from 1 to 10 by the research team member/s) as well as a score for the capacity (human and computer) of the WUA / IB. The research team then gave consideration to the geographic location of the WUA / IB, as a representative spread of WUAs / IBs across South Africa was desired.

The short-list was reduced to 7 potential candidates, which include the following WUAs and IBs across South Africa.

- The Loskop Irrigation Board
- The Nkwaleni WUA and Mfuli and Heatonville Irrigation Boards in the Mhlathuze Catchment
- The Vaalharts Water WUA
- The Oranje-Riet WUA
- The Lower Sundays River WUA
- The Gamtoos Irrigation Board, and
- The Lower Olifants River WUA

A key strategy of the technology transfer project was for the research team to collect high quality GIS data pertaining to the participant WUAs and IBs. The GIS data collected would include input data required by the TT models. The strategy to include a GIS component to the project was based on an observation by the WRC that a GIS enables stakeholders to better understand data of a spatial nature. This is largely due to the graphical nature of GIS packages. The GIS in effect helps transform data into information which stakeholders can query and interpret. The inclusion of the GIS component was thus intended to serve two purposes; firstly the collation of the data would help with the configuration of the models in the TT project, and secondly, and more importantly, the GIS component would promote the willingness of WUAs and IBs to participate in the research. This strategy proved to be a good one, as the participant WUAs and IBs showed a keen interest in the GIS component, and the GIS assisted greatly with the setup of certain of the TT models (e.g. the WAS water release module).

2. DETAILS OF THE PARTICIPANT WATER USER ASSOCIATIONS AND IRRIGATION BOARDS

2.1. Study Area Background

The following figures illustrate the position of the Water User Associations and Irrigation Boards which participated in the Technology Transfer Project. The maps detail Mean Annual Precipitation, Mean Annual Evaporation as well as altitude for the locations of the various participants. It was an important aspect of the project that areas were geographically dispersed throughout the country to take into account the issue of climatic variability. These differences are important when evaluating the performance of model developments and enhancements since greater understanding is thus gained regarding the performance of the respective models under differing conditions.

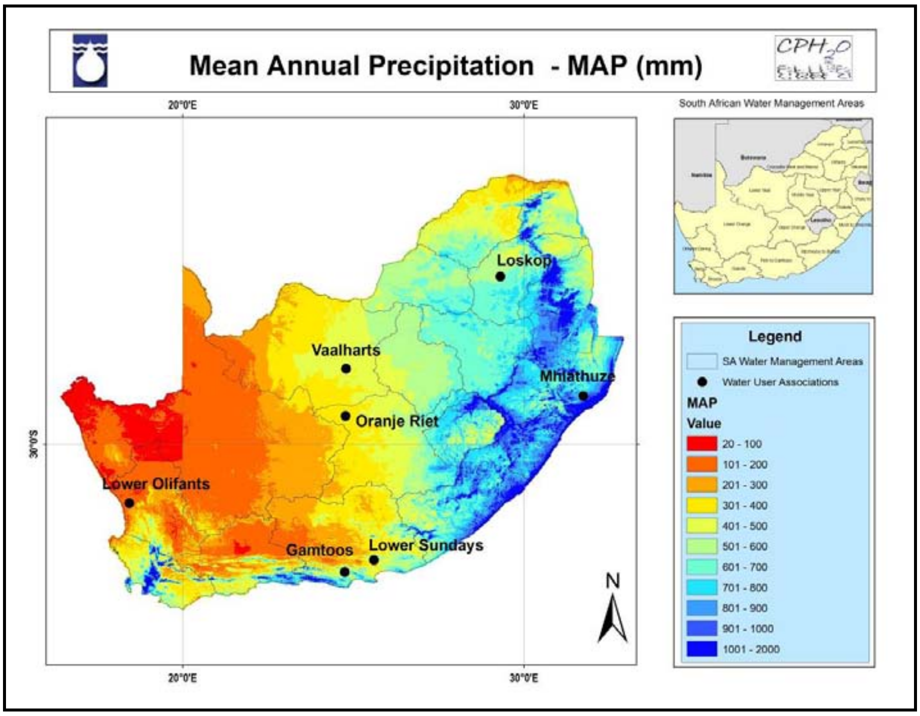

Figure 2.1 Mean Annual Precipitation of Southern Africa (after Schulze, R. E., 2006) with the Locations of the Participant Water User Associations

The above figure illustrates the variation in the amount of rainfall that the respective Water User Associations receive. The rainfall amounts vary from 0-200mm per annum on the west coast of Southern Africa where the Lower Olifants River Water User is located, to 800mm per annum on the east coast where Mhlathuze catchment is situated. Values of 300-500mm are evident in the central regions in the area of the Vaalharts and Oranje Riet Water User Associations.

Figure 2.2 below illustrates mean annual evaporation values for Southern Africa.

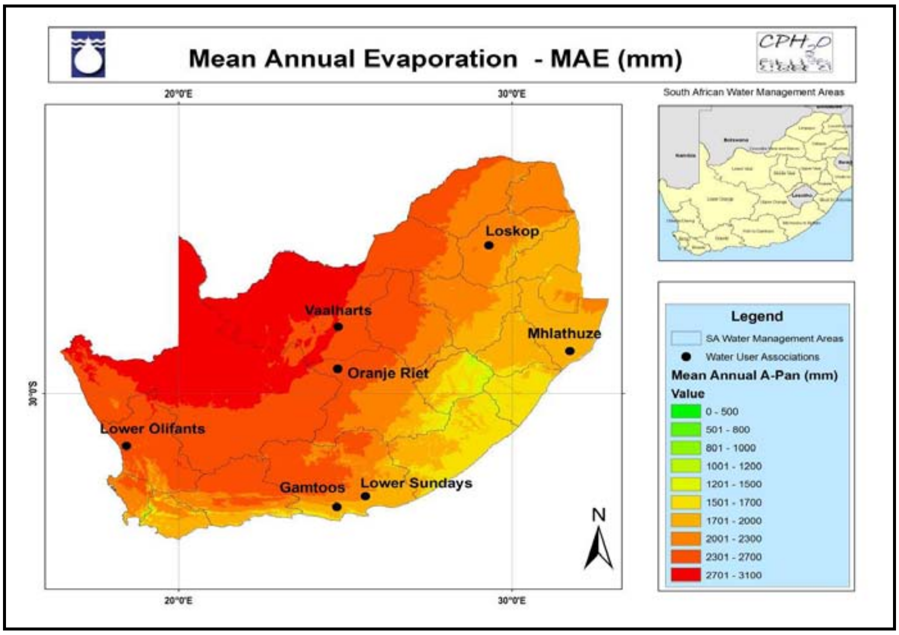

Figure 2.2 Mean Annual Evaporation of Southern Africa (after Schulze, R. E., 2006) with the Locations of the Participant Water User Associations

Figure 2.3 below illustrates the varying altitudes of the water user association locations.

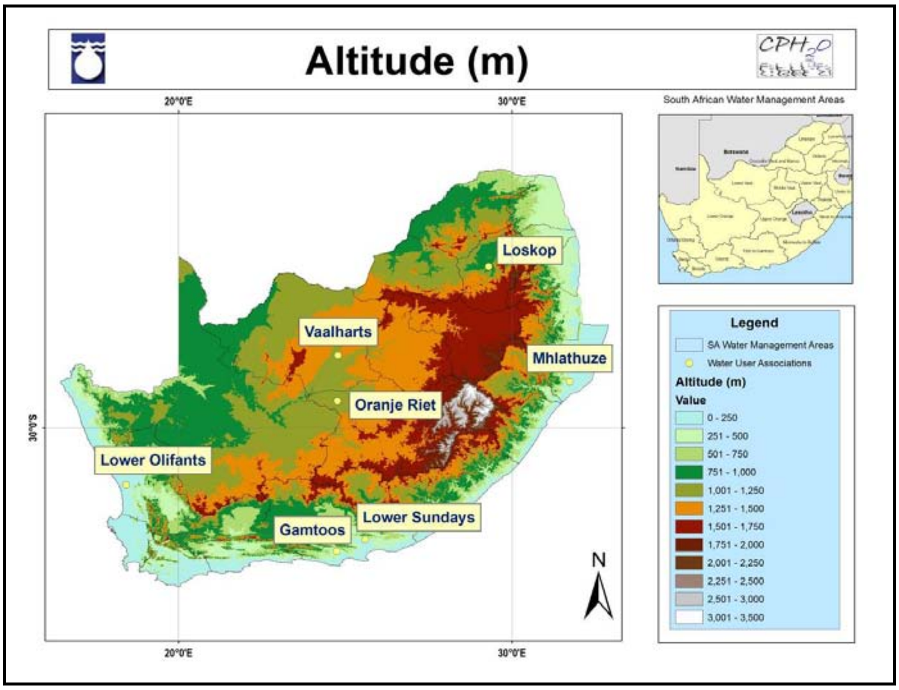

Figure 2.3 Altitude of Southern Africa (after Schulze, R. E., 2006) with the Locations of the Participant Water User Associations

The following maps illustrate the locations of the participating water user associations and irrigation boards in South Africa.

2.1.1. The Loskop Irrigation Board

The Loskop Irrigation Board is located in the Olifants Water Management Area. See Figure 4 below.

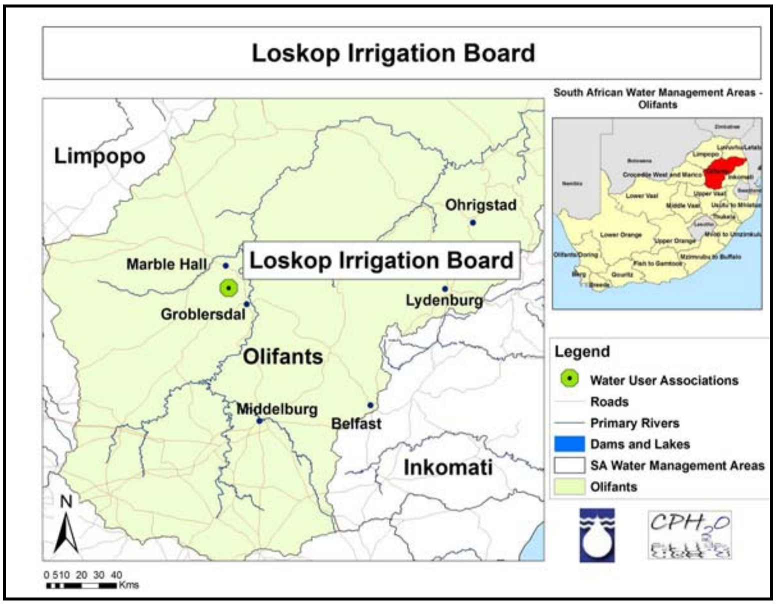

Figure 2.4 Locality Map of the Loskop Irrigation Board

2.1.2. Irrigation Boards in the Mhlathuze Catchment (Nkwaleni, Mfuli & Heatonville)

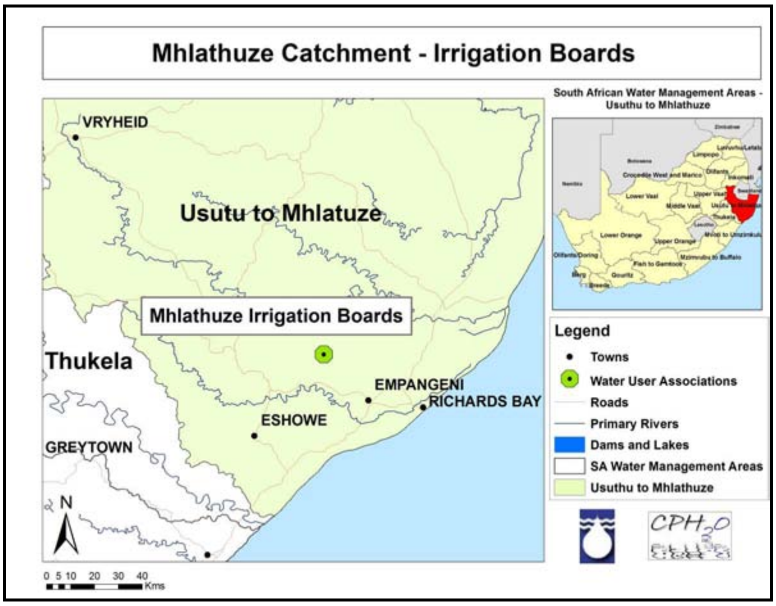

Figure 2.5 Locality Map of the Mhlathuze Catchment Irrigation Boards

2.1.3. The Vaalharts Water User Association

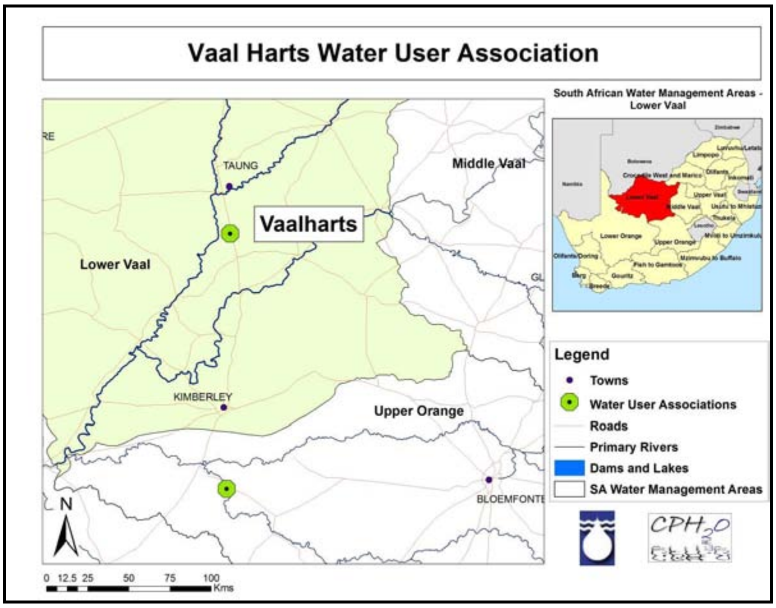

Figure 2.6 Locality Map of the Vaalharts Water User Association

The Vaalharts Water User Association is located in the Lower Vaal Water Management Area.

2.1.4. The Oranje-Riet Water User Association

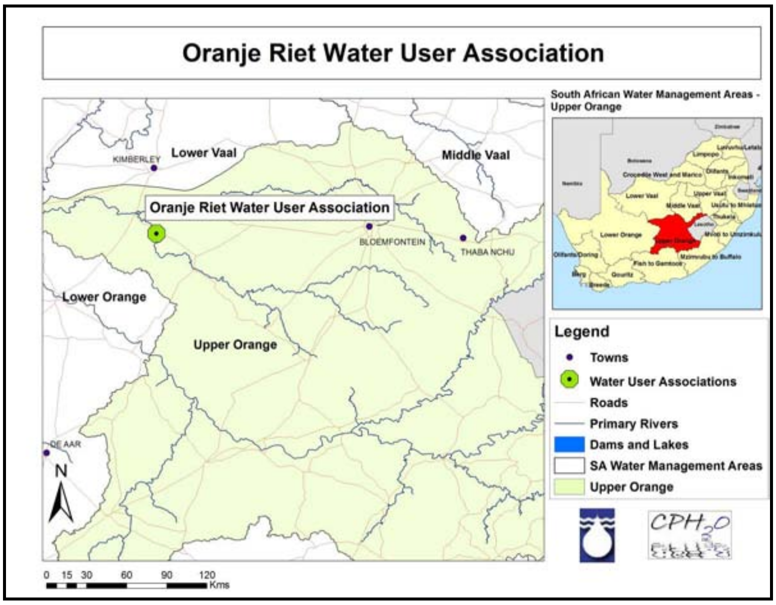

Figure 2.7 Locality Map of the Oranje-Riet Water User Association

The Oranje-Riet Water User Association is located in the Upper Orange Water Management Area.

2.1.5. The Lower Sundays River Water User Association

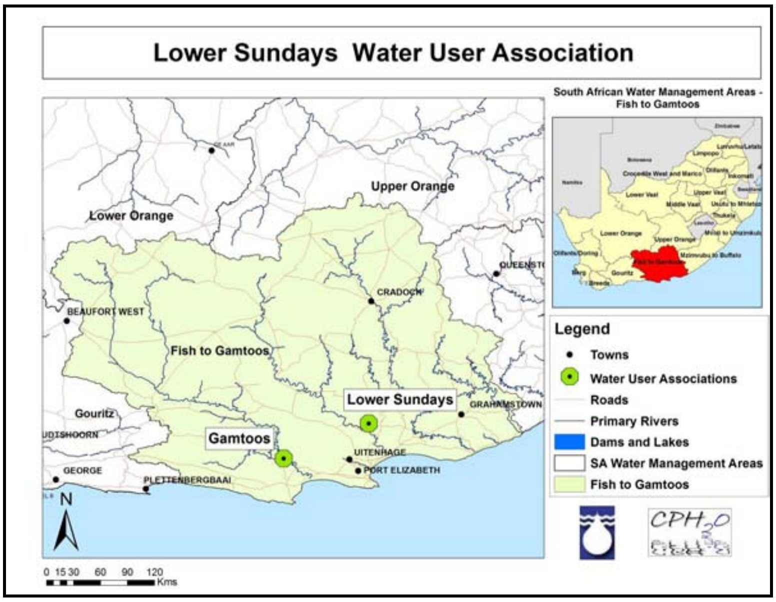

Figure 2.8 Locality Map of the Lower Sundays River Water User Association

The Lower Sundays River Water Association is located in the Fish to Gamtoos Water Management Area.

2.1.6. The Gamtoos Irrigation Board

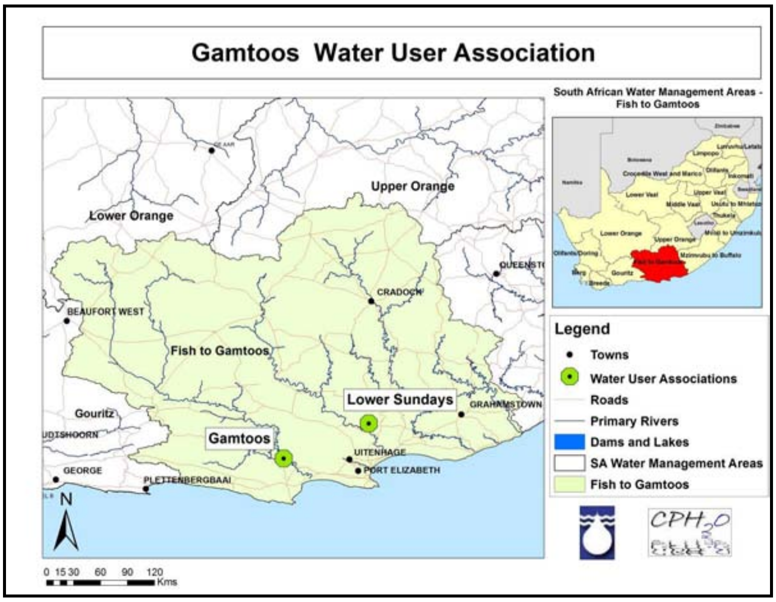

Figure 2.9 Locality Map of the Gamtoos Irrigation Board

The Lower Gamtoos Irrigation Board is situated Gamtoos Water Management Area in the Eastern Cape. It is situated downstream of the Van Stadens Gorge Dam which is situated at the Confluence of the Kariga and Sout Rivers.

2.1.7. The Lower Olifants Water User Association

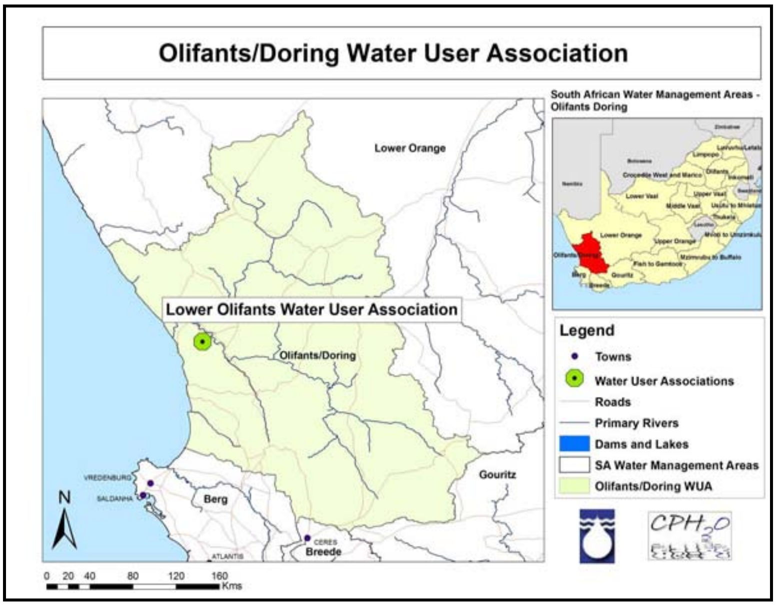

Figure 2.10 Locality Map of the Lower Olifants River Water User Association

2.2. The user needs of the participant Water User Associations and Irrigation Boards

After the short-listing of the participant WUAs and IBs was completed meetings were held to present the models associated with the project and to determine the user requirements for the respective models. Table 2.1 below reflects the outcome of the exercise, with the dark (red) cells representing the models for which a high user need was indicated (per participating WUA/IB), and the lighter (light green) cells representing the models (or modules) that were currently being used by the participating WUAs / IBs at the time of the first interview.

Table 2.1 Indicators of Current Model Usage and Level of Interest in the Modelling Groups

						WAS			
IB / WUA	ACRU	MIKE BASIN	SWB	RISKMAN	SAPWAT	Admin module	Accounts Module	Request Module	Release Module
Mhlathuze	High interest	High interest							
Loskop	High interest	High interest	High interest	High interest		Already using	Already using	Already using	High interest
Vaalharts				High interest	High interest	Already using	Already using	Already using	High interest
Oranje Riet				High interest	High interest	Already using	Already using	Already using	Already using
Lower Olifants						Already using	Already using	Already using	High interest
Lower Sundays River			High interest			High interest	High interest	High interest	High interest
Gamtoos			High interest	High interest		Already using		Already using	

HIGH INTEREST SHOWN IN MODEL / SYSTEM
ALREADY USING THE MODEL / SYSTEM

The research team members undertook to configure and technology transfer the models to the participating WUAs / IBs that showed a high user need for the models. The differences in the user needs for the models for the respective participating WUAs / IBs illustrates the fact that the situations and challenges faced by the respective WUAs / IBs differ from one another.

Table 2.2 below summarises the interest shown by the participating WUAs and IBs in the GIS component of the project. The GIS work consisted of two components:

- Firstly, digital images (photos) were needed for the respective WUA / IB. Satellite imagery was deemed to be too coarse for the objectives of the project, and thus digital ortho-rectified imagery that could be viewed in a GIS was acquired.
- Secondly, GIS coverages needed to be generated, which captured the key features of the irrigation scheme, and which are useful inputs for the models associated with the TT project.

Table 2.2 Interest shown by the WUAs / IBs in GIS

IB/WMA	Imagery	Annotation
Mhlathuze	Available	Available
Gamtoos	Available	Required
Loskop	Required	Required
Lower Olifants	Not interested	Not interested
Lower Sundays River	Required	Required
Oranje Riet	Available	Available
Vaalharts Water	Required	Required

Green (hatched)	Available
Red	Required
White	Not interested

The GIS component of the project is discussed in greater detail in the section 3 which follows.

3. THE GIS COMPONENT OF THE PROJECT

3.1. Background

The collection and capture of relevant data into a GIS was a central objective of the research project, for the following reasons:

- The GIS data collected included input data for the models associated with the TT project. This assisted the research team with the initial setup and configuration of the various simulation models.
- Previous WRC projects indicated that farmers and water resource managers (i.e. WUAs and IBs) had shown a strong interest in the use of a GIS. This interest stems from the fact that the visual graphical nature of a GIS is easier to understand than figures and tables. A GIS in effect enables data to become more meaningful to stakeholders. With the implementation of a GIS it was envisaged that the willingness of WUAs and IBs to participate in the project would be increased. This is in fact what transpired.

After the participant WUAs and IBs were selected, the research team undertook a study of the GIS imagery and coverages available at each of the participating WUAs and IBs. The exercise revealed that imagery was already available for the Gamtoos WUA, the Mhlathuze Catchment as well as the Oranje Riet WUA. The Gamtoos had high quality ortho-rectified imagery at a 1m pixel resolution, which had been acquired as part of a Working for Water (WfW) project in the area. The Mhlathuze had satellite imagery, and digital ortho-rectified imagery available, which had been acquired as part of the DWAF verification and validation process related to the water use licensing process. The Oranje-Riet WUA had recently acquired satellite imagery of their WUA area, which they used with a manual survey to digitise boundaries of fields, roads, rivers, etc. The Lower Orange River did not have any digital imagery available, but had recently acquired hard copy maps of their WUA.

The research team identified professional consultants who could (i) capture and ortho-rectify imagery, and (ii) develop GIS coverages with annotations of relevant feature information. The consultants in question were asked to quote on the provision of (i) the acquisition of ortho-rectified GIS imagery, and (ii) the subsequent annotation thereof for all the schemes that did not have these components implemented. The consultant quoting on the acquisition of imagery was asked to provide 3 separate quotes for imagery of different spatial resolution, including imagery of a 50cm pixel resolution, a 75cm resolution and a 1m resolution.

The consultants quoting on the generation of GIS coverages were given a detailed terms of reference of what was required. The detailed specifications outlined the type of data that needed to be captured in the GIS. The coverages requested, included:

- Farm boundaries (this coverage was to be acquired from the Surveyor General)
- Polygons (i.e. boundaries) of all irrigated fields
- Details of the crops on the irrigated fields. For cash-crops there would be no need for the consultants to detail the crop (as this would change from year to year). However for permanent crops, details of the crop were required.
- Details of the irrigation systems used on each irrigated field
- Details of canals
- Details of roads
- Details of weirs

- ❑ Details of abstraction off-take points

The quotes for the acquisition of the imagery (at 3 levels of resolution), as well as the quote for the GIS layers was then presented to each WUA and IB for which these GIS components were missing. The request put forward was that the WUA / IB would be responsible to cover half the costs of the GIS components themselves, while the research project would cover the balance. This offer was well received by most of the WUA and IBs, and contracts to undertake the GIS work were drawn up accordingly. This arrangement was regarded as a break through as it had never been achieved before. In effect it illustrated the “buy-in” from the irrigation boards and water user associations and showed their interest and commitment to the project.
The screen shots below are examples of the imagery and annotation of the irrigated fields.

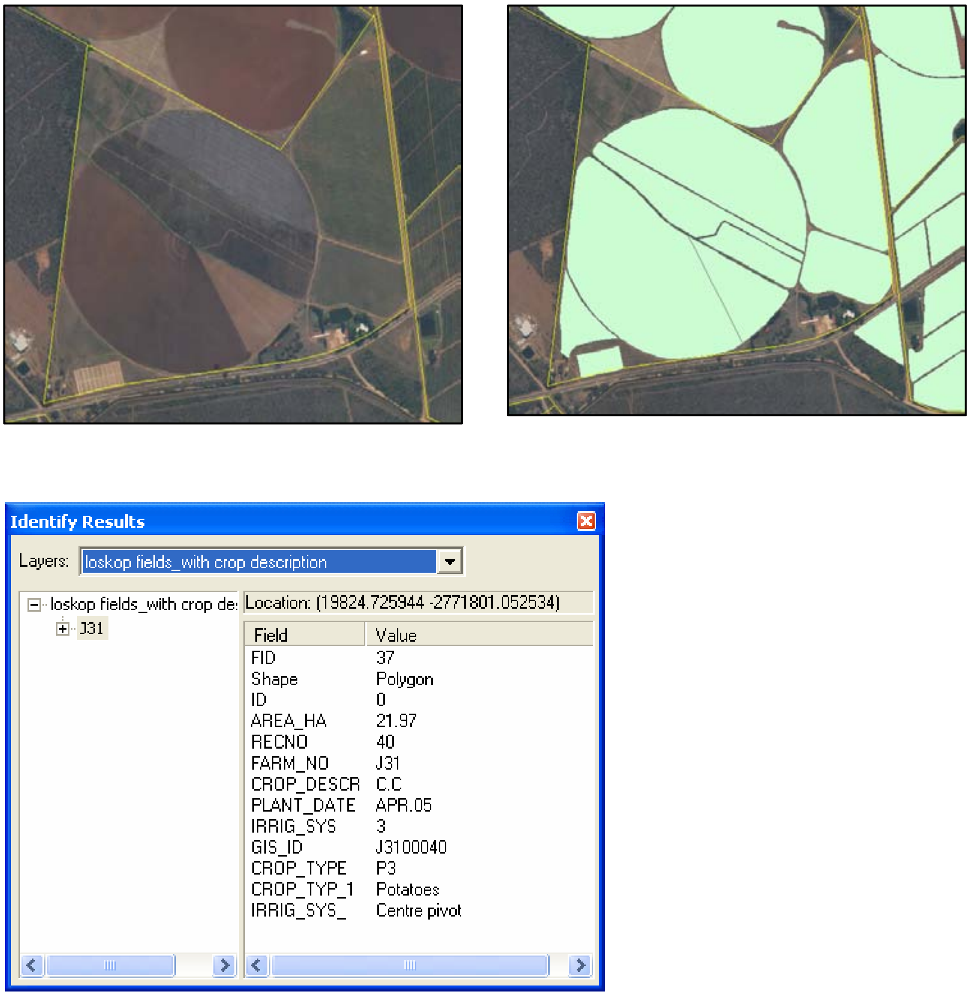

Figure 3.1 Screen shots taken from Arc-GIS illustrating Imagery and Annotation

3.2. GIS Information for the Project Participants

3.2.1. Vaalharts Water User Association

The Vaal Harts Irrigation Scheme is divided into nine management zones. See Figure 3.2 below. The inset illustrates the detail of infrastructure that was captured for management purposes.

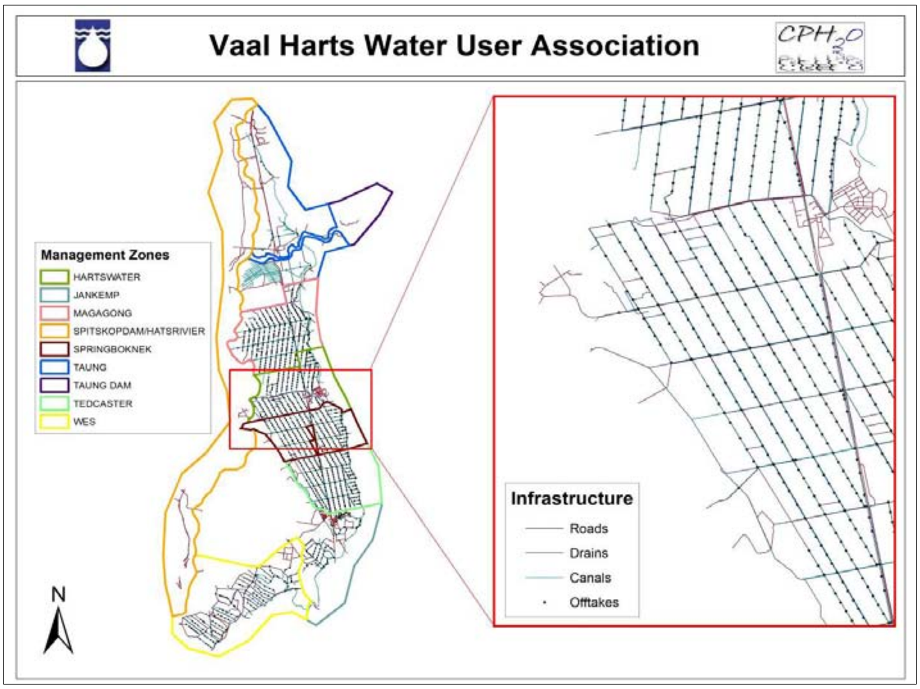

Figure 3.2 Management Zones of the Vaalharts Water User Association

Table 3.1 below details the area of each management zone and the total irrigated area per management zone.

Table 3.1 Irrigation Areas per Management Zone for the Vaalharts Irrigation Scheme

Management Zones	Area of Management Zone (ha)	Irrigated Area per Management Zone (ha)
Hartswater	9003.1	5002.6
Jan Kemp	33671.7	2740.2
Magagong	11607.4	7503.5
Spitskopdam/Hartsrivier	31185.1	76.2
Springboknek	8491.6	5831.6
Taung	22627.5	4106.5
Taung Dam	5278.7	0
Tad caster	9946.6	5484.8
Wes	20140.3	6136.9
TOTAL	**151952.3**	**36882.6**

There are 10 different irrigation systems used in the Vaalharts Irrigation Scheme. Figure 3.3 below illustrates the dominant irrigation systems in the Hartswater and the Springboknek management zones in the Vaalharts Water User Association.

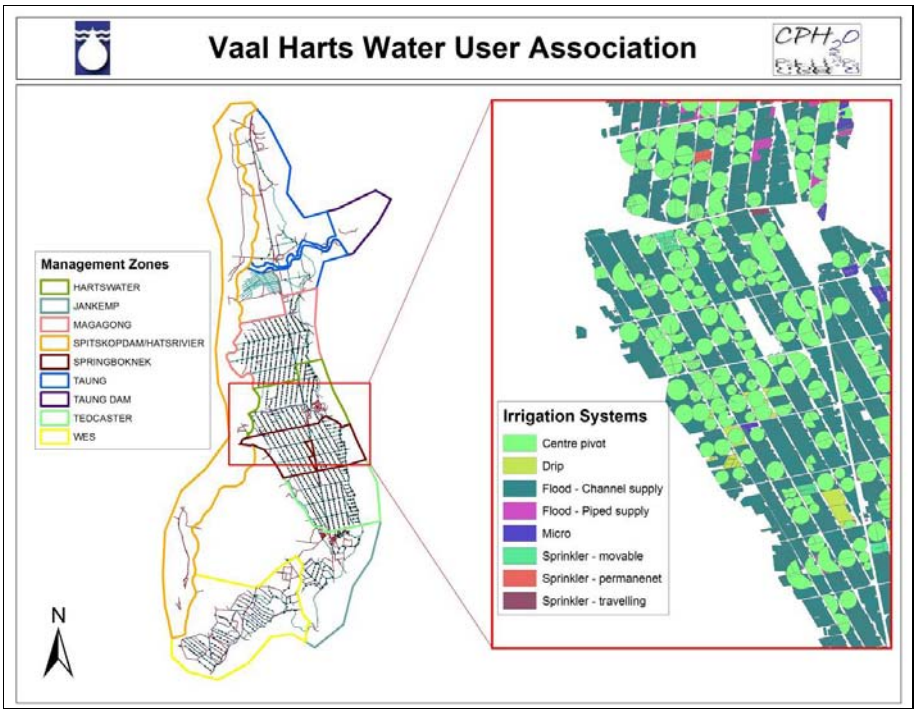

Figure 3.3 Irrigation Systems Employed in the Vaalharts Irrigation Scheme.

From Table 3.2 below it can be seen that the predominant irrigation systems used are centre pivot irrigation, which is a relatively efficient means of applying water, and flood irrigation which if not managed properly is a very inefficient means of irrigation.

Table 3.2 Breakdown of Irrigation System Types Employed in the Vaalharts Irrigation Scheme

Irrigation System	**Hectares (ha)**	**Percentage (%)**
No Irrigation	1380.6	3.7
Drip	283.1	0.7
Micro	501.2	1.3
Centre Pivot	14911.3	40.4
Sprinkler - Permanent	314.0	0.8
Sprinkler - Moveable	1792.8	4.8
Sprinkler - Travelling	12.7	0.03
Flood - Piped Supply	960.1	2.6
Flood - Channel Supply	16597.1	45.0
Swaaibalk	119.8	0.3
Raised Micro (Floppy)	9.7	0.0
TOTAL	**36882.6**	**100**

Table 3.3 Crop Types Cultivated in the Vaalharts Irrigation Scheme

Crop Type	**Hectares (ha)**	**Percentage (%)**
Almonds Standard	6	0.02
Apricot - Early	22.5	0.06
Apricots - Middle	4.9	0.01
Cherries - Early	8.3	0.02
Citrus - Above Average	43.1	0.12
Citrus - Average	2092.6	5.67
Fallow Land	339.8	0.92
Groundnuts Standard	39.6	0.11
Golf Course - Fairways	10.7	0.03
Garden	8.8	0.02
Grape Wine Early	226.6	0.61
Lettuce Winter Crop	14.1	0.04
Lawn - Kikuyu	10.2	0.03
Lucerne Non Dormant	9967.6	27.03
Olives	63.2	0.17
Pastures: Seasonal Rye Grass	24.3	0.07
Peaches - Early	9.4	0.03
Peaches - Middle	16.9	0.05
Peacan Nuts	2331.1	6.32
Pastures: Perennial Grass Mix	83.3	0.23
Pastures: Perennial Kikuyu	8.1	0.02
Sports Fields - Kikuyu	10.2	0.03
Cashcrops	20127.5	54.57
TOTAL	**36882.691**	**100**

Table 3.3 above and Figure 3.4 on the following page show the different crops cultivated in the Vaalharts Irrigation Scheme. The inset illustrates the dominant crop type in the Springboknek and Hartsriver Management Zones.

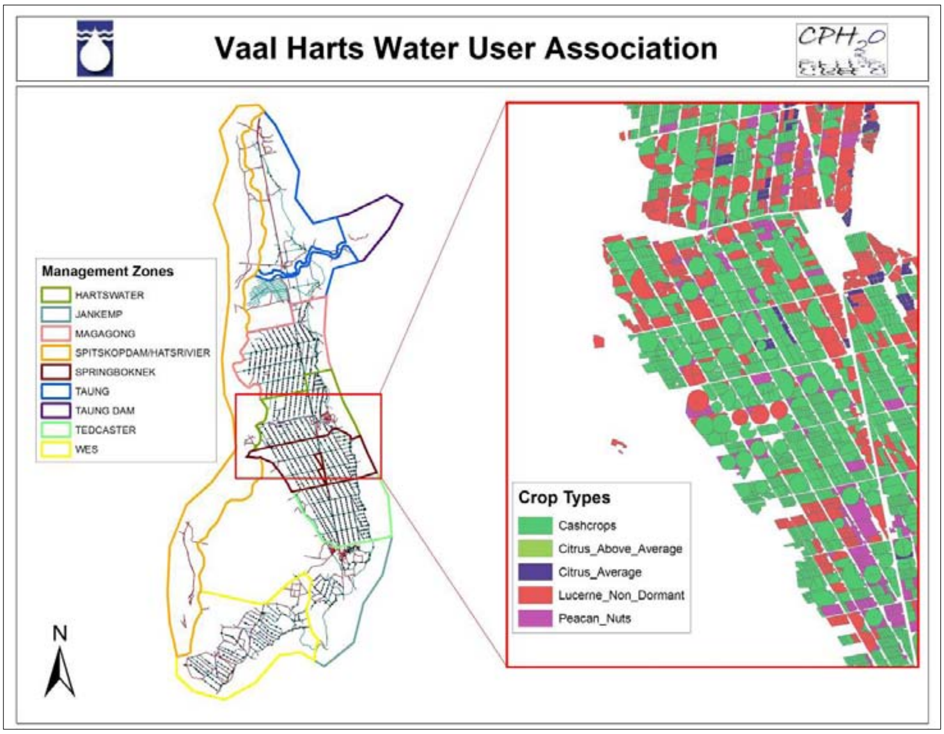

Figure 3.4 Crop Type Descriptions and Cropping Patterns in the Vaalharts Water User Association

3.2.2. Lower Sundays River Water User Association

The Lower Sundays River Water User Association is divided into 4 different management zones.Figure 3.5 below details the existing infrastructure in the Lower Sundays River Water User Association. Capturing this information and having it readily available in a GIS is an important aspect of been able to manage the scheme effectively. Table 3.4 below details irrigated area per management zone.

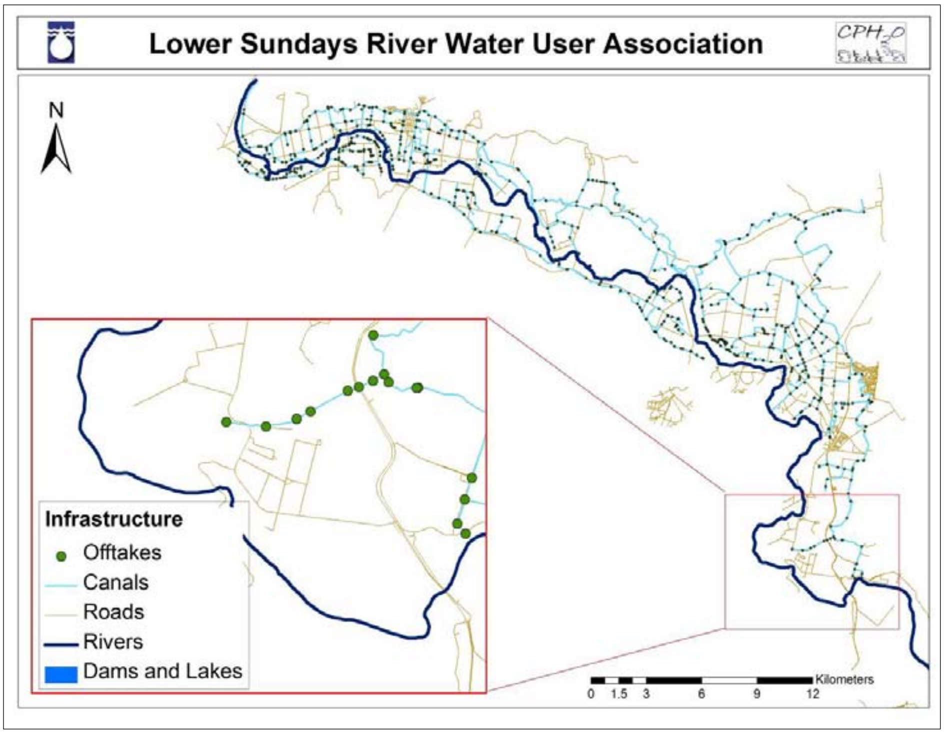

Figure 3.5 Infrastructure in the Lower Sundays Water User Association

Table 3.4 Irrigation Areas per Management Zone for the Sundays River Water User Association

Management Zones	Total Ha of Mgt Zone	Irrigated Hectares	Percentage (%)
1	5254.88	3649.93	21.17
2	9775.403	4600.646	26.69
3	6444.566	3767.879	21.86
4	7565.845	5220.769	30.28
TOTAL	**29040.694**	**17239.352**	**100.00**

In Figure 3.6 below the irrigation systems in use in the Lower Sundays River Water User Association are mapped. It can be seen that water usage in this are is probably fairly efficient since is a predominance of micro and drip irrigation been practiced in this region. This is further evidenced by the summary of the irrigation areas in Table 3.5 below. This type of irrigation practice is consistent with the cultivation of citrus crops. See Figure 3.7 below.

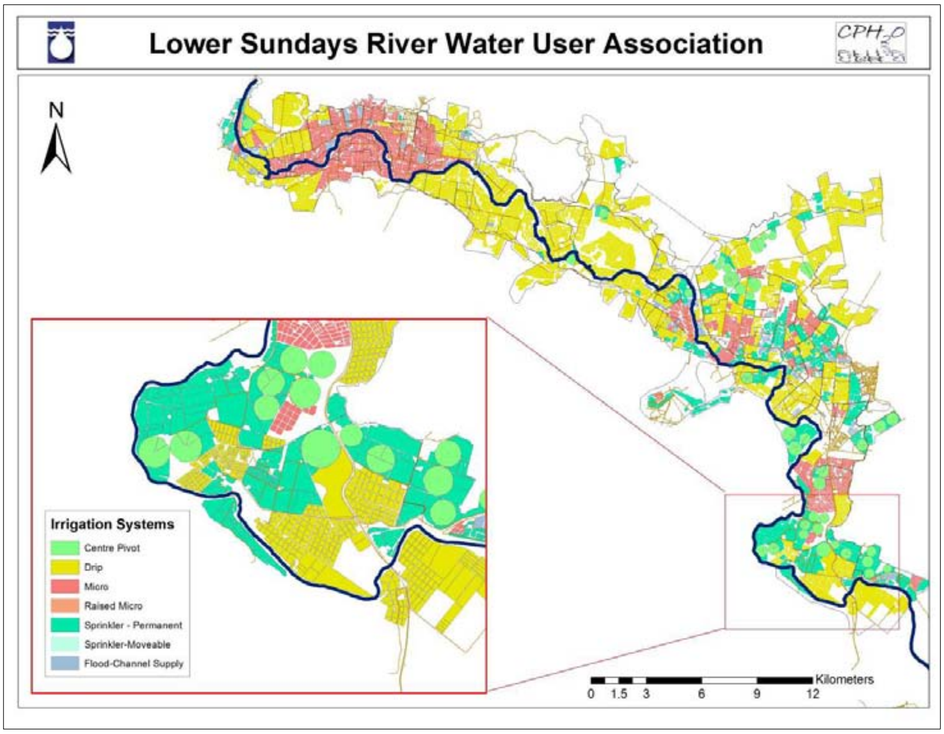

Figure 3.6 Irrigation Systems Employed in the Lower Sundays Water User Association

Table 3.5 Breakdown of Irrigation System Types for the Lower Sundays River Water User Association

Irrigation System	Hectares	Percentage (%)
None	626.7	3.6
Drip	8346.2	48.4
Micro	3027.4	17.5
Centre Pivot	1069.6	6.2
Sprinkler - Permanent	2589.781	15.02
Sprinkler - Moveable	10.797	0.06
Flood - Channel Supply	534.724	3.10
Raised Micro (Floppy)	24.704	0.14
	17239.352	**100**

In Figure 3.7 which follows the dominant crop types in the region are mapped.

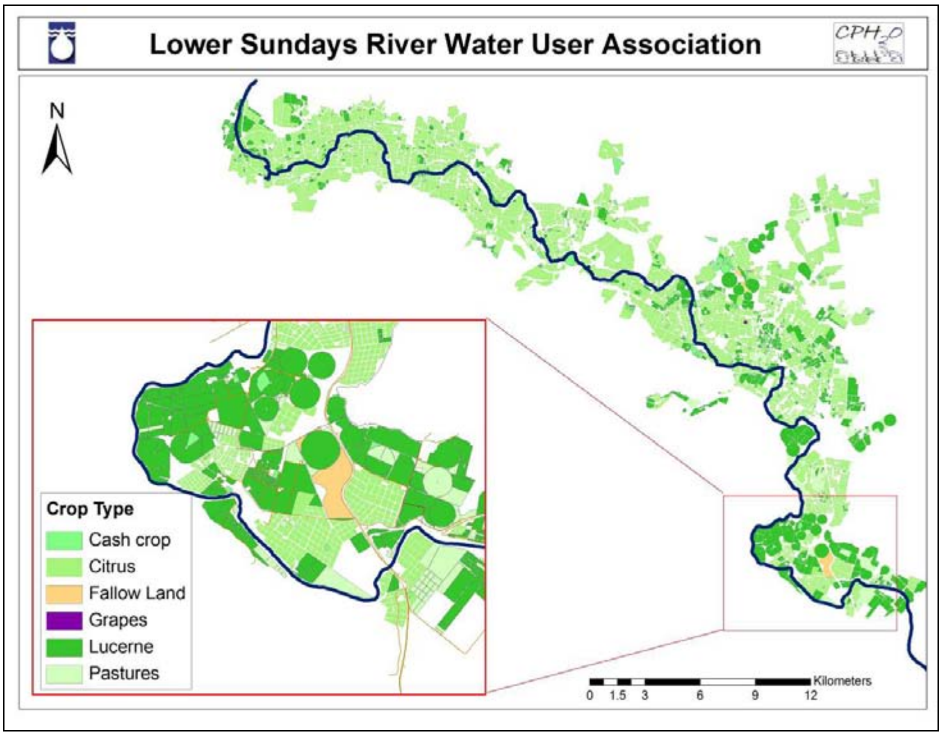

Figure 3.7 Dominant Crop Types in the Lower Sundays River Water User Association

Table 3.6 illustrates that citrus is the major crop cultivated in the region contributing approximately 62% of total the irrigated area.

Table 3.6 Crops Cultivated within the Lower Sundays River Water User Association

Crop Type	Hectares	Percentage (%)
Citrus	10619.806	61.60
Cash Crops	538.235	3.12
Fallow Land	94.040	0.55
Grapes: Table Middle	3.163	0.02
Lucerne	3566.956	20.69
Management	626.769	3.64
Pastures: Seasonal	804.280	4.67
Sports Field	6.088	0.04
Windrow	979.689	5.68
TOTAL	**17239.352**	**100**

3.2.3. Gamtoos Irrigation Board

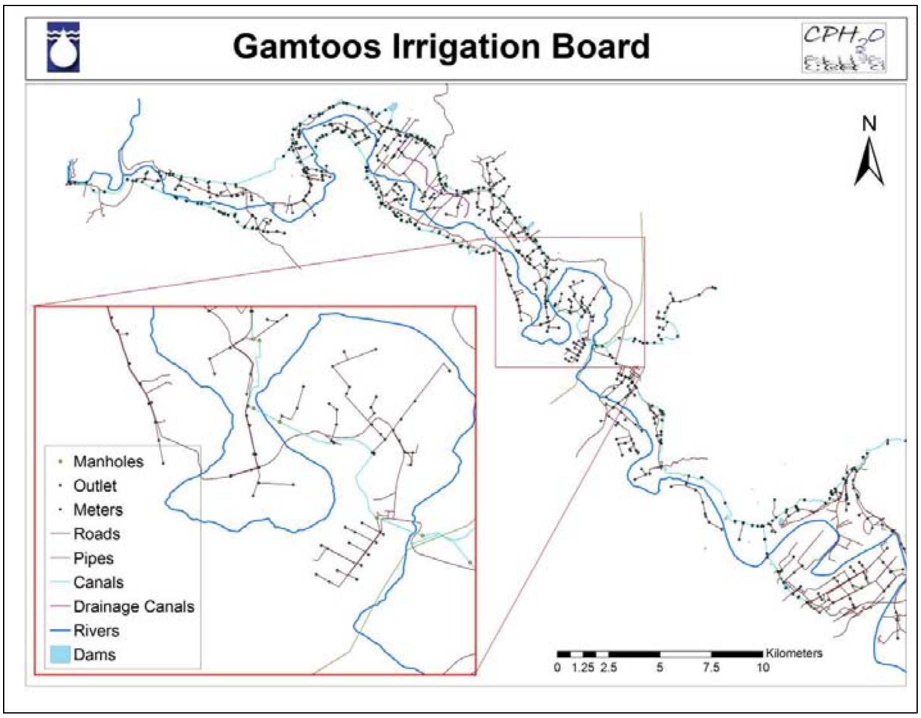

Figure 3.8 Gamtoos Irrigation Board Infrastructure

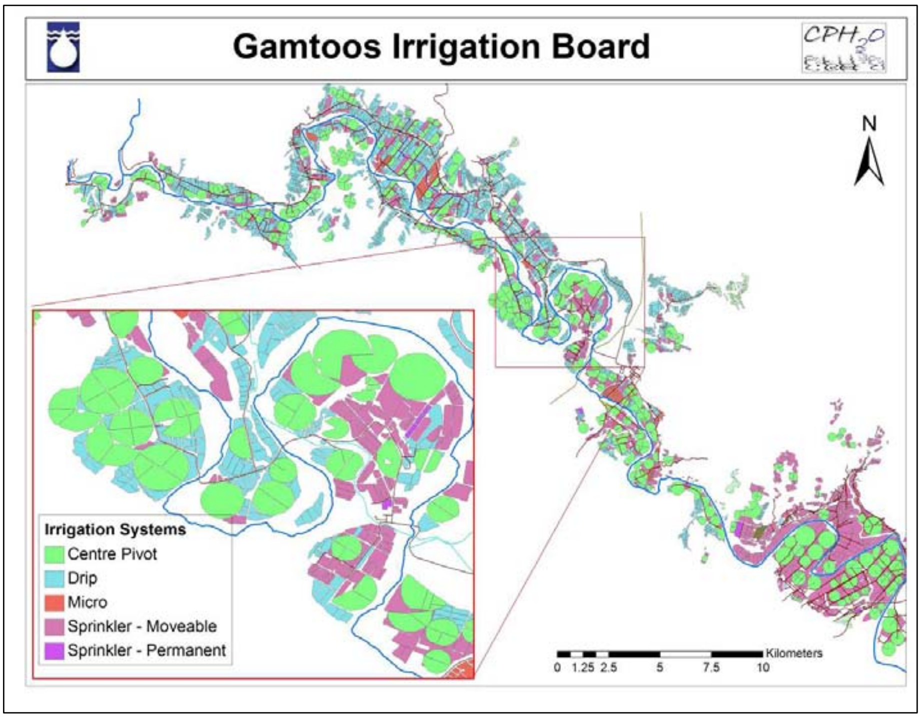

Figure 3.9 Gamtoos Irrigation Board Irrigation Systems

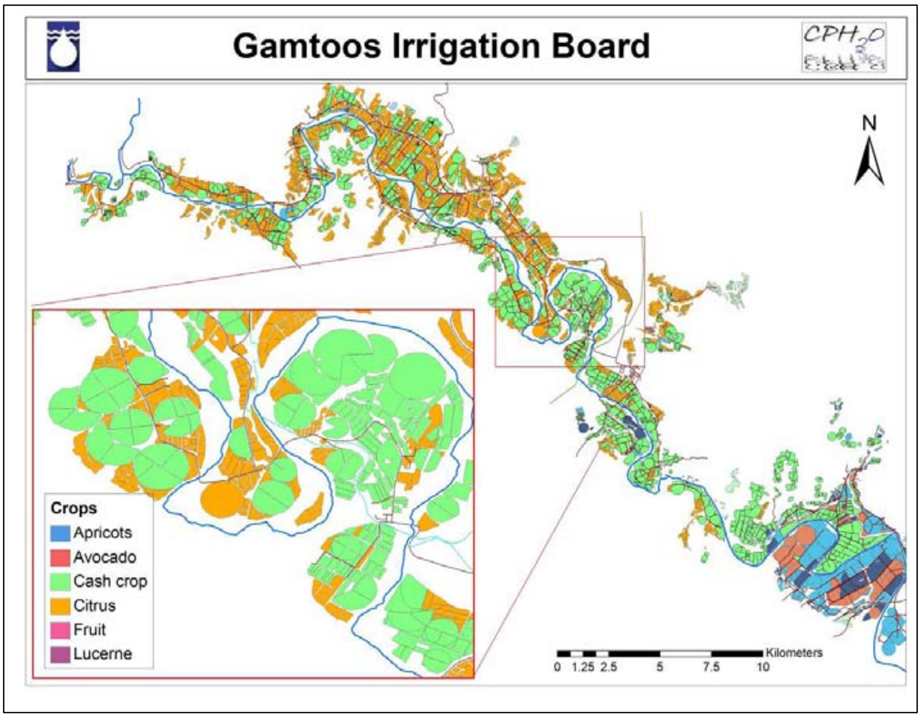

Figure 3.10 Dominant Crops Cultivated in the Gamtoos Irrigation Board

3.2.4. Oranje Riet Water User Association

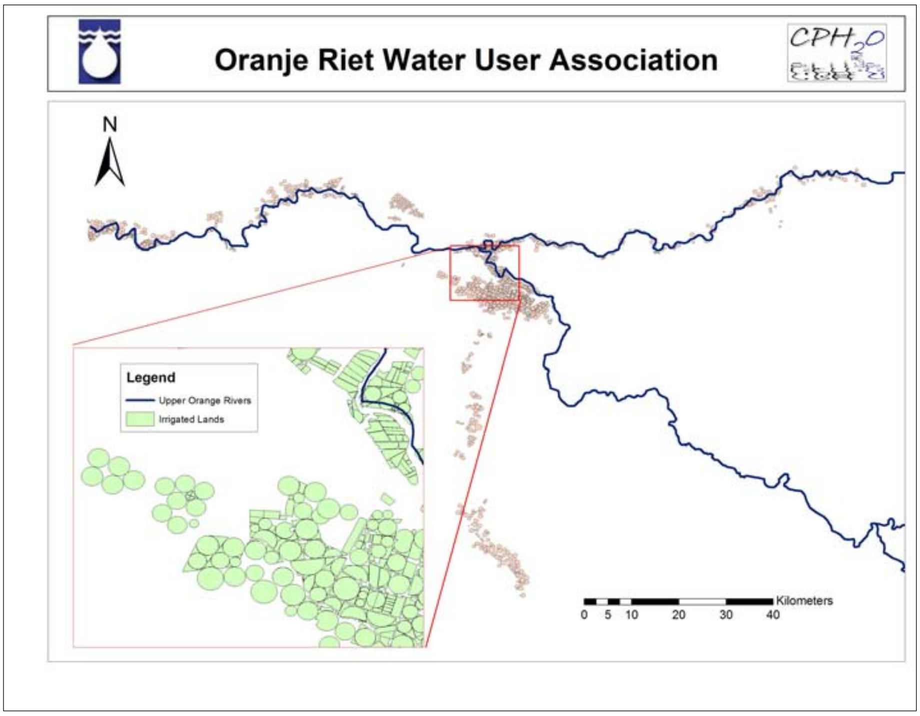

Figure 3.11 Captured Irrigated Crops for the Oranje-Riet

3.2.5. Mhlathuze Catchment

GIS data collection in the Mhlathuze catchment did not form part of the TT project however existing information from other studies was available. See Figure 3.12 below.

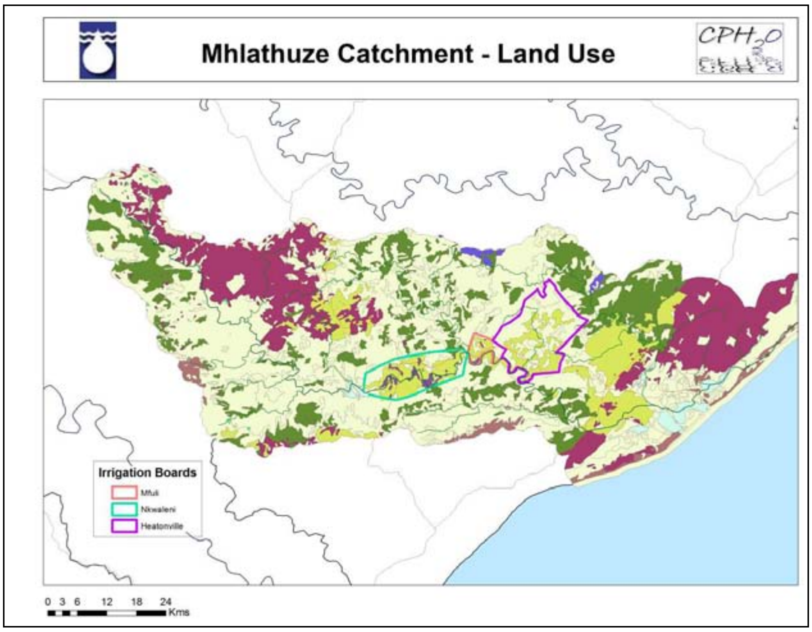

Figure 3.12 Landuse in the Mhlathuze Catchment

3.2.6. Loskop Irrigation Board

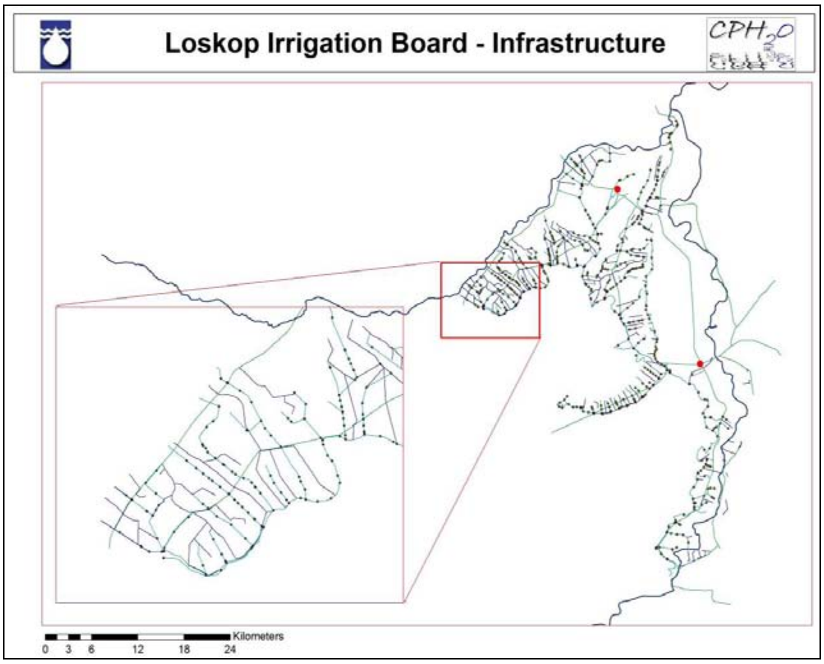

Figure 3.13 Loskop Irrigation Board Infrastructure

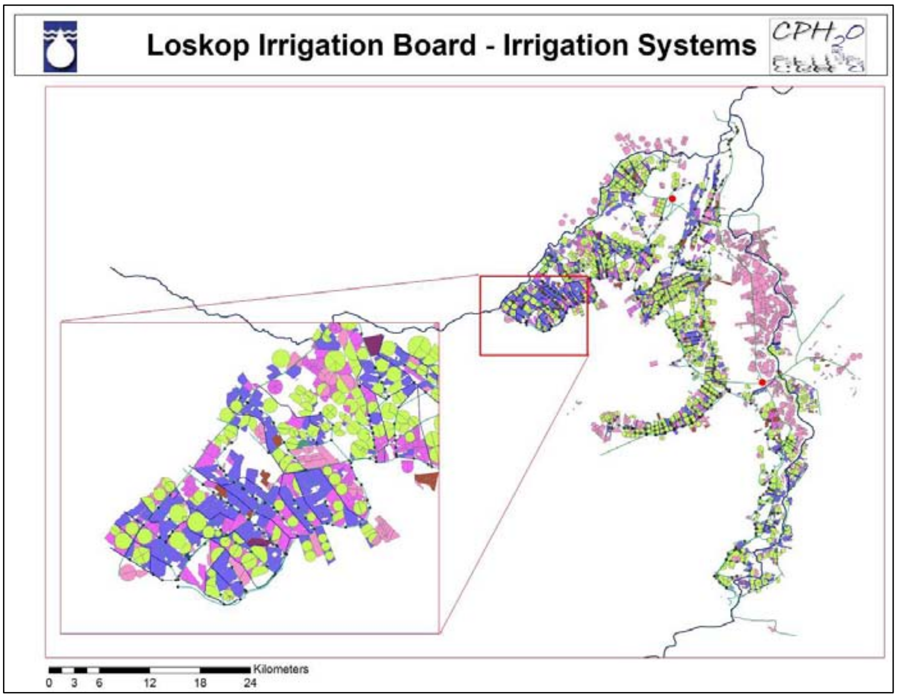

Figure 3.14 Irrigation Systems Employed in Loskop Irrigation Board

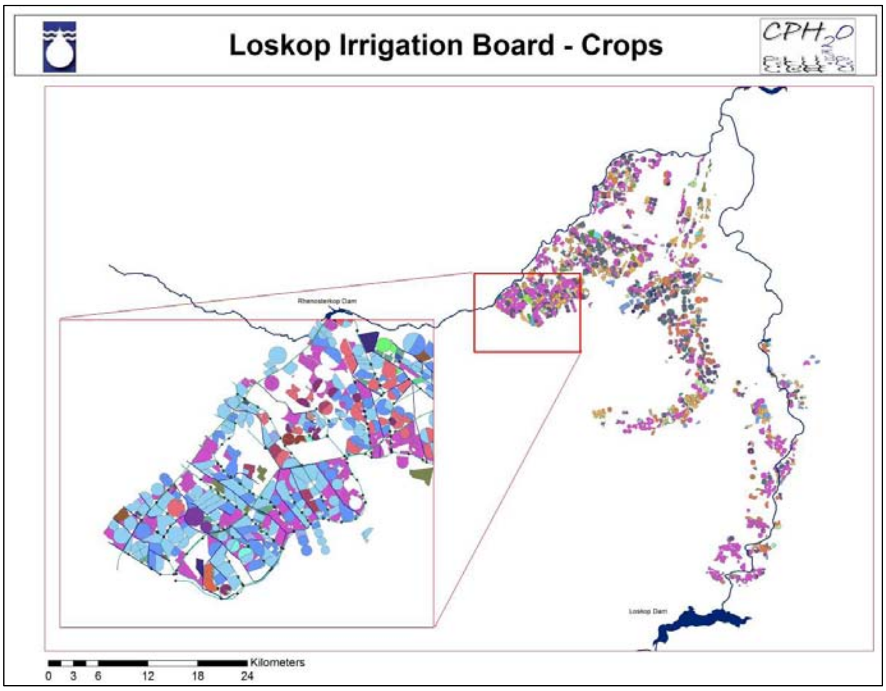

Figure 3.15 Crops Cultivated Within Loskop Irrigation Board Boundaries

3.2.7. Lower Olifants River Water User Association

No GIS information was available since the Water User Association had already acquired hard copy maps of their region.

3.3. Conclusions

It is often said that you cannot manage what you do not or can not measure. With the advent of GIS technology and the availability of high resolution aerial photography this scenario has changed. The benefits of capturing data into a GIS are clearly evident and since it enables managers to manage their areas on both a micro and a much broader scale.

4. ACRU AND MIKE BASIN TECHNOLOGY TRANSFER (AAMG)

Two of the models forming part this project included the ACRU model and the MIKE BASIN model. This chapter details the integration of the two models. The AAMG is an extension that, when added to the ArcGIS program, enables the ACRU model menus to be populated from a GIS environment and for the initial base run to be generated in a relatively short space of time. In the past, the required setup time was a factor influencing the application of the ACRU model in water resources management. The AAMG is an acronym for Amalgamation of Agrohydrological Modelling Groups.

With the added functionality of the MIKE BASIN program, which is also an extension to ArcGIS, initial output from the ACRU base run can be compared to gauged flows at known locations. We thus have a combined view of the flow record in both space and time. Further functionality of the AAMG extension allows for the easy manipulation of the physical variables which form input to the ACRU model. This function thus decreases the time required to verify and calibrate the ACRU model further reducing setup and running costs. Once the modeller is confident that a suitable verification has been achieved the model output forms the input to the MIKE BASIN node and channel simulation model where operating rules can be imposed on the system and new users can be added to the system exploiting the full range of the MIKE BASIN functionality. Thus a basis can be established for testing different water use scenarios in a specific catchment by experimenting with different demand patterns under varying operating rule conditions. The integration enables the two models to better meet the needs of the Water User Associations (WUAs) and other users as opposed to running the models independently. The sustained use of the models, which is a key objective of the technology transfer, project is thus promoted.

4.1. Background

ACRU is a daily time step rainfall runoff model which has been developed by the School of Bio-Resources Engineering and Environmental Hydrology at the University of KwaZulu-Natal. The acronym ACRU is derived from the Agricultural Catchments Research Unit. The development of the ACRU model is a long term project which has enjoyed generous funding from the Water Research Commission. ACRU, which is continually being developed and improved as our understanding of the physical processes within the Hydrological Cycle is enhanced, has been used in many projects throughout South Africa, the neighbouring states as well as overseas.

Schulze et al. (1995) state that ACRU model has been applied extensively since 1986 to assist in providing answers to a range of water resources related problems. Examples are provided by Schulze et al. (1995) where the ACRU model has successfully been implemented in:

- water resources assessments,
- design flood estimation,
- irrigation water supply and demand scenarios,
- crop yield and primary production modelling,
- assessments of impacts of land use changes on water resources,
- assessments of hydrological impacts of wetlands,
- groundwater modelling, and
- assessments of potential impacts of global climate change on crop production and hydrological responses.

4.1.1. Review of ACRU

The ACRU agrohydrological modelling system is defined as being a physical conceptual model. As such, the model is not a parameter optimising model and the parameters that are used in the model are generally estimated from the physical characteristics of the catchment that is being simulated. ACRU also runs on a daily time step and revolves around a multi-layer soil water budget which results in ACRU being a versatile total evaporation model. This attribute makes the ACRU soil water budget sensitive to any changes in climate and landuse. It can also be adjusted to take into account any agricultural management practices such as different irrigation applications and soil tillage practices. A further advantage of the ACRU model is that is can be used at different levels of complexity depending on the purpose of the application and the availability of suitable data. Therefore it is flexible in its scope of application. The general structure of the ACRU model that has been described briefly in this paragraph thus far can be observed graphically in Figure 1 below.

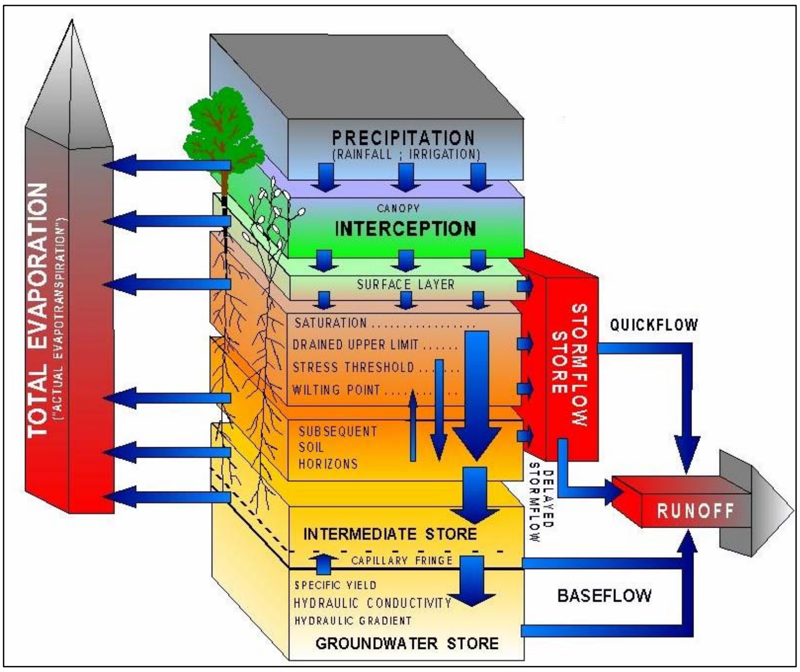

Figure 4.1 The ACRU Agrohydrological Modelling system: General structure (Schulze et al., 1994a)

Figure 1 illustrates that the streamflow that is output from the ACRU model, termed RUNOFF, is a combination of the storm flow, which is termed QUICKFLOW, and the contribution from the base flow store, termed BASEFLOW. These three different outputs can be used as daily inputs into the MIKE BASIN Model, either as two separate components, or as the combined runoff. The MIKE BASIN is a node and channel network simulation model. These combinations will be illustrated in a later section where the conceptual link between ACRU and MIKE BASIN is described further and should become clearer in the example.

The ACRU model is very data intensive and can take a long time to set up depending on the level of complexity of the catchment and the particular scenario that is being modelled. This, coupled with a lack of readily available data, has contributed to relatively long set up times for an initial base run and consequently the model has possibly not been utilised to its full potential in the South African environment.

The advent of the new National Water Act (Act 36 of 1998) has entrenched the need for the assessment of the impacts of landuse change and daily hydrological modelling especially for the assessment of licenses. ACRU is the ideal tool to help us examine possible solutions to many of the questions posed by the Act. In order to achieve the goals of the technology transfer project and ensure that technology transfer of the ACRU model is achieved these problems need to be overcome. The

AAMG makes the link between ArcGIS, the MIKE BASIN node and channel network and the ACRU model to help achieve this aim.

4.2. MIKE BASIN

4.2.1. Background

MIKE BASIN is a node-and-channel network model which has been developed by the Danish Hydraulic Institute (DHI). The model which has flexible time steps operations (DHI, 2005). Node-and-channel network models are used to link water users with sources of water for given operating rules. MIKE BASIN however requires streamflow as one of its key sources of input. The MIKE BASIN model has been fully developed within the ArcGIS environment and is added as extension. See Figure 2 below.

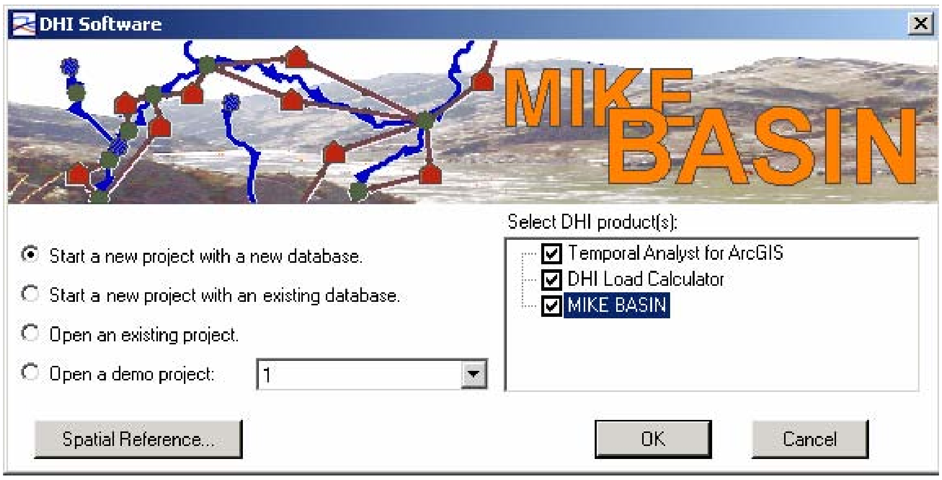

Figure 4.2 MIKE BASIN Program Start-up Dialog Box

4.2.2. Review of MIKE BASIN

MIKE BASIN is a node and channel network model which can run on any time step greater than a second. Therefore it can be run in combination with the ACRU model at a daily time step. It is a simulation model that is capable of allocating water based on the hydrology occurring in a catchment. This hydrology is also represented within space and time in the model. MIKE BASIN operates within a GIS environment thus exploiting the spatial capabilities of the GIS framework. MIKE BASIN, with the added functionality of Temporal Analyst, then adds the time dimension to the space dimension. Consequently, the combination is ideal for data management in a catchment (DHI, 2005).

The model operates on the basis of a digitized catchment setup, with river networks and sub-catchments, generated directly on the computer in the GIS environment. All the information that is concerned with the configuration of the catchment, such as the river branch network, locations of water users, channels for intakes and outlets to and from water users and reservoirs are all also defined within the GIS framework (DHI, 2005).

Input into MIKE BASIN consists of time series data of various types. A time series of catchment runoff is the only essential input that is required to have a model configuration that runs. Then many other additional input files are required depending on the complexity and configuration of the setup. These could include reservoir characteristics and operation rules, data describing hydraulic conditions in river reaches and channels, meteorological time series and data pertinent to each water supply or user, and the list continues (DHI, 2005).

4.3. The AAMG

The Automated ACRU Menu Generator (hereafter referred to as the AAMG) is a new development that facilitates the setting up initial ACRU runs from a GIS environment that links allowing us to bring the functionality of the MIKE BASIN model into play.

4.3.1. Background

Why integrate ACRU and the MIKE BASIN model?

In the National Water Act 1998 there is a requirement to assess the impacts that various land and water use activities will have on the catchment as a whole. ACRU is able to easily simulate the impact of dry-land landuse and management practices. MIKE BASIN can simulate the operating rules associated with water users taking water from both dam and river resources. These users usually include water users requiring abstraction licenses, which includes abstraction for irrigation, domestic or industrial purposes. The impact of landuse changes and water use operating rules can thus be effectively simulated. The conceptual link between the two models is illustrated in Figure 3 on the following page.

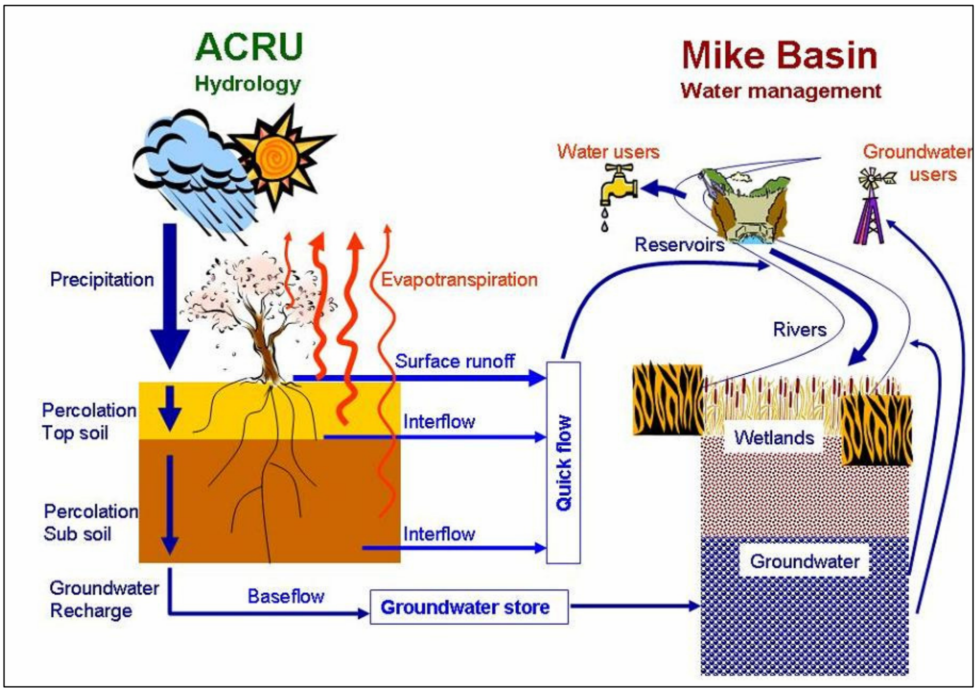

Figure 4.3 Conceptual Link between the ACRU and MIKE BASIN models

In summary the link between ACRU and MIKE BASIN enables one to combine the strengths of ACRU, a proven South African model for accurately simulating stream flows at a daily time step, with MIKE BASIN, a node and channel network model which has been validated on a world stage. With the integration we can model within a GIS environment, inputting ACRU runoff time series into MIKE BASIN and implement operating rules at a catchment or even sub-catchment scale.

Why have a GIS based application to run both ACRU and MIKE BASIN?

One of the key challenges faced with the integration of ACRU and MIKE BASIN was to simplify the procedure of setting up and running ACRU, and then transferring the files to MIKE BASIN. It was decided to develop a GIS-based application which enables (i) ACRU to be configured using the sub-catchments delineated by MIKE BASIN and (ii) enables ACRU to be configured with pre-populated weather, soil and landuse information which is available for South Africa in the form of GIS coverages. These coverages have been developed by the UKZN-BEEH over a number of years from WRC funding (Lynch, 2004; Schulze, 1997). The GIS-based application automatically configures ACRU, and transforms the ACRU output files for use by MIKE BASIN.

The initial menus are generated quickly and easily within the GIS framework. This has been a significant limitation with ACRU up to now, in that it used to take considerable time to get a base run started. A base (initial) run can now take a matter of minutes.

4.3.2. Potential applications

The AAMG has been developed in response to certain of the challenges introduced by the National Water Act (1998). Listed below are some areas where the AAMG could be applied.

- Assist with the water allocations and compulsory licensing process
    - Risk and reliability of supply for reservoir operators
    - Risk and reliability assessment for all stakeholders
- Assessment of water license applications on other users
- Reservoir operations
    - Drought mitigation and management
- Environmental management including the water quality aspects
- Stakeholder interaction and communication

4.3.3. Further developments

The ultimate objective or vision for the ACRU – MIKE BASIN development via the use of the AAMG is to develop an easy to use, intuitive, scientifically credible fine-time step modelling system to be used by DWAF, CMA's and consultants for water supply, water demand and operating rule scenarios. The temporal scale at which the model is to be run is a daily time step. In this way operations can be appropriately reflected as they occur in practice. The spatial scale of scenarios can range from broad catchment scale scenarios to far more detailed scheme-scale and even farm-scale scenarios. The integrated ACRU-MIKE BASIN modelling system should be able to accommodate scenarios pertaining to changes to dryland landuses (i.e. type, and/or area), irrigation areas and practices, operating rules, and development (e.g. dam and inter-basin transfer) options. The modelling system should provide meaningful indicators to help water users and water resource managers with their water resource planning and operational decisions, as well as to assist managers in water use licensing decisions (e.g. abstraction licenses, SFRA licenses, licenses to impound water and licenses to discharge waste).

A number of developments have already taken place to meet this development objective, however at the time of writing this user manual further enhancements are still ideally required. These developments will need to be funded by a new project, or funded internally by the developers. All models have three key components, including:

(i) input,
(ii) computation and
(iii) output.

The developments that are still required are discussed under these respective headings below.

Input

- There is a need to continually update and improve on the weather, soils and landuse datasets (i.e. the national GIS coverages for South Africa), from which ACRU is configured using the AAMG.
- The database of observed flow for South Africa requires validation and patching. This has not been done in the course of this project, and will be very valuable to undertake.

- The database of large dams in South Africa currently has incomplete data. Validation of the existing dam data sets is required.
- The ACRU model is currently unable to run on a near-real time step in an efficient manner. The ACRU model needs to be further developed so that it can be "hot-started", which will enable it to be run using near-real time, as well as forecast rainfall data.
- The databases of licensed water users captured in the WARMS database should ideally be accessible by the ACRU / MIKE BASIN development.

Computation

The irrigation module which has feedback loops with MIKE BASIN requires further development. The Danish Hydraulic Institute are, at the time of writing this manual, in the process of developing an irrigation module which is able to generate crop yields for various crops, and is able to calculate the return flows from the irrigated lands. The irrigation module is able to accommodate various scenarios, including changes to the type of crop being irrigated, the type of irrigation system used, the nature of the irrigation schedule adopted, and various crop rotation options. This module will be very valuable as it will provide crop yield information which can then be fed through a financial model (e.g. RISKMAN).

Output

At present MIKE BASIN outputs large amounts of data associated with scenario runs. Indicators need to be developed which make use of the output data. The development of indicators will assist water resource managers and water users to better interpret the salient aspects of scenario runs, thereby aiding in improved decision making. Indicators envisaged at this stage are yield curves, as well as assurance-of-water supply details for all water users in an easy-to-understand tabular format.

4.4. Conclusion

The integration of the ACRU model with MIKE BASIN via the AAMG is useful to quickly and easily test scenarios related to dryland activities, irrigated activities, dams and inter-basin transfers as well as various operating rules. This functionality is useful in over-allocated catchments in particular, where stakeholders may want a quick and easy, yet scientifically credible, system of assessing various courses of action to address the over-allocation of water use entitlements in the stressed catchments.

In conclusion, the AAMG development, which integrates ACRU and MIKE BASIN, is believed to be a successful and valuable development which will promote the use of the ACRU model by consultants and DWAF officials and possibly by WUA's, as it simplifies the setup of the model tremendously.

4.5. Catchment Applications

The AAMG tool was applied to two separate case studies for the purposes of the technology transfer project. These case studies were the Oliphant's River catchment above Loskop Dam and the Mhlathuze River catchment in KwaZulu-Natal. Included in each case study section is a description of the physical area, the model data requirements, the model configuration and an analysis of the verified model output.

4.5.1. Mhlathuze Catchment

The Mhlathuze River catchment is situated in the Province of KwaZulu-Natal, and is located within the uSutu-Mhlathuze Water Management Area (WMA). The Mhlathuze catchment is one of six secondary catchments within the WMA, and it consists of nine quaternary catchments. Water use in the catchment is high, and the catchment has been declared to be "water stressed". This means that the theoretical water use exceeds the availability of water supply at the correct levels of assurance. The water use in the catchment is varied, with irrigated agriculture, industry, domestic water use and forestry all utilizing the available resources. The Mhlathuze catchment is also one of the pilot locations at which the DWAF compulsory licensing and water allocation reform strategies will be tested. For these strategies, the impact of new water use licenses or assessing old licenses and allocations is important in determining how water will be redistributed during the allocation reform process. Figure 4.1.1 below shows the Mhlathuze catchment and the relevant water resource aspects that are present.

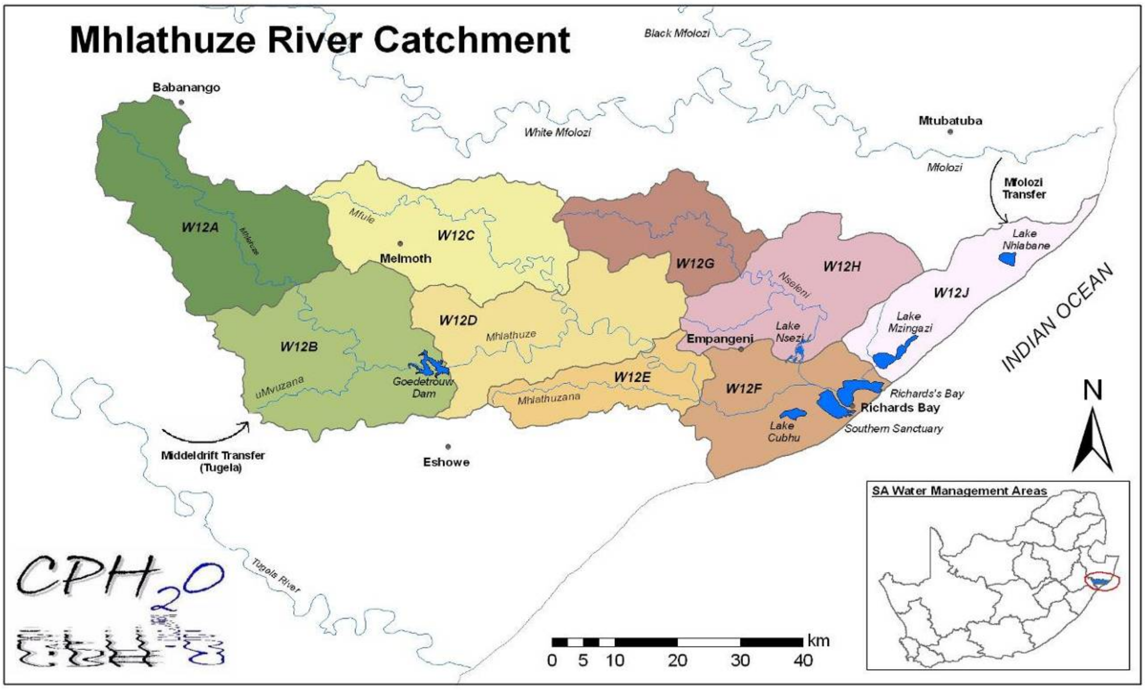

Figure 4.4 Mhlathuze River catchment locality map.

The Goedertrouw Dam, located on the Mhlathuze river (coordinates *28°46'21"* S; *31°28'00"* E) is the primary water resource in the catchment. There are also five natural lakes in the lower areas of the catchment that contribute significantly to the industrial and domestic water use in Richards Bay and Empangeni. Even with these natural lakes, the water supply in the catchment still needs to be augmented. For this purpose, two inter-basin transfers are present. These are the Tugela transfer at Middledrift, and the Umfolozi Transfer into Lake Sokulu.

4.5.2. Catchment Information

The Mhlathuze catchment information that was required to model the hydrology and water resources is dealt with in this section. Different aspects that will be covered include base information, such as rainfall, evaporation and land use, water user information such as location and abstraction rates, and infrastructural information such as gauging weirs.

4.5.2.1. Rainfall

The rainfall in the Mhlathuze catchment differs significantly from a spatial perspective. The coastal areas receive an annual average rainfall of between 1200 and 1400mm. Further inland, in the middle regions of the catchment, the rainfall decreases substantially. This is partially due to a rain shadow affect caused by large mountains in the area that prevent moisture from the coastal regions from penetrating inland. This rain shadow can be clearly observed in Figure 4.1.2 where the mean annual rainfall is depicted together with topography. The large mountain that causes the rain shadow can be observed. Figure 4.5 also shows how the rainfall increases again in the higher upper reaches of the catchment near Eshowe in the South, and Babanango in the North.

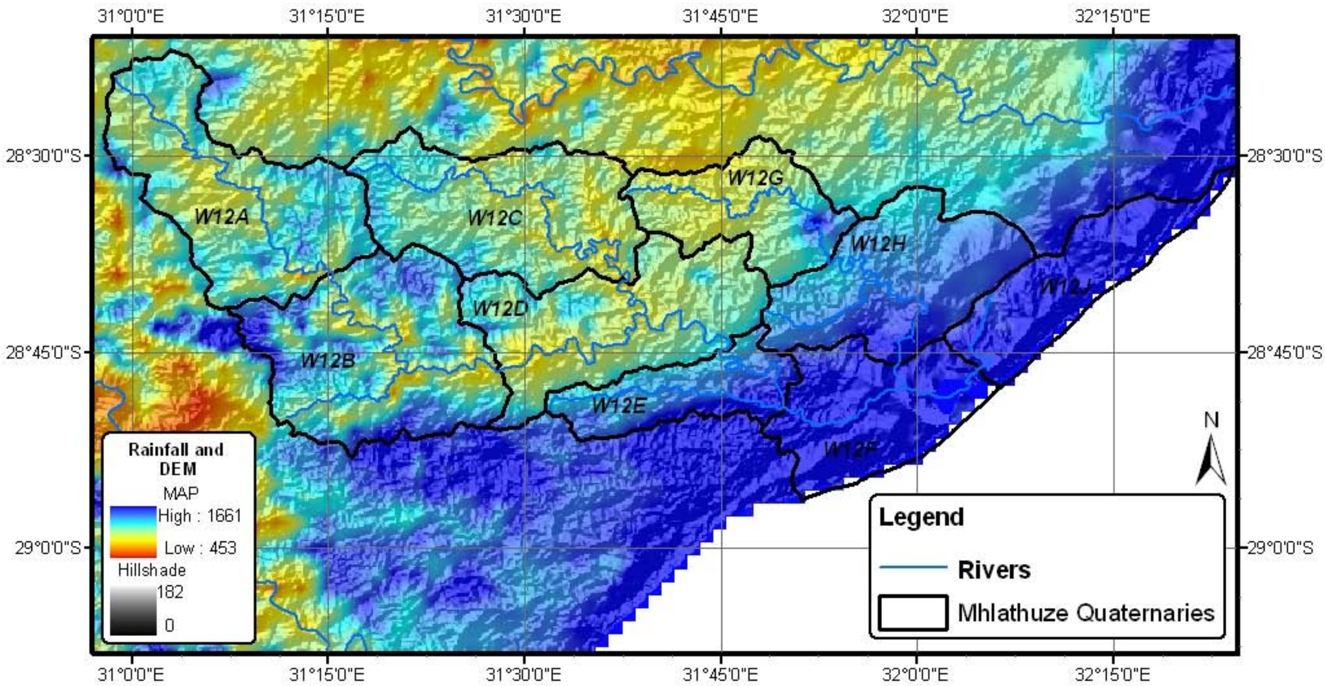

Figure 4.5 Mean annual rainfall with topography illustrating the topographical forcing that occurs.

To successfully simulate the hydrology of a catchment with the ACRU model, a representative driver rainfall station needs to be selected or created for each homogenous response area that is identified. The homogenous response areas for the Mhlathuze are discussed in a later section, but just to provide perspective, a map of all the possible stations that could be used for this driver rainfall methodology were included in a map of the mean annual rainfall. This is presented in Figure 4.6 on the following page. It should be noted that there were areas in the catchment that had a poor distribution of daily rainfall stations that could be used. The W12C and W12B quaternary catchments were particularly poor with very few rainfall stations present. This has potential to negatively impact simulations of the hydrology with the ACRU model because the daily rainfall for a specific area may not be represented correctly, and this would then result in the stream flow originating from the catchment being incorrect.

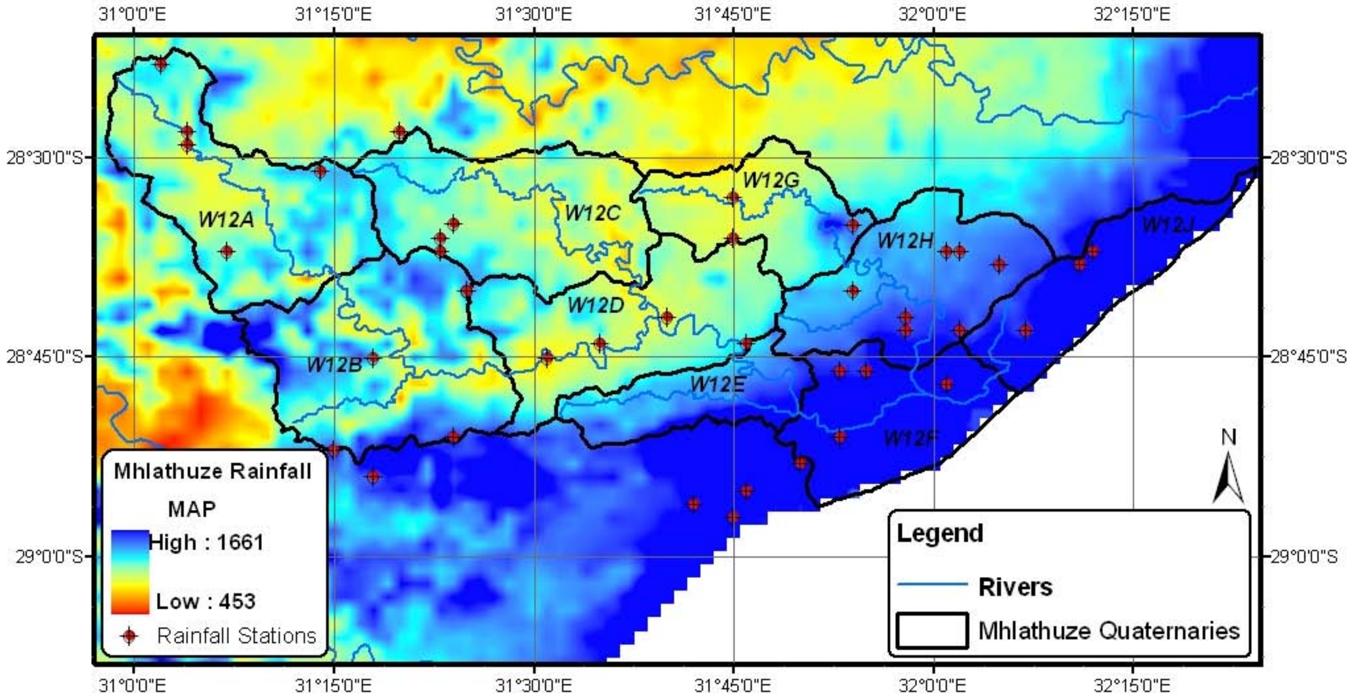

Figure 4.6 Mean annual rainfall with the location of daily rainfall stations.

In addition to the rainfall, the atmospheric demand for different areas in the catchment is also important from a hydrological perspective. The atmospheric demand determines the rate of water use by the different landuses that are present in the catchment. Therefore, a brief description of the mean evaporation patterns that occur in the catchment is presented next.

4.5.2.2. Evaporation

The mean annual A-pan evaporation is similar to the rainfall in that is varies substantially in the catchment. The areas that had a high annual rainfall generally have a lower evaporation relative to the areas that had low rainfall. This is particularly evident in the area affected by the rain shadow that was discussed earlier. The rain shadow areas have a high annual evaporation relative to the surrounding areas not affected by the rain shadow. These aspects are represented in Figure 4.7. From a quantitative perspective, Figure 4.7 shows that the evaporation in the catchment varies from a low of 1600 mm per year to a high of approximately 1800 mm per year. The areas with a higher mean annual evaporation are those in which irrigated agriculture is practiced. This will be seen in the landuse section further on, but it is worth noting at this point that the relatively higher evaporation rates and relatively lower rainfall values contributed to a large water demand from irrigation in these areas.

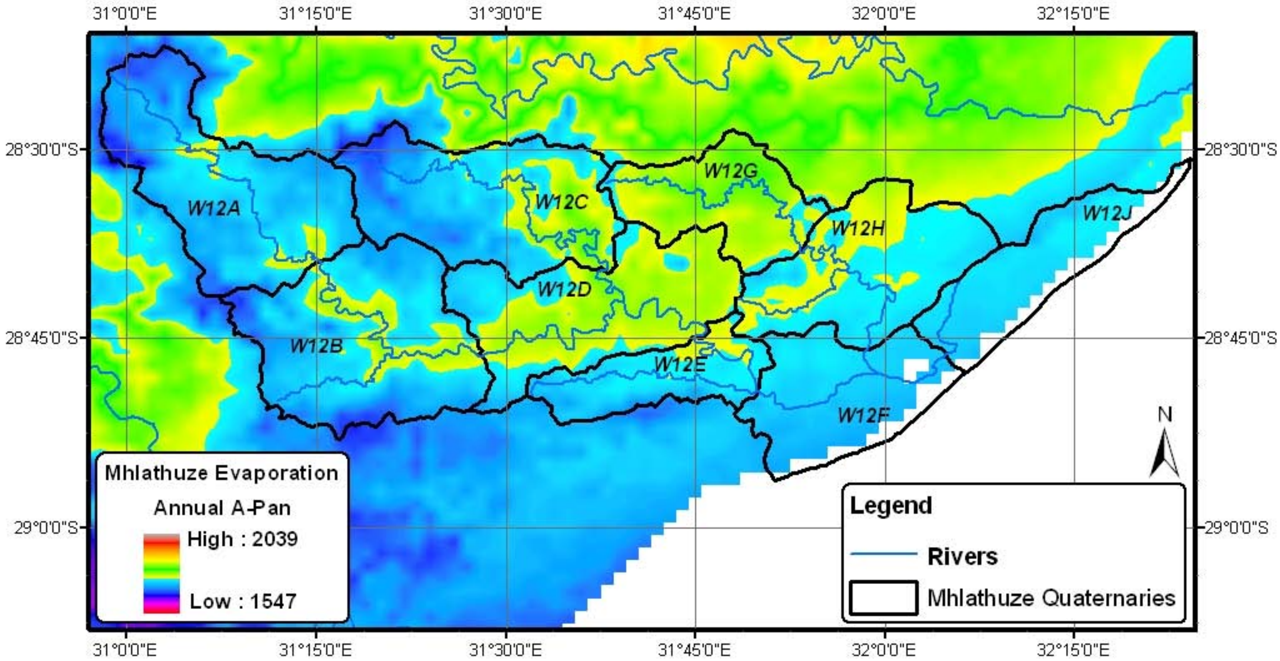

Figure 4.7 Mean annual evaporation in the Mhlathuze Catchment.

4.5.2.3. Landuse Information

The two landuses in the catchment that are the most important from a hydrological perspective are the commercial forestry and sugarcane areas. Forestry is classed as a Stream Flow Reduction Activity (SFRA) and needs to be taken into account, and the sugarcane areas are generally irrigated. Therefore, they are as important in the water resources in the catchment. The forestry and sugarcane areas in the catchment are depicted in Figure 4.7a. The focus of the technology transfer project is for using models to improve water management in commercial agriculture. From Figure 4.7a it can be seen that due to the large amount of commercial timber and sugarcane agriculture in the catchment, it is an ideal area to test the application potential of the ACRU and Mike Basin.

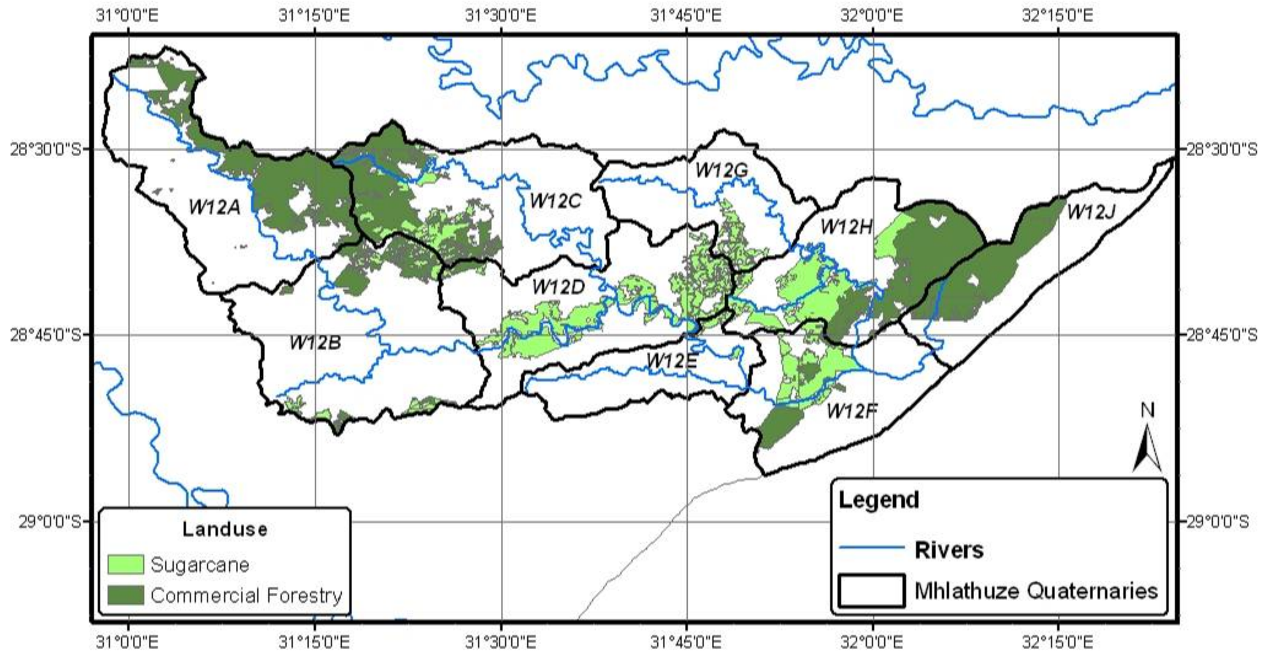

Figure 4.7a Sugarcane and commercial forestry landuse areas in the Mhlathuze Catchment.

4.5.2.4. Gauging Weirs and Catchment Infrastructure

There are several river and canal gauging weirs that are functional in the Mhlathuze catchment. The location of these weirs and the codes associated with each of them is shown in Figure 4.1.6. The descriptions associated with each weir code in Figure 4.1.6 are listed below:

- W1H005 - Mfuluzana River at Melmoth,
- W1L001 - Mhlathuze River at Stewards Farm,
- W1H009 - Mhlathuze River at Riverview,
- W1H032 - Mhlathuze River at Mhlathuze Valley,
- W1H028 - Right Canal from Goedertrouw Dam,
- W1H029 - Left Canal from Goedertrouw Dam,
- W1H030 - Mhlathuze River below Goedertrouw Dam,
- W1R001 - Goedertrouw Dam Water Level, and
- W1L002 - Level reading in the Mfule River

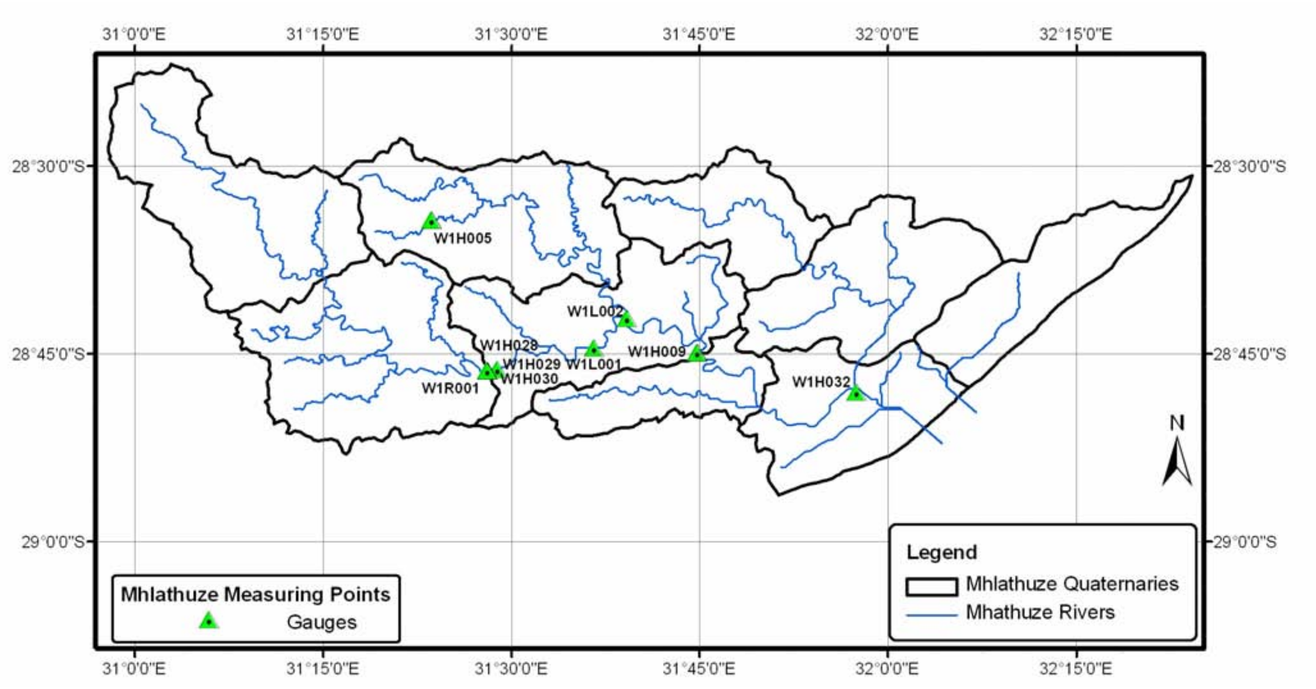

Figure 4.8 Location of river gauging weirs in the Mhlathuze Catchment.

From an assessment completed by Hallowes *et al*. (2002) it was established that the W1H005 and W1H009 river gauging stations were the only reliable flow stations. The periods for verifications at the two weirs would be from 1989/01/01 to 1991/12/31 and 1963/01/01 to 1975/12/31 respectively. It would also be possible to do a monthly verification on the Goedertrouw dam inflow by completing the dam water balance with available water level data (W1R001) and the outflow data (W1H028, W1H029 and W1H030). This verification would be when the Goedertrouw dam was not overflowing from 1987/01/01 to 1995/12/31.

4.5.2.5. Water Users

The individual water users in the catchment and their associated options of water supply needed to be identified for the system to be configured properly in Mike Basin. The water users that were present in the system were identified in a literature review and from personal knowledge of processes occurring in the catchment. Literature reviewed included reports by WRP (2004) and DWAF (1999). In total, there were 22 users that needed to be included in the system. These lists of water users that rely on different water resources in the Mhlathuze Catchment include irrigation, industrial and domestic users are provided below:

- Heatonville
- Nkwaleni
- Mfule
- KwaZulu 1
- KwaZulu 2
- Lower Mhlathuze

→ Irrigation Users (6)

- Tongaat Huletts Felixton
- Mondi Felixton
- Mondi Richards Bay
- Indian Ocean Fertilizers
- Richards Bay Minerals Smelter
- Richards Bay Minerals Evaporation Ponds
- Hillandale ISCOR mine
- Fairbreeze ISCOR mine
- Alusaf

→ Industrial Users (9)

- Richards Bay
- Eshowe
- Melmoth
- Empangeni
- Ngwelezana
- eSikaweni
- Nseleni

→ Domestic Users (7)

From assessing the literature it was possible to identify the different supply options to each of these users. This is discussed further in the initial model configuration when these priority rules had to be specified in the Mike Basin model.

4.5.3. Initial Model Configuration

The initial model configuration in the ACRU and Mike Basin model is described in this section. Aspects that needed to be addressed in this process, and that will be described in this section, include:

- Quinary Catchment Identification,
- Rainfall Station Identification,
- Water Infrastructure (Reservoirs and Lakes) Information and Operating Rules,
- Water User Information and Operating Rules, and
- Complete Setup.

4.5.3.1. Quinary Catchment Identification

In order for the hydrology to be simulated with the ACRU model it is necessary to sub-divide the catchments into smaller more homogenous response units. These smaller catchments are referred to as *Quinary Catchments*, and facilitate the hydrology to be simulated at a fine scale. These Quinary Catchments were also defined by using important infrastructure locations such as the Goedertrouw Dam and the different gauging stations in the various rivers in the Mhlathuze Catchment. The primary data sources that were used to delineate these catchments were the spatially distributed Mean Annual Rainfall and Evaporation grids that were sourced from the South African Atlas of Agrohydrology and –

Climatology (Schulze, 1997). The Quinary, and the original 9 Quaternary catchments, are depicted in Figure 4.9.

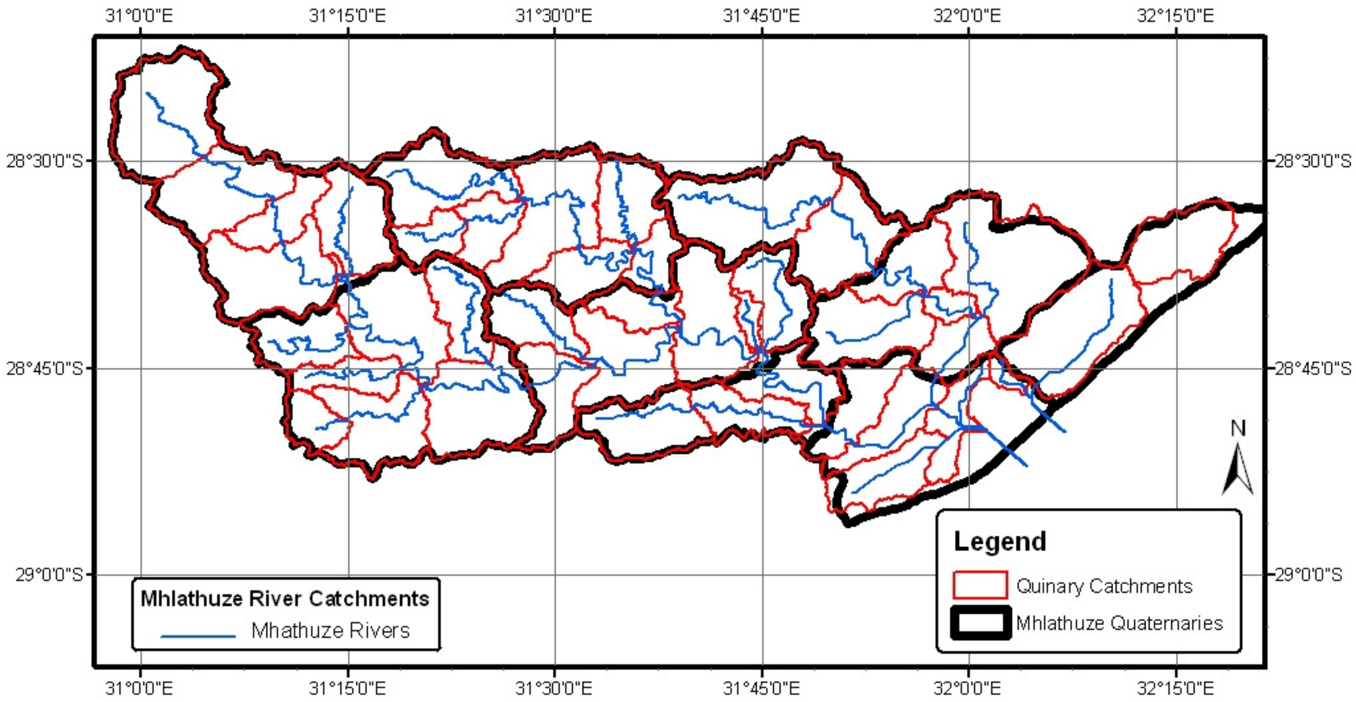

Figure 4.9 The Mhlathuze Quaternary Catchments and the associated Quinary Catchments that were identified

In some instances, the outlet positions of Quinary catchments were located at points where important hydrological information was required. For example, a catchment outlet was located at each of the river gauging station in the catchment so that observed stream flow records could be compared with simulated hydrological results from the ACRU model. These points were at the expense of establishing hydrologically similar catchments, but could not be avoided for obvious reasons. The use of the Mike Basin model made the catchment delimitations from these important points and all other points in the setup very simple. A 20 metre Digital Elevation Model (DEM) was used to automatically determine the contributing catchment area to each catchment node in the model configuration. This method of determining the catchment areas was substantially quicker and less time consuming than if the areas had to be manually determined with large scale orthophotos or topographical maps.

After each of the Quinary catchments had been determined, suitable driver rainfall stations had to be identified. The process of selecting and creating a suitable station is discussed next.

4.5.3.2. Rainfall Station Identification

Figure 4.6 showed the location of rainfall stations in the Mhlathuze Catchment and surrounding areas. A suitable selection out of those stations shown needed to be identified. The selection process was based on observed record length within the period of interest. If a station had 30 or more years of observed data, it was considered suitable for use. The daily observed rainfall values from these stations were then used in an interpolation and conditioning methodology to create a daily rainfall surface for the Mhlathuze Catchment and surrounding areas. The boundaries of the Quinary catchments (see Figure 4.9) were then used to create a daily rainfall value per catchment from the daily conditioned rainfall surface that was created. This was completed for a record length from 1950 to 1999 and the result was a composite rainfall dataset for each Quinary catchment in the Mhlathuze.

4.5.3.3. Water Infrastructure (Reservoirs and Lakes) Information and Operating Rules

The operating rules of the different reservoirs and lakes in the Mhlathuze system was based on findings by WRP (2004) and DWAF (1999). The priorities of supply and the different users supplied by each impoundment was also based on the WRP (2004) and DWAF (1999) documents. In summary, the users supplied by each of the different lakes and Goedertrouw dam are provided in the list below:

- **Lake Nsezi:** - Richards Bay Minerals Smelter
  - Richards Bay Minerals Evaporation Ponds
  - Richards Bay
  - Alusaf
  - Indian Ocean Fertilizers
  - Nseleni
  - Empangeni
  - Mondi Richards Bay
- **Lake Cubhu:** - eSikaweni
- **Lake Mzingazi:** - Richards Bay
  - Alusaf
  - Indian Ocean Fertilizers
- **Lake Nhlabane:** - Richards Bay Minerals Smelter
  - Richards Bay Minerals Evaporation Ponds
- **Goedertrouw Dam:** - Empangeni
  - Ngwelezana
  - Heatonville
  - Nkwaleni
  - Mfule
  - KwaZulu 1
  - KwaZulu 2
  - Lower Mhlathuze
  - Tongaat Huletts Felixton
  - Mondi Felixton
  - Mondi Richards Bay
  - Indian Ocean Fertilizers
  - Richards Bay Minerals Smelter
  - Richards Bay Minerals Evaporation Ponds
  - Hillandale ISCOR mine
  - Fairbreeze ISCOR mine
  - Alusaf
  - Richards Bay
  - Eshowe

The two inter basin transfers were also conceptualised in the model according to operating rules defined by WRP (2004) and DWAF (1999). These operating rules were dependant on the water levels in the impoundments into which the water was transferred, viz Goedertrouw Dam for the Tugela transfer and Lake Sokulu for the Umfolozi transfer, and the availability of water in each of the supplying catchments. In simple terms, if the transfer was required and there was sufficient water for the transfer to occur, it would. In principle, this is exactly how such inter basin transfers would be operated.

4.5.3.4. Water User Information and Operating Rules

For each of the users in the system, their priorities of water use also needed to be determined. If a user had access to more that one water source, the order in which they would prefer to access this water would need to be input into the Mike Basin model. The information for these decisions was also based on data from (2004) and DWAF (1999) and is summarized in Table 4.1.1.

Table 4.1 Priorities of water access

Heatonville	1. Mhlathuze River 2. Goedertrouw Dam
Nkwaleni -	1. Mhlathuze River 2. Goedertrouw Dam
Mfule	1. Mfule River 2. Goedertrouw Dam
KwaZulu 1	1. Mhlathuze River 2. Goedertrouw Dam
KwaZulu 2	1. Mhlathuze River 2. Goedertrouw Dam
Lower Mhlathuze	1. Mhlathuze River 2. Goedertrouw Dam
Tongaat Huletts Felixton	1. Mhlathuze River 2. Goedertrouw Dam
Mondi Felixton	1. Mhlathuze River 2. Goedertrouw Dam
Mondi Richards Bay	1. Lake Nsezi 2. Goedertrouw Dam
Indian Ocean Fertilizers	1. Lake Mzingazi 2. Lake Nsezi 3. Goedertrouw Dam
Richards Bay Minerals Smelter	1. Lake Nsezi 2. Lake Nhlabane 3. Goedertrouw Dam
Richards Bay Minerals Evaporation Ponds	1. Lake Sokulu 2. Lake Nhlabane 3. Lake Nsezi 4. Lake Mzingazi 5. Goedertrouw Dam
Hillandale ISCOR mine	1. Mhlathuze River
Fairbreeze ISCOR mine	1. Mhlathuze River
Alusaf	1. Lake Mzingazi 2. Lake Nsezi 3. Goedertrouw Dam
Richards Bay	1. Lake Mzingazi 2. Lake Nsezi 3. Goedertrouw Dam
Eshowe	1. Goedertrouw Dam
Melmoth	1. Mfuluzana River
Empangeni	1. Lake Nsezi
Ngwelezana	1. Mhlathuze River
eSikaweni	1. Mhlathuze River 2. Lake Cubhu
Nseleni	1. Lake Nsezi

The water user consumption figures for each of the users were obtained from DWAF (1999). They were used in the Mike Basin model accordingly. The complete Mhlathuze Catchment was then completed in the Mike Basin model. This is illustrated and discussed briefly in the following section.

4.5.3.5. Complete Mike Basin Setup for the Mhlathuze River Catchment

The complete Mike Basin setup for the Mhlathuze catchment was achieved using the data and operating rules that have been highlighted in the report up till this point. Figure 4.10 shows the complete setup. The different lakes, Quinary catchments, rivers, water users and link channels can all be observed. Figure 4.10 also shows that if an individual user has access to water from different resources, and operation rules associated with each source, such a situation can be represented in the model. These two different aspects have been shown in the red circles marked ***A*** and ***B***. The ***A*** circle, which represents the Richards Bay Minerals Evaporation Pond Industrial user, shows how abstraction from many different sources can be represented. Similarly, the ***B*** circle shows how the Goedertrouw Dam is the source of water for many different users in the catchment.

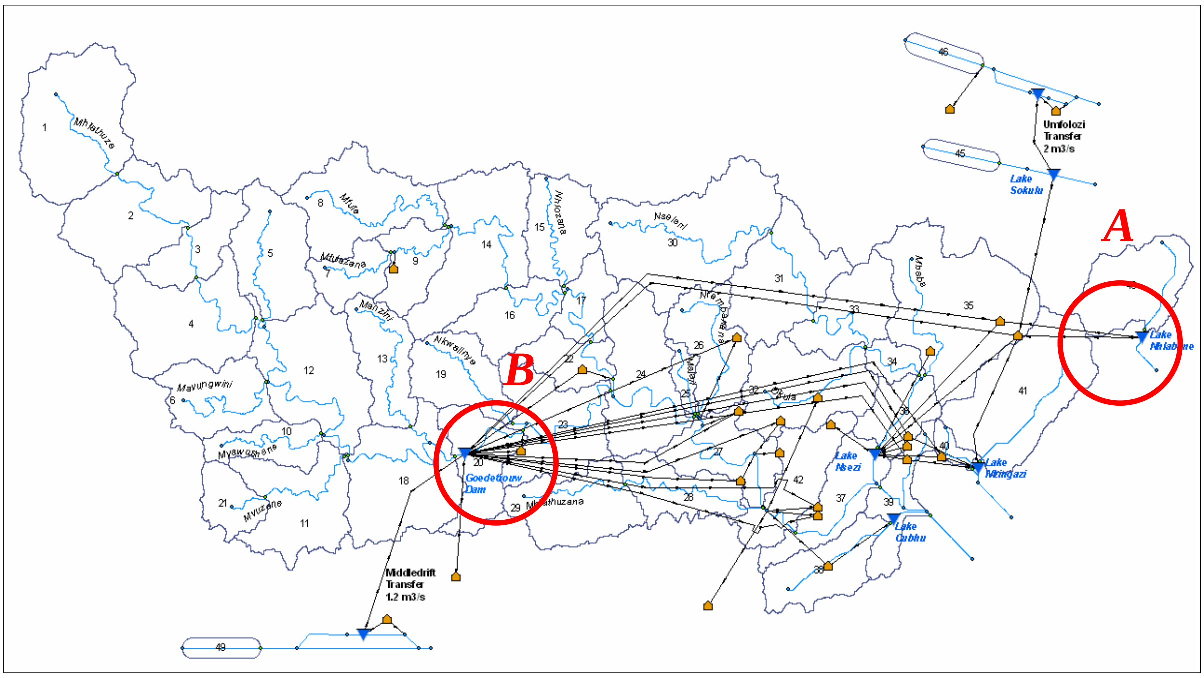

Figure 4.10 Complete Mike Basin setup for the Mhlathuze River Catchment.

Figure 4.10 also shows how the inter-basin transfers from the Tugela and Umfolozi catchments were conceptualised. The functioning of these transfers and the actual operating rules associated with them were represented in the model.

4.5.4. Simulation Results and Verifications

The output from the ACRU model needs to be compared with observed stream flow for verification purposes. The gauging weirs that were available for this task were described in a previous section. However, as previously stated, not all of the gauges were suitable for verification purposes. This section is a description of the locations and time periods that will be used in the verification process. The verification of the Mhlathuze hydrology was undertaken over three different time periods at three different locations within the catchment. These different locations and time periods are given below:

1. 1963 to 1975 for the Mhlathuze River at the W1H009 gauging station (Mhlathuze River at Riverview). This verification was meant to represent the hydrology at this point prior to construction of the Goedertrouw Dam in 1979. Catchment area = 2409 km^2.
2. 1987 to 1995 for the Mhlathuze River at the W1R001 gauging station (Goedertrouw Dam water level). By completing a water balance for Goedertrouw Dam, it was possible to determine the water inflow at a monthly time step. Catchment area = 1278 km^2.
3. 1989 to 1991 for the Mfuluzana River at the W1H005 gauging station (Mfuluzana River at Melmoth). Catchment area = 45 km^2.

The verification process was achieved by following guidelines established by Schulze and Smithers (1995) and adjusting necessary ACRU parameters. It should be noted that the parameters were only adjusted to ranges that were justifiable and therefore they can be regarded as physically plausible.

4.5.4.1. Location 1

A time series of monthly simulated and observed streamflow for gauging weir W1H009 is presented in Figure 4.11. The observed time series for this gauging location was not good and had many periods within the verification period that were missing or not reliable. The corresponding simulated data within these unreliable periods was not used for the comparison. Figure 4.12 and 4.13 are a scatter plot pf observed versus simulated streamflow and a graph of accumulated simulated and observed flow respectively. An analysis of the results obtained for this verification location is made after the figures.

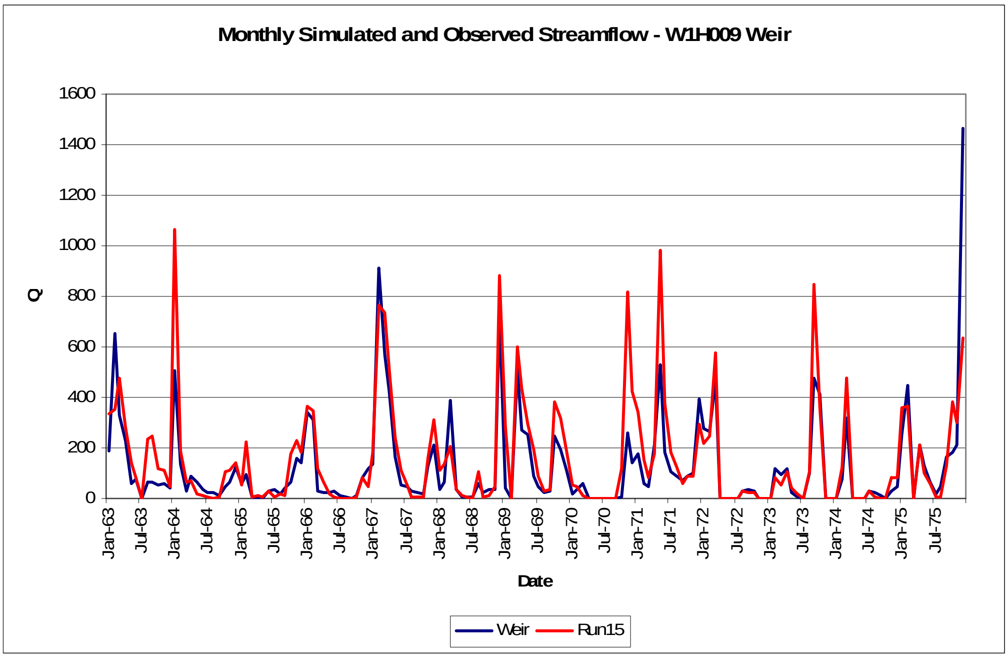

Figure 4.11 Monthly simulated vs. observed streamflow time series for the W1H009 gauging site.

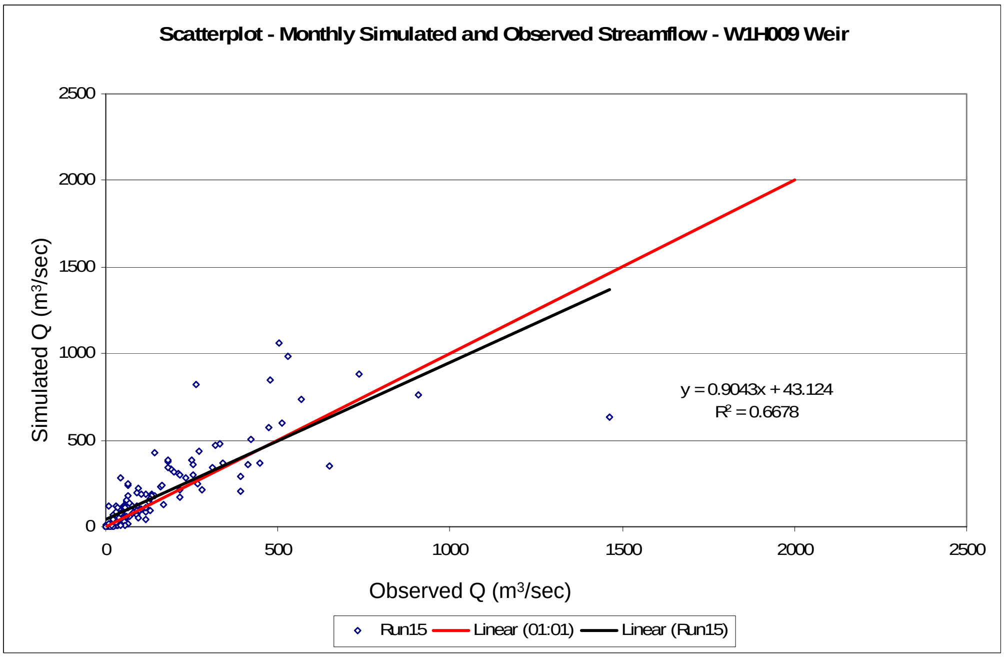

Figure 4.12
Scatter plot of simulated vs. observed streamflow for the W1H009 gauging site.

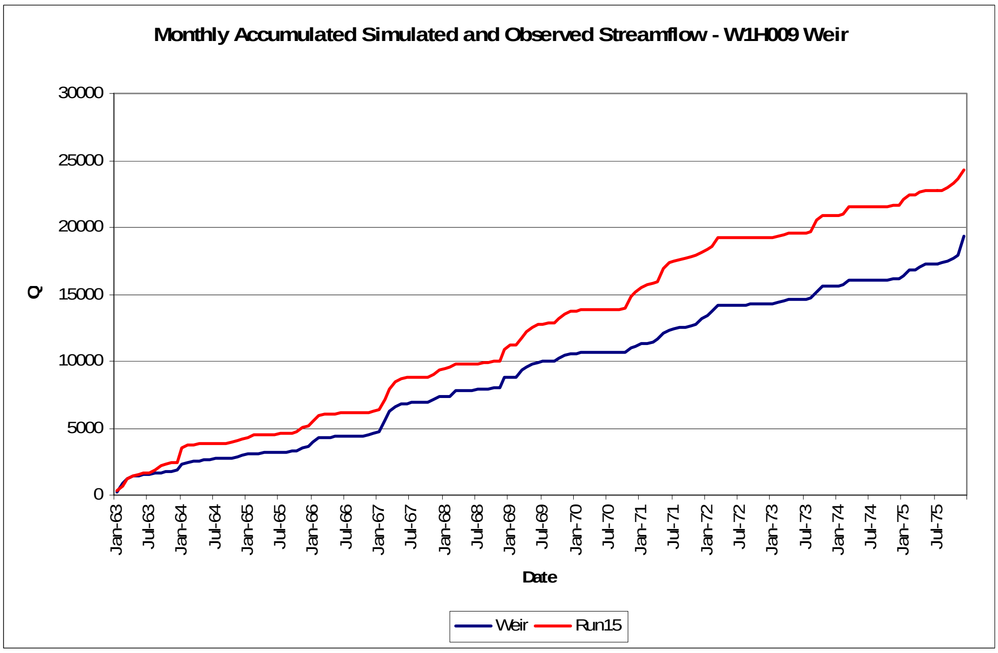

Figure 4.13 Accumulated simulated and observed stream flow for the W1H009 gauging site

Figure 4.12 shows that the model is fairly accurate in simulating the observed hydrology. A Pearson's R^2 value of 0.67 for the monthly regression is reasonable. The problem with the W1H009 gauging site is the uncertainty of historical water use by irrigators upstream and of extensive forestry areas that are located in the upstream catchment areas of the gauging site. The landuse that was used for the ACRU simulations was based on data captured in 1996. Therefore, there is a chance that the model input is not accurately representing the landuse during the verification period.

The results for verification location 2, the Goedertrouw Dam inflow (W1R001) are presented and discussed next.

4.5.4.2. Location 2

A time series of monthly simulated and observed streamflow for gauging weir W1R001 is presented in Figure 4.14. The observed time series that is shown in Figure 4.14 is actually a calculated value based on a mass balance for the Goedertrouw Dam. The monthly inflow is determined based on the water level in the dam, and the outflows that are recorded. Therefore, the observed time series could have slight anomalies if errors were present in the input data used to calculate the time series. However, Figure 4.14 shows that the model was well configured to represent the hydrology upstream of the dam.

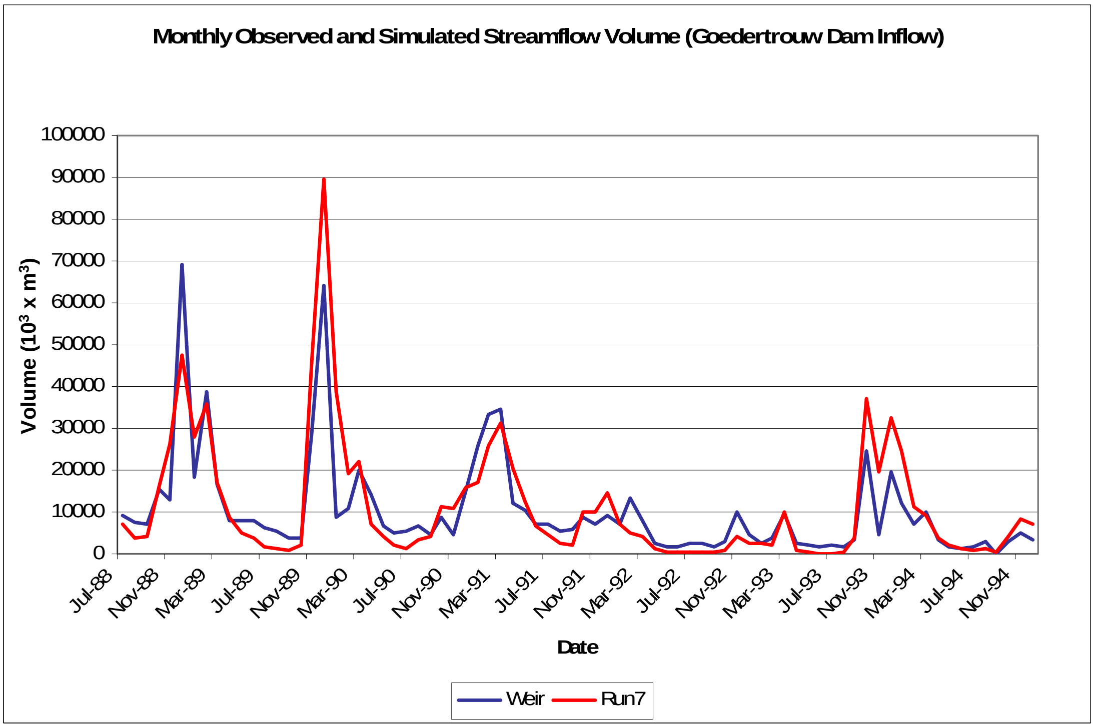

Figure 4.14 Monthly simulated vs. observed streamflow time series for the W1R001 gauging site

Figure 4.14 and 4.15 are a scatter plot of observed versus simulated streamflow and a graph of accumulated simulated and observed flow respectively. The Pearson's R^2 value for this verification location was 0.76, which was an improvement in the value from the previous W1H009 location.

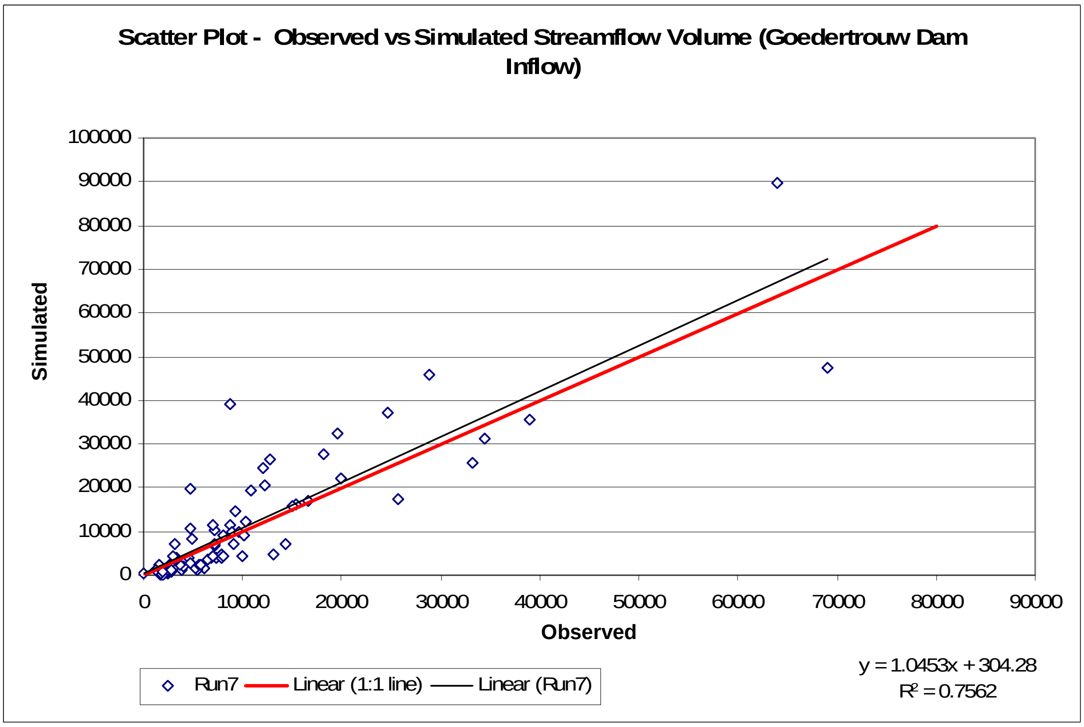

Figure 4.15 Scatter plot of simulated vs. observed streamflow for the W1R001 gauging site.

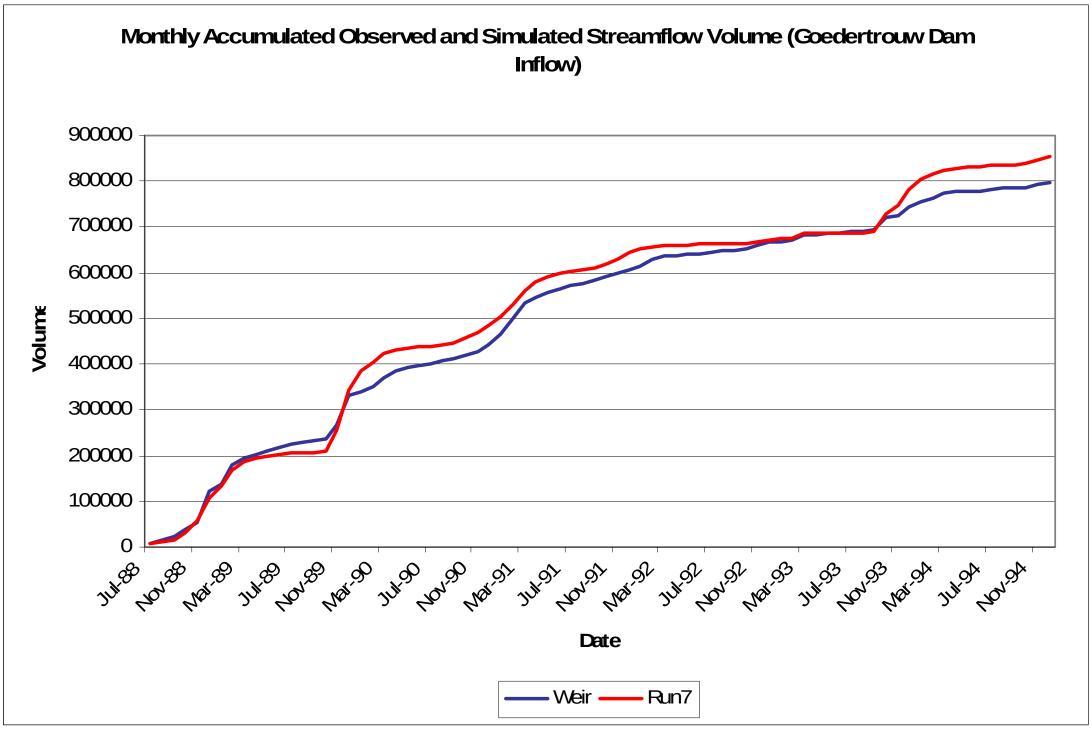

Figure 4.16 Accumulated simulated and observed stream flow for the W1R001 gauging site.

Figure 4.15 shows that generally the simulated output matches the observed values both quantitatively and at the correct temporal scale. Two periods in the verification period were over simulated by the model; these were in the summer of 1990 and the summer of 1994. These periods can also be observed in Figure 4.16.

The graphs and results from the last verification location, viz, the W1H005 gauging weir, are presented next.

4.5.4.3. Location 3

A monthly time series of the simulated and observed results is presented in Figure 4.17. The duration of the verification period as this location was only 3 years. It should be noted that the town of Melmoth extracts water from the Mfuluzana River just above this verification location. The water use by the town was not included in the simulations. Therefore, any inconsistencies between the observed and simulated output could be partially attributed to the abstraction from the town. However, it can be seen from Figure 4.17, that the model still performs satisfactorily.

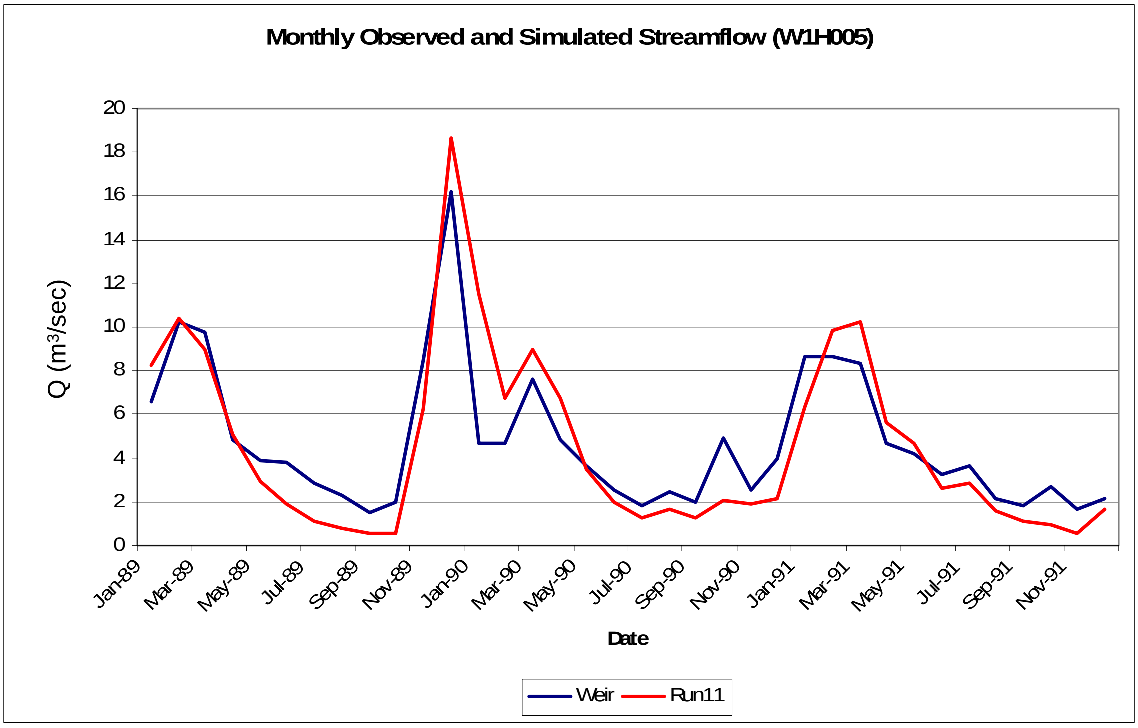

Figure 4.17 Monthly simulated vs. observed streamflow time series for the W1H005 gauging site.

Figure 4.18 and 4.19, which are presented next, are a scatter plot of observed versus simulated streamflow and a graph of accumulated simulated and observed flow respectively. The Pearson's R^2 coefficient for this location within the verification period was 0.83, which is acceptable. The accumulated time series shown in Figure 4.19 also reveal how the observed streamflow and the simulated streamflow are similar.

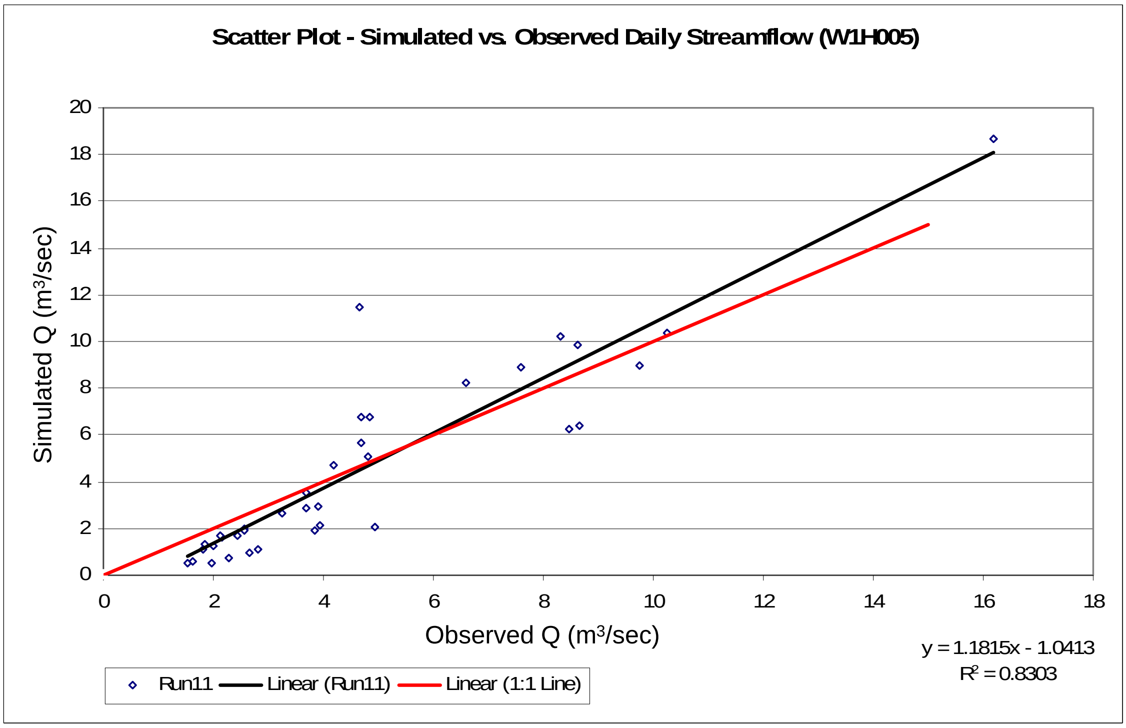

Figure 4.18 Scatter plot of simulated vs. observed streamflow for the W1H005 gauging site.

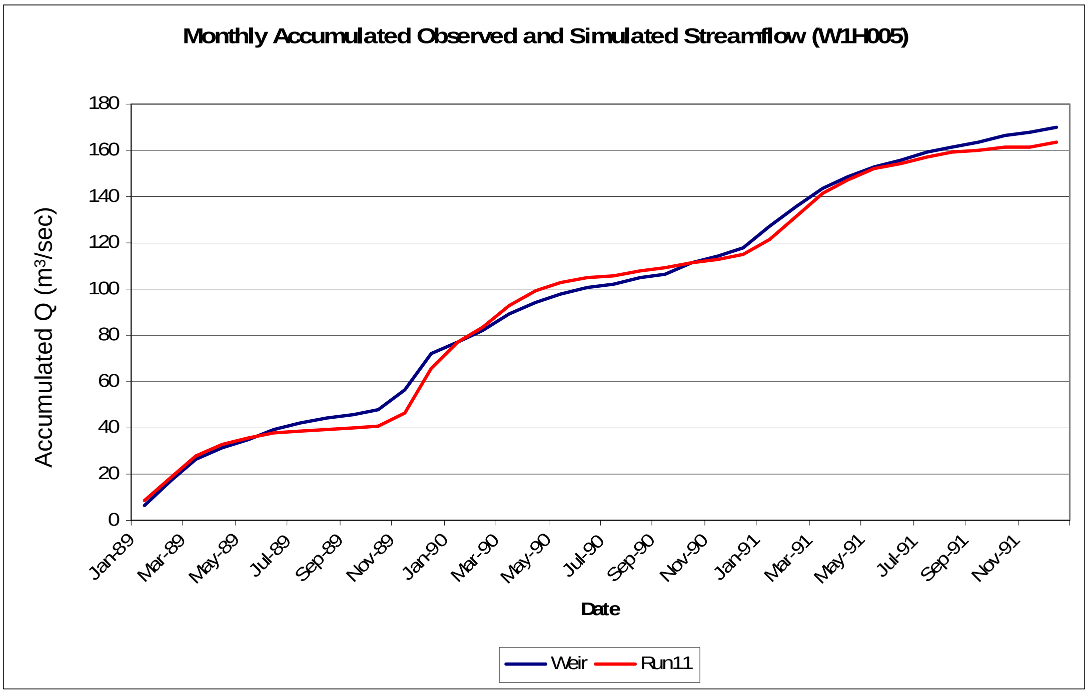

Figure 4.19 Accumulated simulated and observed stream flow for the W1H005 gauging site.

4.5.5. Discussion of Mhlathuze Results

Guidelines suggested by Schulze and Smithers (1995) were used to improve the simulation results that were obtained. The verification process aims to change the model parameters such that responses from rainfall events are represented correctly. Table 4.2 is a summary of the results obtained form each of the three verification locations.

Table 4.2 Summary of Mhlathuze verification results (poor quality data excluded)

Location	***Verification Period***	***Simulated (m^3/ann)***	***Observed (m^3/ann)***	***Percent Difference (%)***	***Monthly Pearson's R^2***
W1R001	01/07/1988 to 01/01/1995	126 722 769	122 373 384	96.6	0.76
W1H005	01/01/1989 to 01/01/1992	4 705 920	4 898 880	96.1	0.83
W1H009	01/01/1963 to 01/01/1976	161 097 317	128 702 656	125.2	0.67

In general, the verifications at W1R001 and W1H005 were acceptable. However, the verifications at location W1H009 could still be improved, but, it must be reiterated that the focus of this case study application and report was not to obtain perfect simulation results. It was rather a proof of concept application, and therefore, prolonged effort in improving simulations was not justifiable within the time constraints of this aspect of the study.

The second case study, to which the ACRU, Mike Basin and the AAMG were applied, was the upper Oliphant's river catchment above Loskop Dam. This application is introduced and the results obtained from the models are discussed in the next section.

4.5.6. Upper Olifants Water Management Area - The Area Upstream and Including the Loskop WUA (Secondary Catchments B1, B2 and B3)

In this section a similar approach is followed in using the AAMG to set up the catchment area that contributes to runoff entering Loskop Dam and to area below the dam where the Loskop WUA is located. In this section we will also examine the effect of imposing a hypothetical water user on the system using the MIKE Basin functionality. This is an effective way of assessing the impact of a new water user on the system. Thus the effectiveness of the AAMG application as tool for assisting in the licensing process will be illustrated.

4.5.7. Catchment information

The area which is the focus of this study, namely the B1, B2 and B3 secondary catchments, form part of the Olifants Water Management Area and is situated in the Province of Mpumalanga. Parts of the western portion of the upper B3 catchment do however fall within the Gauteng and the Limpopo Province. The study area consists of three of the nine secondary catchments which make up the Olifants Water Management Area. The B1 secondary consists of 16 quaternary catchments, the B2 secondary catchment comprises 9 quaternary catchments while the B3 catchment is made up by 18 quaternary catchments. However, only those quaternary catchments in the B3 area that contribute to the Loskop Dam catchment are modelled. Water use in these catchments is high. The water use activities and the major resources in the study area are briefly discussed below. A locality map of the study area is presented in Figure 4.2.1.

The major river in the B1 sub-drainage region is the Olifants River and its main tributary the Klein Olifants. The Olifants River has its origin near Bethal in the South East and its largest tributary is the Steenkoolspruit. The origin of the Klein Olifants is near Hendrina and drains the Eastern part of the sub- region. The main reservoirs in this region are Witbank Dam (Olifants River) and Middelburg Dam (Klein Olifants River). The Klein Olifants River flows into the Olifants River downstream of Middelburg Dam. (DWAF – Mpumalanga Hydrology)

The main activities in the B1 secondary drainage area are coal mining, power generation, agriculture, and it is characterised by industrial development and large residential areas. Intensive water quality monitoring is constantly conducted in the region due to the potential pollution caused by the mentioned features of the drainage region.

The major river in the B2 sub-drainage region is the Wilge River and its main tributary the Bronkhorstspruit River. The origin of the Bronkhorstspruit River is near Delmas and its main tributary is the Koffiespruit. The Wilge River drains the Eastern part of the region and has its origin near Leandra. The main reservoir is the Bronkhorstspruit Dam and is situated in the Bronkhorstspruit River near the town of Bronkhorstspruit. The Wilge River flows into the Bronkhorstspruit River downstream of Bronkhorstspruit town. (DWAF – Mpumalanga Hydrology).

The main activities in the B2 secondary drainage area are agriculture and the area is characterised by low industrial development and residential areas.

The Olifants River and its smaller tributaries drain the B3 area. The Western part of this region is drained by the Elands and Moses Rivers. The Elands River has its origin near Hammanskraal in the far South Western part of the region. Water from the B2 drainage region joins the Olifants River upstream of Loskop Dam. The major reservoir in this region is Loskop Dam and is situated in the Olifants River near the town of Groblersdal. The two major reservoirs in the Elands River are Rhenosterkop and Rust de Winter Dams and are responsible for mainly irrigation purposes respectively. (DWAF – Mpumalanga Hydrology).

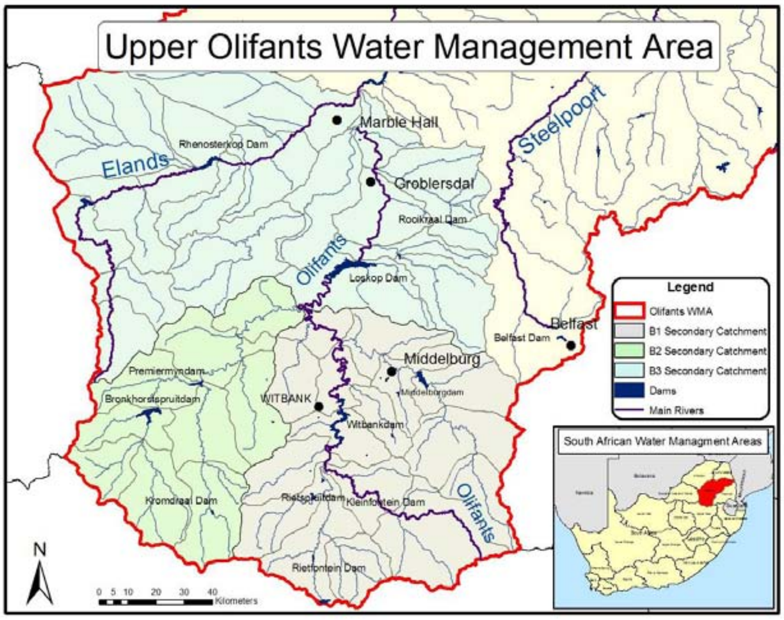

Figure 4.19 Study Area Locality Map in the Upper Olifants Water Management Area

4.5.7.1. Rainfall

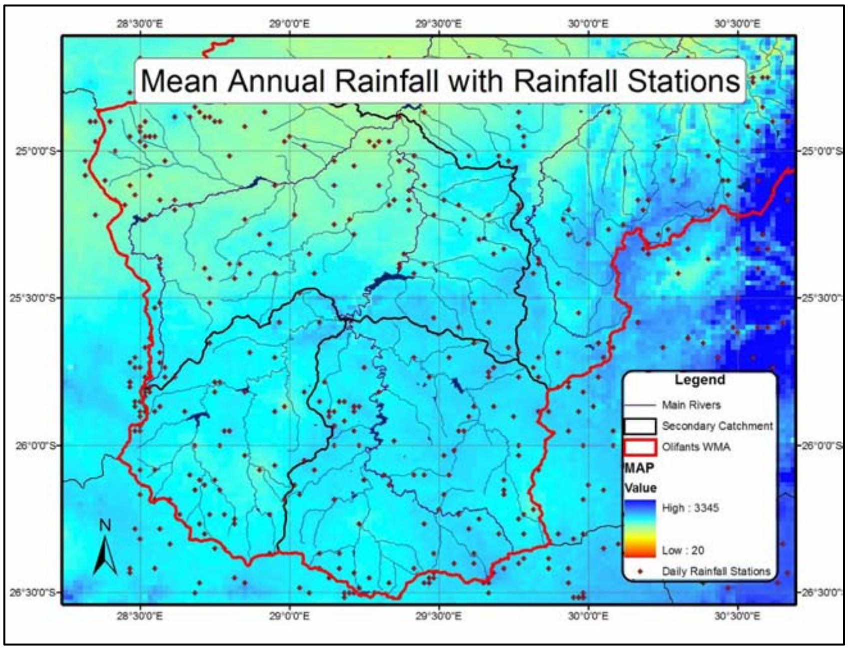

Figure 4.20 Mean annual rainfall with the location of daily rainfall stations.

The rainfall patterns are closely associated will topography (See Figure 4.22 below) with higher rainfall occurring in the B1 and B2 catchments while it decreases significantly below Loskop Dam.

The rainfall stations will a daily record are also illustrated in Figure 4.20. This is important since daily rainfall is the primary driver for the ACRU model. It can be seen that there is a good distribution of daily rainfall gauges in the study area.

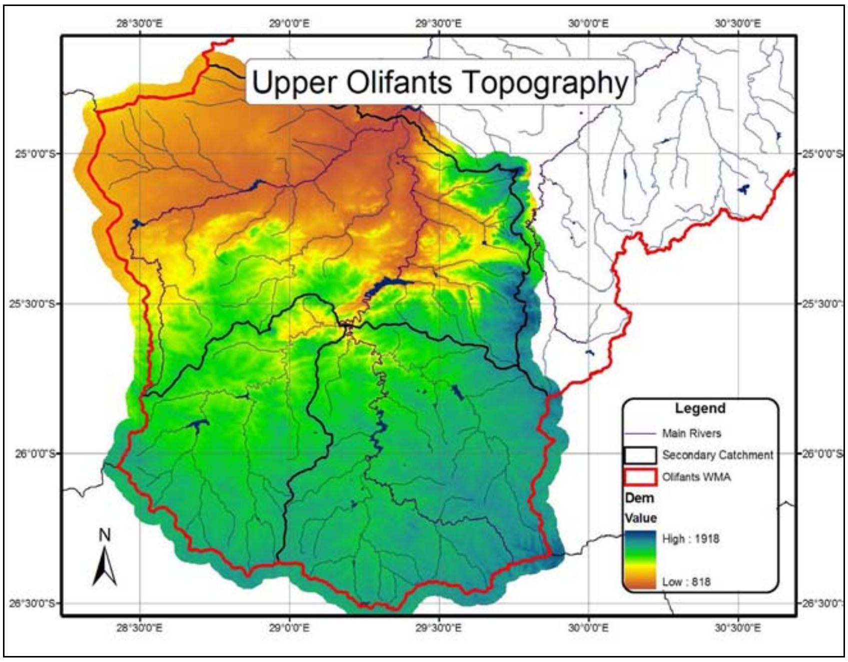

Figure 4.21 Topography of the Upper Olifants Water Management Area

In addition to the rainfall, the atmospheric demand for different areas in the catchment is also important from a hydrological perspective. The atmospheric demand determines the rate of water use by the different landuses that are present in the catchment. Therefore the mean evaporation patterns that occur in the catchment are presented next.

4.5.7.2. Evaporation

A-pan evaporation varies from 1950 mm per annum in the B1 and B2 catchments to as high as 2200mm in the B3 catchment.

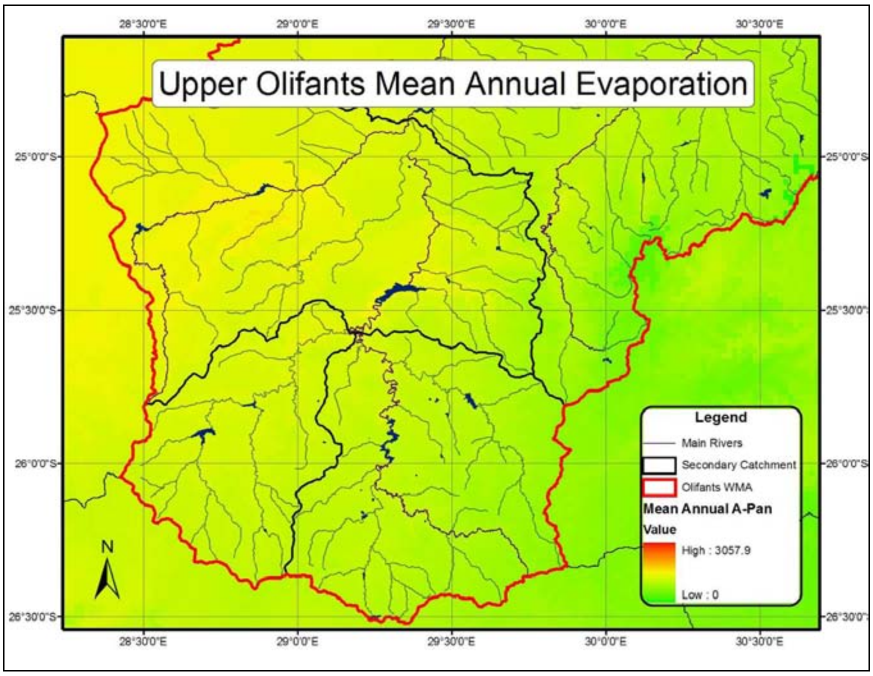

Figure 4.22 Mean Evaporation in the Upper Olifants Water Management Area

4.5.7.3. Landuse

Landuse is in the B1 and B2 catchments is characterised by dryland agriculture. This is mainly due to the higher rainfall occurring in these areas. Irrigated agriculture prevails below Loskop Dam (Loskop Water User Association) where higher atmospheric demands dictate the need for irrigation. See Figure 4.23 below.

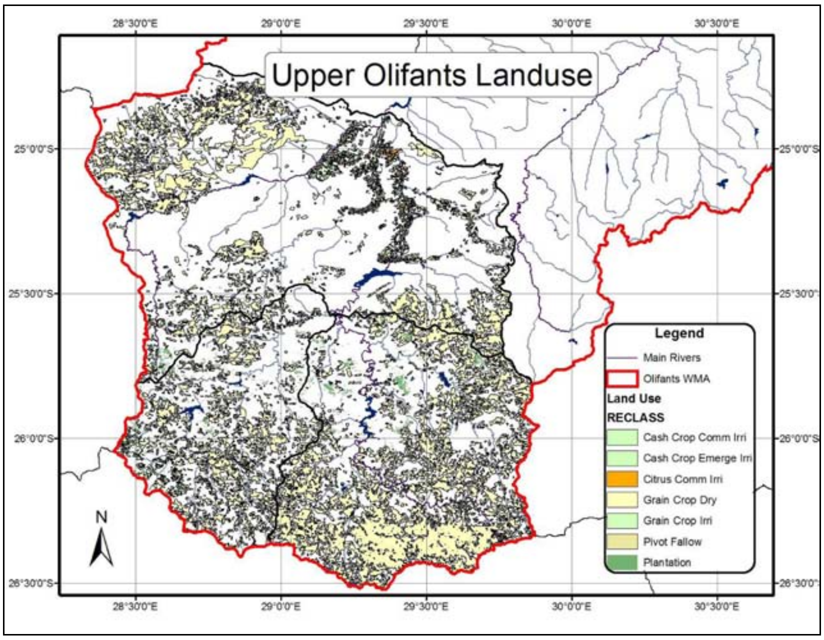

Figure 4.23 Landuse in the Upper Olifants Water Management Area

4.5.7.4. Gauging Weirs and Catchment Infrastructure

The area above the Loskop Dam is characterised by a comprehensive gauging network. This is important since for AAMG tool to be effective, simulated flows need to be compared to the observed record in order to establish a degree of confidence in the simulation results.

Major resources upstream of the Loskop Dam include the Middelburg Dam, Witbank Dam as well as the Bronkhorstspruit Dam. See Figure 4.24 below

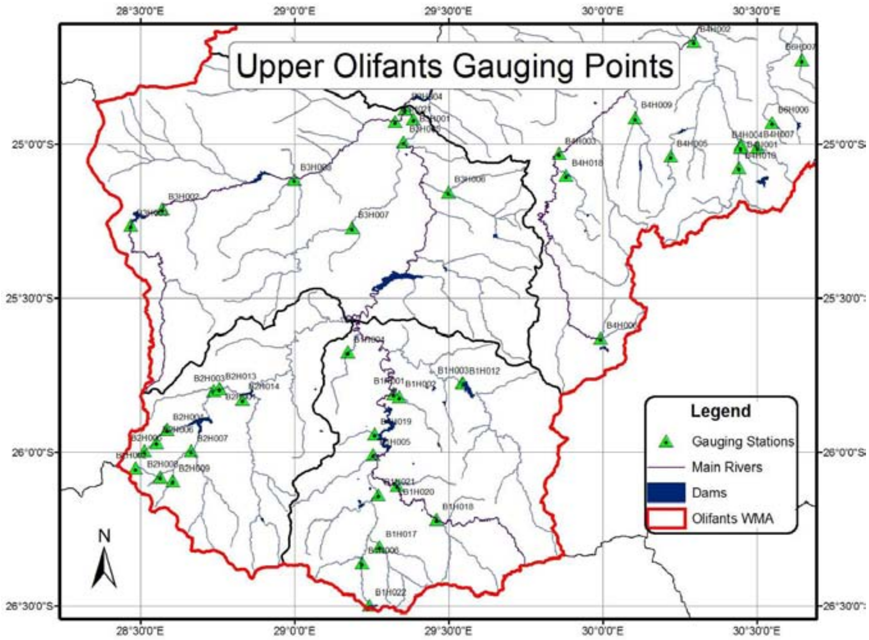

Figure 4.24 River Gauging Network and Major Dams in the Upper Olifants Catchment

4.5.7.5. Water Users

Water use in upper Olifants Water management Area is characterised largely by mining, industrial and domestic water supply.

4.5.8. Initial Model Configuration

The initial model configuration in the ACRU and Mike Basin model is described in this section.

4.5.8.1. Quinary Catchment Identification

As mentioned in section 4.1.2.1, in order for the hydrology to be simulated with the ACRU model it is necessary to sub-divide the catchments into smaller more homogenous response units. These smaller catchments are referred to as *Quinary Catchments*, and facilitate the hydrology to be simulated at a fine scale.

See Figure 4.25 below. Note that most of the catchments are still at quaternary level since such a large area is being modelled.

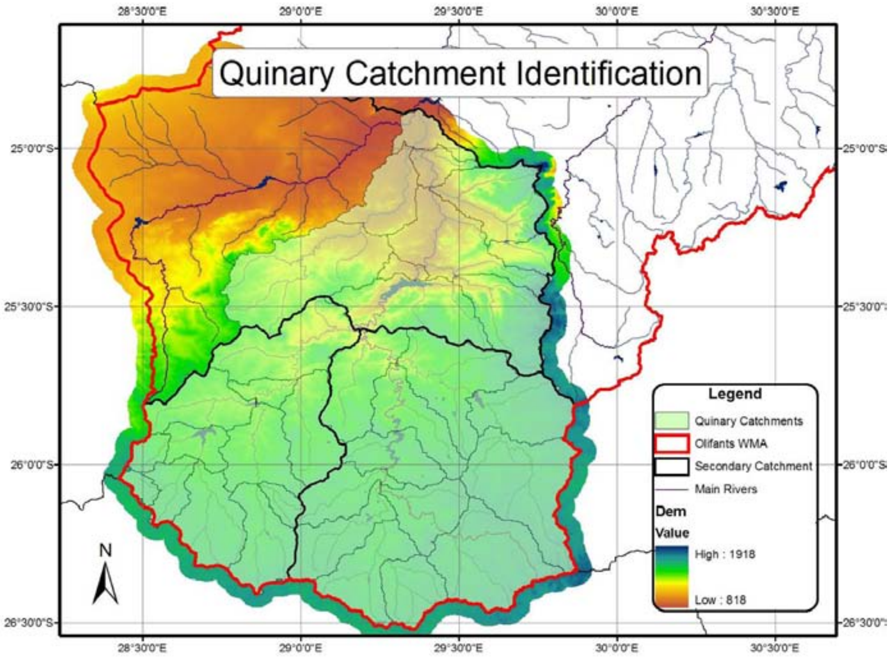

Figure 4.25 Quinary Catchment Identification

4.5.8.2. Rainfall Station Identification

Figure 4.2.2 showed the location of rainfall stations in the Upper Olifants Catchment Area and surrounding areas. A suitable selection out of those stations shown needed to be identified. The selection process was based on observed record length within the period of interest. If a station had 30 or more years of observed data, it was considered suitable for use.

4.5.8.3. Water Infrastructure, Users and Operating Rules

Collating all the water use, historical water use and operating rule data for such a large area is a huge task and is outside the scope of this project since it is a largely proof of concept project. As such certain assumptions regarding water usage have been made.

4.5.8.4. Complete Setup

The complete Mike Basin setup for the Upper Olifants Water Management catchment area is illustrated in Figure 4.26. Due to the large area being studied the water usage and the correct operating rules are at best a good estimate. Water usage from similar sectors has been lumped where applicable.

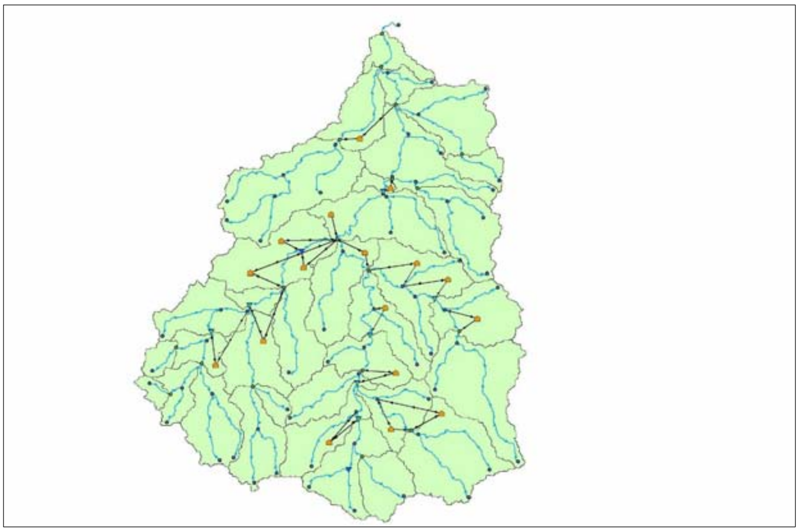

Figure 4.26 MIKE BASIN setup for Upper Olifants Water Management Area

4.5.9. Simulation Results

Using the functionality of the AAMG extension, files of observed stream data were imported into Temporal Analyst and compared to simulated flow. One gauge from the B1 secondary catchment was selected and Gauge B2H007 was chosen from the B2 secondary catchment.

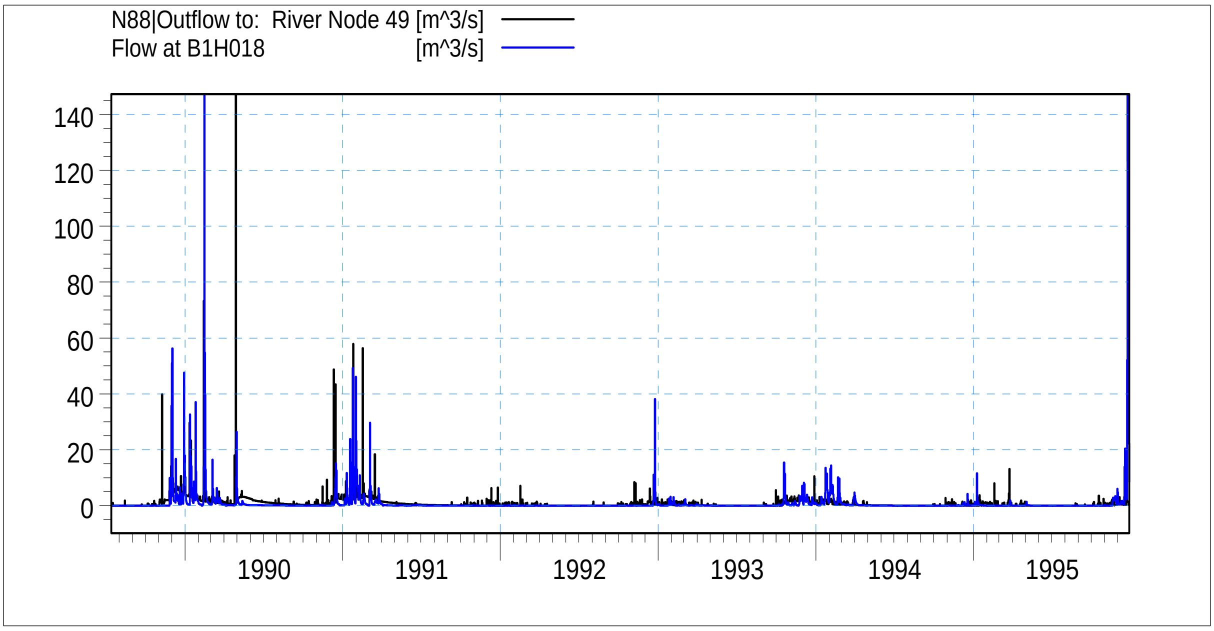

Figure 4.27 Gauge B1H018

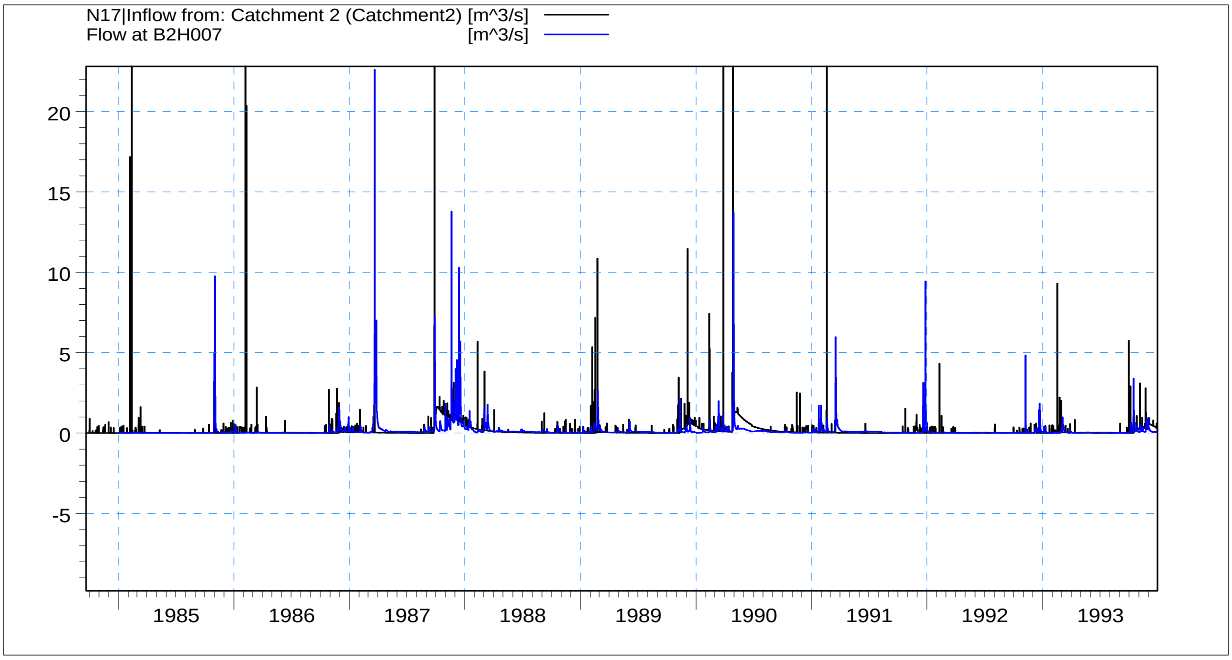

Figure 4.28 Gauge B2H022

In both cases the simulated flow tended to over-simulate observed flow.

4.5.10. Example of Adding a Water User

Once the model has been run and acceptable simulation results have been obtained it is possible to generate different scenarios in water resource management context. One such scenario would be assessing a license application in terms of the National Water Act (Act 36 of 1998). In the following example a new water user was added to the MIKE BASIN set and its impact on the flows into Loskop Dam was assessed. By examining Figure 4.29 the impact can be clearly seen as the simulated blue line of daily flow drops below the black line which represents the observed flow at that point.

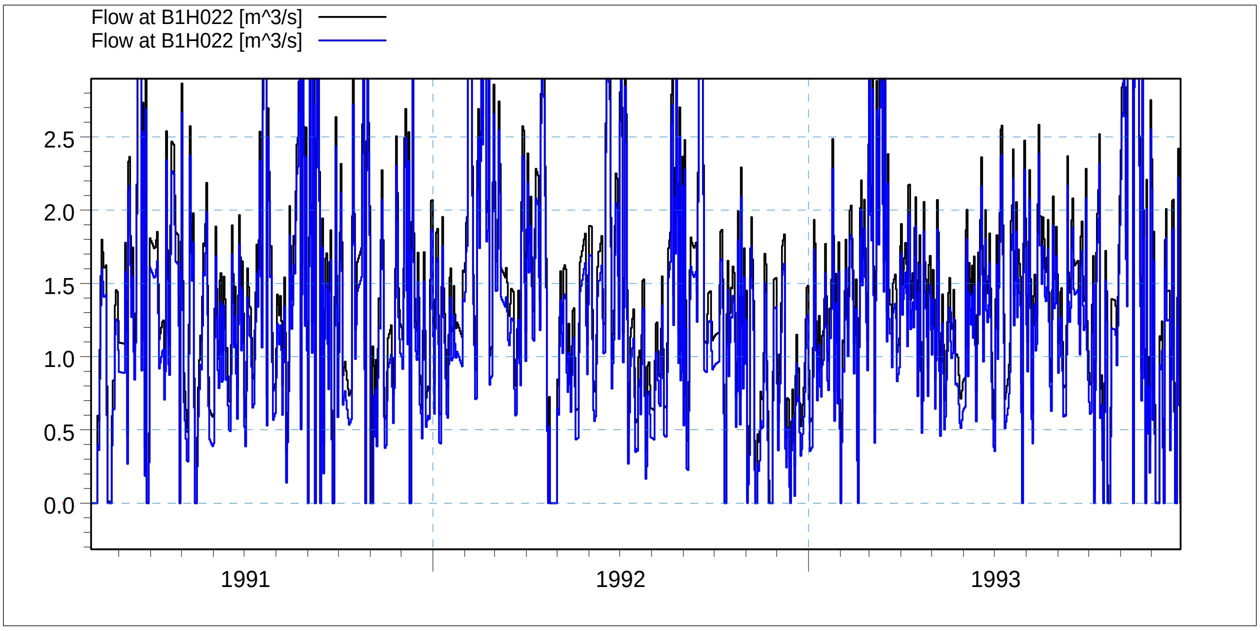

Figure 4.29 Simulated vs Observed Flow for Potential New User on the System

Similarly the impact on the storage capacity of Loskop Dam can be illustrated. See Figure 4.2.12 below. Note that a large hypothetical user was added so that the effect could clearly be seen.

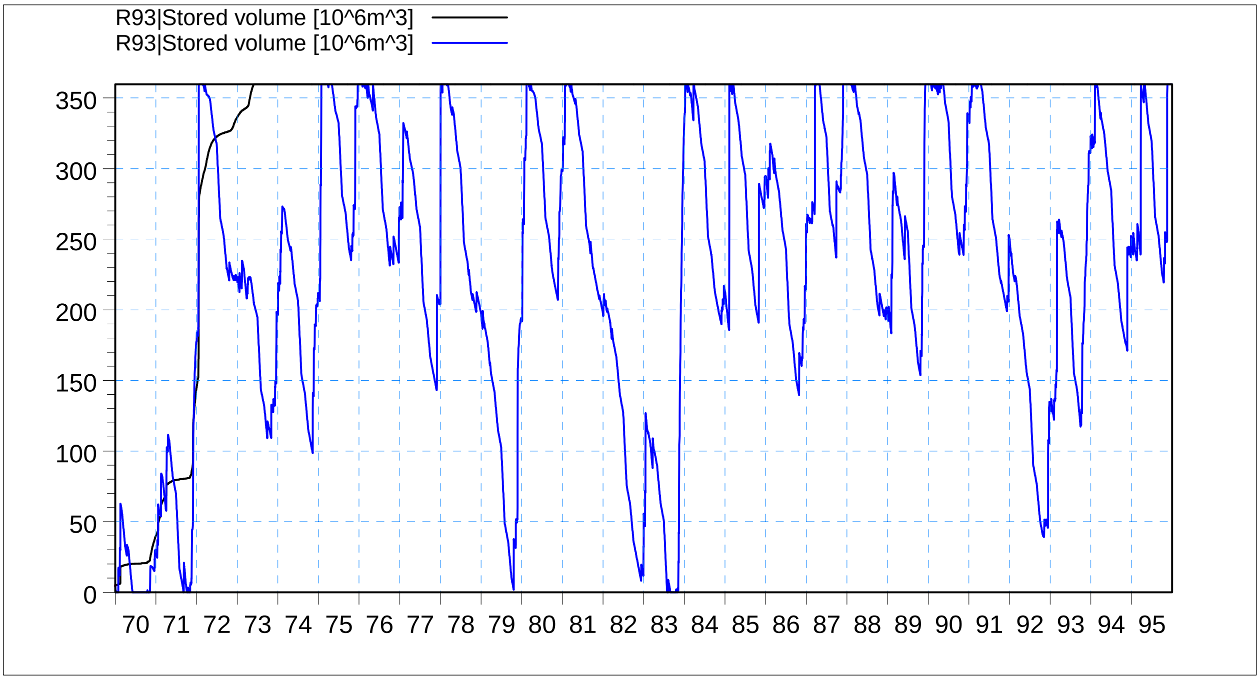

Figure 4.30 Effect of a new User on the Storage of Loskop Dam

4.5.11. Discussion of Upper Olifants Water Management Area Results

In most instances the simulation results were higher than the observed results. This can be attributed to possible incorrect rainfall station selection as well as incorrect input data especially data relating to water use where assumptions may have been made especially with regard to the historical record and operating rules.

In general, the verifications at B1H018 and B2H022 as illustrated above over-simulated the observed flow and the verifications can be improved. However, as previously stated the focus of this case study application and report was not to obtain perfect simulation results. It was rather a proof of concept application, and therefore, prolonged effort in improving simulations was not justifiable within the time constraints of this aspect of the study.

4.6. Discussion

The linkage between the ACRU model and the Mike Basin model has been successfully implemented in the two case studies which have been described in this report. This was facilitated by the development of the AAMG which was completed during this project. The results obtained from these applications have been satisfactory. Both of the modelling exercises were achieved in a time that was considerably shorter than if they had been attempted with other configuration methods and tools. Hence the transaction cost of modelling these case studies was considerably less. This smaller transactional cost was a result of characteristics that are included in the AAMG and Mike Basin models that assist the user in a quick hydrological and water resources modelling configuration. A list of some of these characteristics is provided below.

- Pre-packaged GIS database for the whole of SA, this data includes:
  - Spatially represented observed weir data from DWAF, with associated quality codes, for quick comparison with simulated data,
  - Spatially represented observed and patched rainfall data,
  - Spatially represented hydrological soil input parameters from BEEH,
  - 90 meter digital elevation model (for automatic catchment delineation in Mike Basin),

Spatially represented landuse information, and

Primary, secondary, tertiary and quaternary catchment boundaries for reference.

- Automatic river tracing tool and catchment delineation based on the digital elevation model and point of interest,
- User friendly functionality to specify water user nodes, water supply nodes and reservoirs,
- User friendly functionality to specify operating rules associated with priorities of water use and water supply,
- Verification tool to adjust hydrological parameters per catchment to improve model simulations relative to observed data.

It is important to realize that the AAMG tool that was applied for these case studies is not something to be used as a substitute for hydrological knowledge. The initial base configuration provided by the AAMG and ACRU *will* have to be verified and adjusted according to how well the simulation performed against observed data. A detailed knowledge of both the strengths and weaknesses of ACRU and Mike Basin is also necessary. Without this knowledge, it is likely that a user will misrepresent either the hydrology, the water resources operating rules, or both.

4.7. Conclusions and Potential Applications

The purpose of this report and the project as a whole are to promote sustainable use of applicable simulation models that are available in South Africa for assisting commercial agriculture. The use of the models should specifically be for the benefit of improving water management. With reference to the two models that were described and applied for this report, the benefit of using of the Mike Basin and ACRU models in conjunction with one another are that the natural processes, namely the hydrology, and the water allocation and management operational procedures, can be combined at a daily time step to assess water resource management related issues at a catchment scale. An example of one of these potential operational management issues is the water licensing processes and how to assess how an extra individual license, or a collection of licenses, are likely to impact other existing downstream users in a catchment. Such a situation is achievable with the ACRU and Mike Basin models because the hydrology is process based and the Mike Basin model is spatially representative at a scale which is flexible and specified by the modeller. The downstream impact of any additional water use at a specific location in a catchment can be explicitly determined. This licensing issue has significant application potential in the commercial agricultural arena if the aforementioned downstream impacts negatively affect an irrigation board or Water User Association.

4.8. References

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5. WAS TECHNOLOGY TRANSFER

5.1. Background

The Water Administration System consists of a number of modules. Figure 5.1 below displays the four main modules of the WAS program. Some of the modules can be run independently without requiring the use of all the other modules. Table 5.1 below illustrates in which of the technology transfer case study areas the WAS model was installed before the start of the project. The table furthermore indicates which modules were used, as well as the modules for which a high interest was shown.

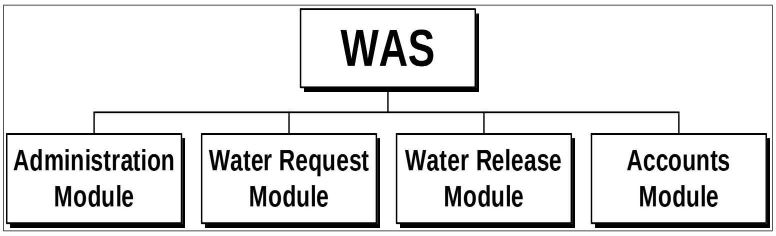


Figure 5.1 WAS Modules

From Table1 below it is clear that the administration, accounts and request modules were in use at most of the project research areas. Only the Mhlathuze and Gamtoos WUA were not using the accounts module. The Gamtoos WUA had indicated a medium interest in adopting the accounts module at the start of the project, but they decided not to use it in the end.

Table 5.1 WAS Implementation and User Needs Before the Start of the Project

	WAS			
IB / WUA	Admin module	Accounts Module	Request Module	Release Module
Mhlathuze				
Loskop	ALREADY USING THE MODEL / SYSTEM	ALREADY USING THE MODEL / SYSTEM	ALREADY USING THE MODEL / SYSTEM	HIGH INTEREST SHOWN IN MODEL / SYSTEM
Vaalharts	ALREADY USING THE MODEL / SYSTEM	ALREADY USING THE MODEL / SYSTEM	ALREADY USING THE MODEL / SYSTEM	HIGH INTEREST SHOWN IN MODEL / SYSTEM
Oranje Riet	ALREADY USING THE MODEL / SYSTEM	ALREADY USING THE MODEL / SYSTEM	ALREADY USING THE MODEL / SYSTEM	ALREADY USING THE MODEL / SYSTEM
Lower Olifants	ALREADY USING THE MODEL / SYSTEM	ALREADY USING THE MODEL / SYSTEM	ALREADY USING THE MODEL / SYSTEM	HIGH INTEREST SHOWN IN MODEL / SYSTEM
Lower Sundays River	HIGH INTEREST SHOWN IN MODEL / SYSTEM	HIGH INTEREST SHOWN IN MODEL / SYSTEM	HIGH INTEREST SHOWN IN MODEL / SYSTEM	HIGH INTEREST SHOWN IN MODEL / SYSTEM
Gamtoos	ALREADY USING THE MODEL / SYSTEM		ALREADY USING THE MODEL / SYSTEM	

HIGH INTEREST SHOWN IN MODEL / SYSTEM (red)
ALREADY USING THE MODEL / SYSTEM (green)

The release module on the other hand was only adopted in the Oranje Riet WUA before the project started. All the other research areas had shown a high interest in adopting the release module except for Gamtoos where water is delivered on demand through meters which makes the calculation of a release virtually impossible. The release module is expensive and time consuming to configure, which probably explains why this module had not been adopted by most of the research areas at the time. The release module also requires a trained operator to make use of the full potential of the release module. One of the key objectives of the technology transfer project was to configure the WAS release module, and to train the WUA personnel in the use of the module.

This document also reports on the development of a 6 hourly distribution sheet to meet the needs of the Lower Olifants WUA, as well as the associated technology transfer of this module to the Lower Olifants WUA. The Lower Olifants WUA has a unique method of ordering and releasing water, which necessitated tailoring, WAS to meet their needs.

The GIS component provided data that assisted in the configuration of the canal network that was needed for the release module. The GIS is also an excellent tool to verify the chainages to the different off takes on the canal network. This information is needed for the accurate calculation of lag times in the release module. Loskop, Vaalharts, Oranje Riet and Lower Olifants irrigation schemes have been using the WAS program since 1986, 1994, 1994 and 1996 respectively. Oranje Riet was the only scheme to use the release module for the last couple of years. The Water release module is by far the most difficult and time consuming module in the WAS program to implement. The calculation of water releases using WAS is totally different from any release calculations that are currently in use. It requires an in depth understanding of water distribution, computer literacy and a positive attitude to change to the new system.

Every scheme in South Africa has a unique water distribution and release calculation method and it is therefore important to ensure that the solution suits their needs and that it can be implemented. The Water release module will not be used by a scheme if there is any doubt on their side that the calculated release will deliver the right amount of water at the right place at the required time within the limitations of the water distribution network. Some modifications/simplifications were made to the application of the Water release module at Vaalharts and the same approach was followed at Loskop once all the practicalities had been sorted out. Vaalharts has converted to this method of water release calculation 100% with a major improvement in their water losses and water management. Loskop has configured and captured all the data and test runs for the water release calculation have been done, but they still need to make the final conversion from their old method of calculation to the latest one. All the data has also been captured for the Lower Sundays River WUA and a totally new water order form has been developed to suit their needs. They are in the implementation and testing phase which will carry on for the next couple of months. The following chapter gives an overview of the WAS water release calculation procedure.

5.2. WAS Water Release Calculation Procedure

The Water release module links with the water administration and request modules and is used to:

- ❑ Minimize distribution losses on canal networks and in river systems.
- ❑ Calculate water releases for the main canal and all its branches allowing for lag times and water losses such as seepage and evaporation.
- ❑ Determine operational procedures for a dam with varying downstream inflows and outflows in a river allowing for lag times and water losses such as seepage, evaporation and transpiration.

A schematic layout of the total canal network or river system is captured with details such as the cross-sectional properties, position of sluices or pumps, canal/river slope, measuring structures and canal capacities. Every reach can be analyzed and calibrated on its own with a built in properties calculator. Global changes to the canal or river data is simplified by means of built in tools.

Discharges are converted to the corresponding measuring plate readings where needed. Calculated water releases, water distribution sheets and water loss analysis reports can be printed. Graphical output of all inflows, outflows, cross-sections and longitudinal profiles can be viewed on the screen or sent to a printer. Water release graphs, calculated with different settings, can be superimposed for comparison purposes.

WAS calculates water releases on a weekly or on a date and time basis. Water distribution on canal networks is normally done on a weekly basis and river system calculations are done on a date and time basis.

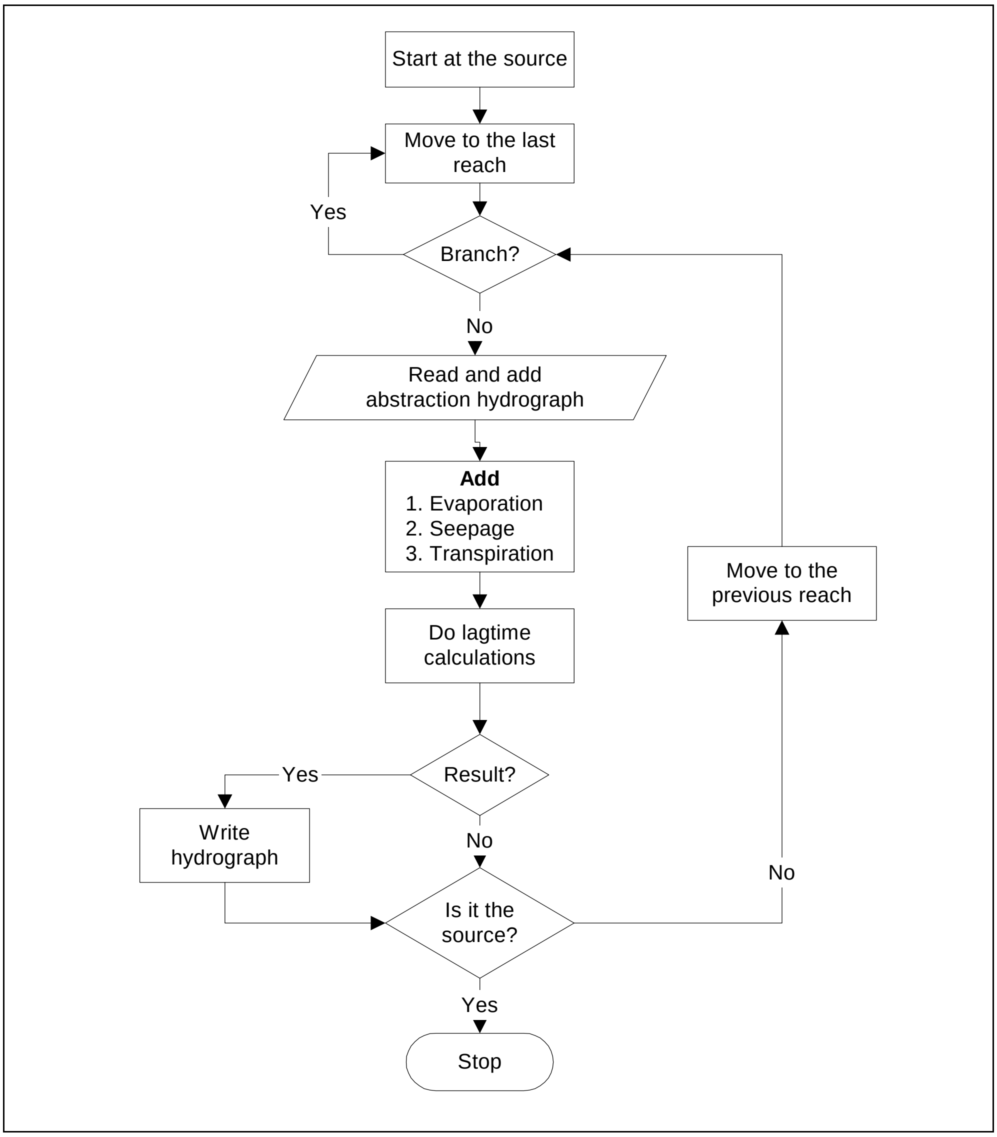


Figure 5.2 Release calculation procedure

The release calculation procedure starts at the source and moves down to the end of the last reach. From there it will move back towards the source processing every reach by adding the abstraction and losses and calculate the lag time for the reach. If it encounters a branch the solution is temporarily saved. The procedure is repeated for the branch, the saved solution is added and the procedure continues its path back to the source.

The solution handles branches on branches up to 6 levels deep. The operator can also specify any number of arbitrary points on the canal or river where the solution can be saved for later viewing. The number of reaches that WAS can handle is only limited to the size of the hard drive.

5.2.1. Calculation of lag times

The lag time in a reach is calculated with the following equation:

$$Lagtime = \frac{Reach\ lengh}{Average\ velocity}$$

5.2.2. Calculation seepage losses

The seepage loss in a reach is calculated using:

$$Seepage = Seepage\,rate \times Reach\ length \times Wetted\ perimeter$$

The seepage rate is specified in l/s per 1000m^2-wetted area.

5.2.3. Calculation of evaporation losses

The evaporation loss in a reach is calculated using:

$$Evaporation = Evaportion\,rate \times Reach\,length \times Water\ surface\,width$$

The evaporation rate is specified in mm/day.

5.2.4. Calculation of transpiration losses

The transpiration loss in a reach is calculated using:

$$Transpiration = Transpiration\,rate \times Reach\,length \times (Riparian\,width - Water\ surface\,width)$$

The transpiration rate is specified in mm/day.

Weather forecasts are handled by capturing the weather data in advance. WAS will use the forecast data where necessary, just remember to replace the forecast data with the real data when it becomes available.

5.3. Calculation settings

Figure 5.3 shows the calculation settings form for weekly calculations (canal networks).

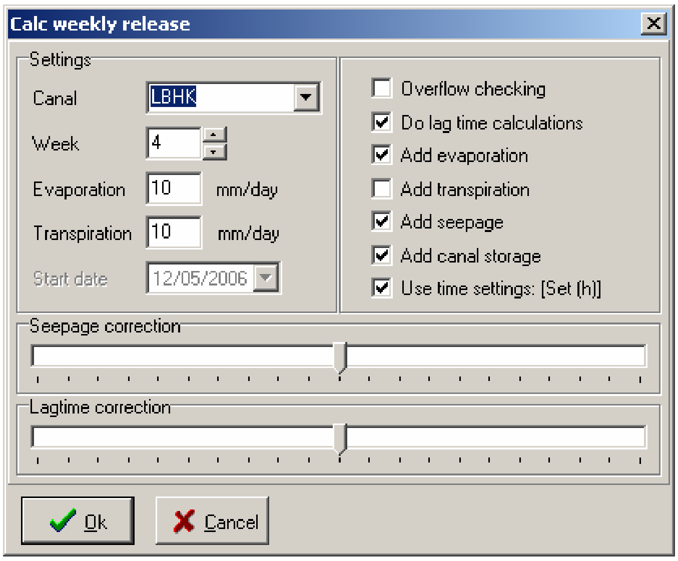


Figure 5.3 Calculate weekly release

Canal

Canal or river identification string.

Week

Specifies the week number between 1 and 53.The week number is only visible for weekly calculations as can be seen in the previous two figures.

Evaporation

Loss of water due to evaporation from the surface of the water. This is measured in millimeters per day (mm/day).

Transpiration

Loss of water through foliage in the riparian zone. This is measured in millimeters per day (mm/day). Transpiration losses are not taken into account for canal networks. It is only relevant for river systems.

Start date

Start date of the 17-day date and time related calculations. The start date is only visible for date and time related calculations as can be seen in the previous two figures.

Overflow checking

The discharge in each reach will be checked against the capacity discharge of the specific reach. If the discharge exceeds the canal capacity, a message is written in the messages page.

Do lag time calculations

The lag time will be calculated for each reach by making use of the mean velocity and the length of the specific reach. The lag times will vary depending on the discharge in the canal.

Add evaporation

The evaporation loss will be calculated for each reach considering the free water surface.

Add transpiration

If checked, the transpiration loss will be calculated for each reach.

Add seepage

The seepage loss will be calculated for each reach considering the wetted area.

Add canal storage

The canal storage will be added to the calculated release. This option is normally used if the canal is empty and it needs to be filled.

Use time settings

WAS can calculate time settings at intervals as small as five minutes. Sluice settings on most irrigation schemes are done on intervals of 12 hours. A 5 minute interval is therefore too small for any practical purposes. The Use time setting is used to enforce a practical time interval to change sluice settings. The time setting is only relevant for the main canal and branches, it cannot be used for turnouts into farms.

Seepage correction

The slide bar can be used to increase or decrease the seepage factor for the total canal network or river system. The seepage factor in the database will be multiplied by the value of the slide bar during a calculation. Changing the slide bar will have no effect on the seepage factors in the database.

Lag time correction

The slide bar can be used to increase or decrease the lag times for the total canal network or river system. The lag time factor in the database will be multiplied by the value of the slide bar during a calculation. Changing the slide bar will have no effect on the lag time factors in the database.

5.4. Developments undertaken in order to better meet user needs

WAS has been further developed during this project from user needs identified for the Lower Olifants Water User Association (LORWUA), Vaalharts Water User Association (VHWUA) and for the Lower Sundays River Water User Association (LSRWUA). A need for a new distribution sheet was identified at LORWUA and VHWUA and a need for a new type of water order form was identified at LSRWUA.

5.4.1. 6-Hourly Distribution Sheet

Irrigation schemes historically (the old manual system) used 12 hourly intervals for the calculation of their water distribution sheets. The water distribution sheets in WAS are therefore also based on 12 hourly intervals. Over time some of the irrigation schemes diverted from the 12 hourly interval standard. In the case of LORWUA, they have developed a 6 hourly distribution sheet which is better suited to their operational activities. They also developed a "rolbeurt" (revolving chance) system which has been added to WAS and it works well. According to the “rolbeurt” system farmers are not allowed to order water with the same starting day every week. The starting day is rolled over to the next day in the following week. The reason for this is to put the maximum amount of water into the canal without exceeding the Maximum Abstraction Right (MAR) as LORWUA has canal capacity problems during peak periods.

They call their 6 hourly distribution sheet a "bokvel" which is compiled every week once all the water orders for the following week have been received. The term "bokvel" (buck skin) is probably used as the size of the spreadsheet is so large that it resembles the tanned hide of a buck (a large buck at that!). The "bokvel" is a giant spreadsheet with the different off-takes and delivery points in each row. Each column represents 6 hours of a specific week. The columns are then added up to get the totals for all the delivery points in the canal network. The 6 hourly totals of each delivery point are then checked to see if it exceeds the Maximum Abstraction Right at that point in the canal. If it does the water control officer (previously referred to as a water bailiff) will "move" the water of certain abstractions 6 hours to the left or right until the MAR is ok.

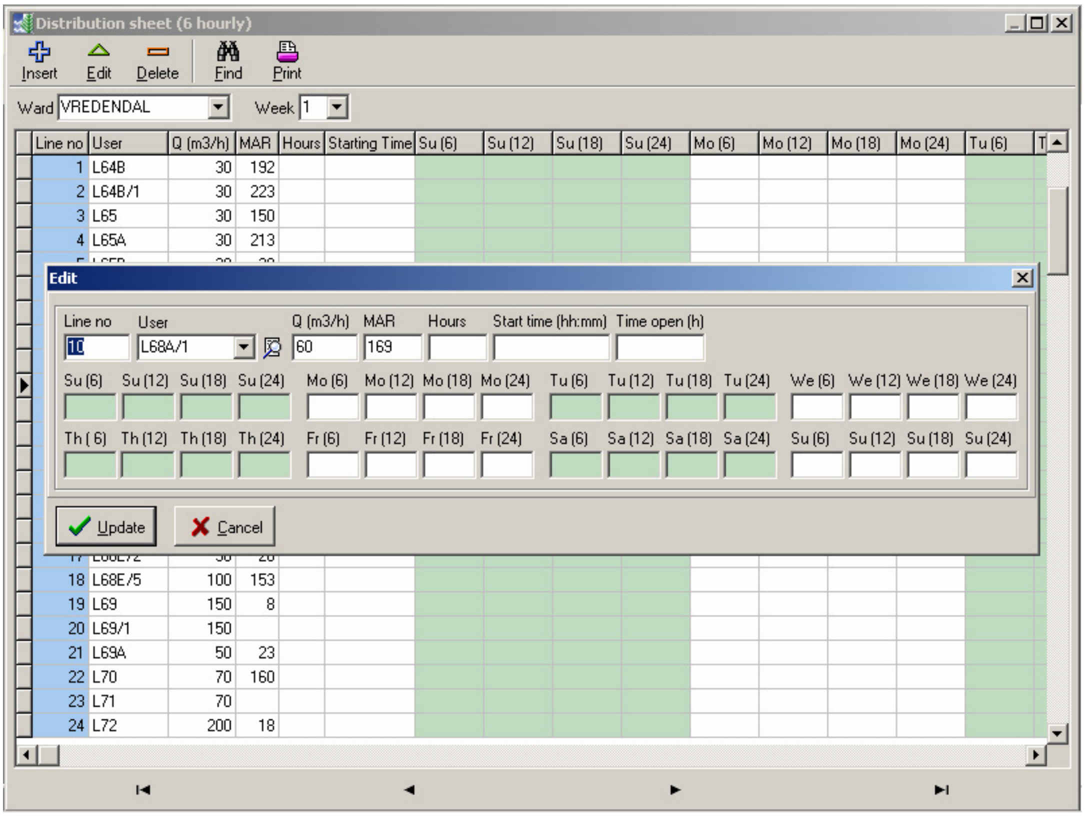


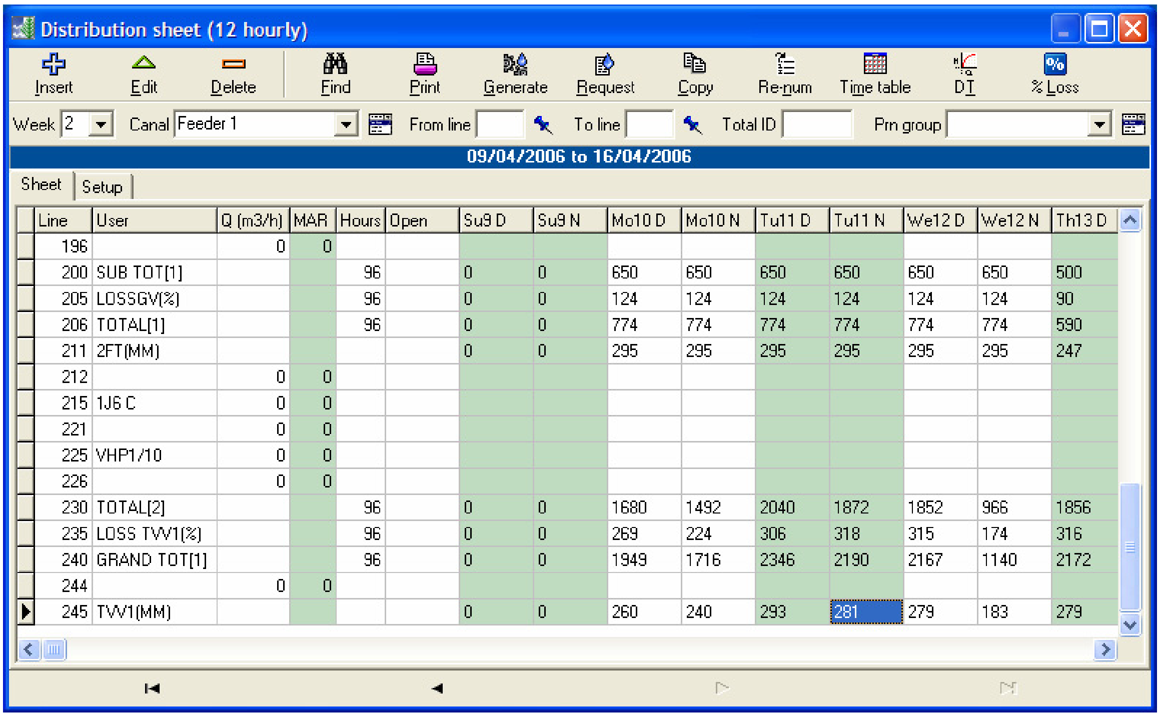
Figure 5.4 6-Hourly Distribution sheet and capturing screen

The development entails the creation of a 6 hourly "spreadsheet" shown in Figure 5.4 (covering 8 days horizontally) that will represent their "bokvel". The "spreadsheet" must have the capability to add groups of abstractions that represent specific delivery points. It must be possible to move the 6 hourly totals manually in each cell to the left or the right after which the "spreadsheet" must be recalculated. It must also be possible to print the "spreadsheet" in pre-defined sections (or water wards) that will be given to the different water bailiffs.

It is possible that the development of the new distribution sheet will only be used by the LORWUA, however, it may be adopted by other WUAs after it has been show-cased to other WUAs. The development has been successfully completed, training has been given and the 6 hourly distribution sheet is fully operational at LORWUA.

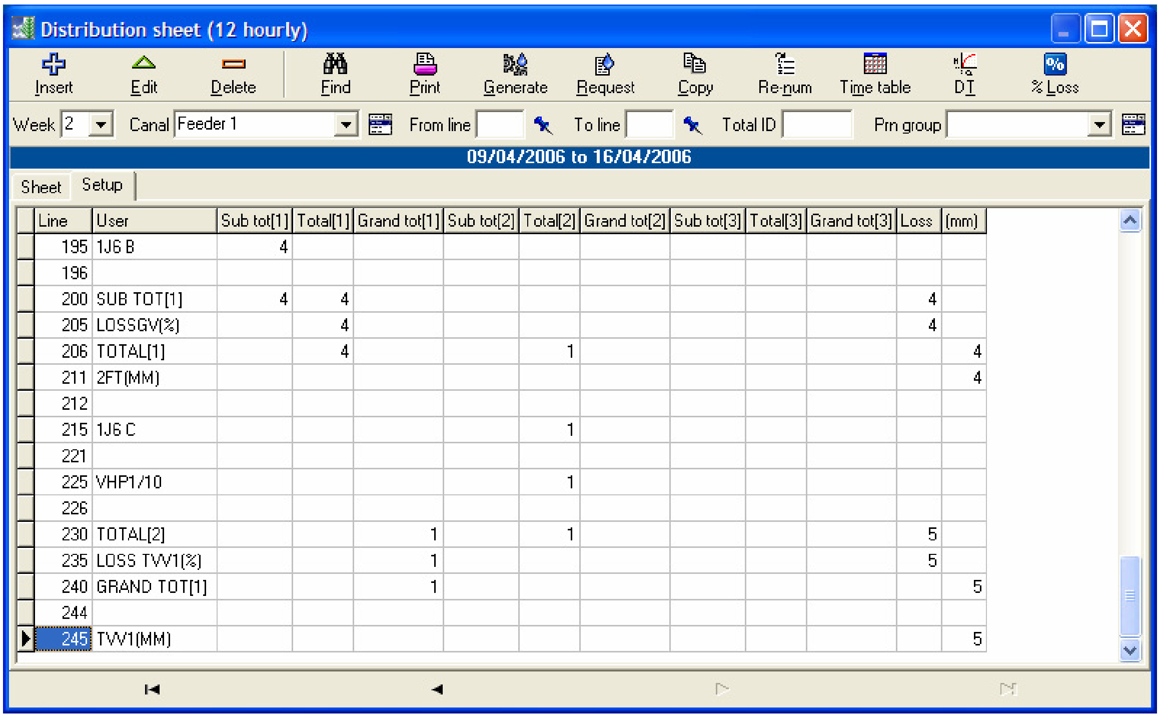
5.4.2. 12-Hourly distribution sheet

Attempts to implement the Water release module of the WAS program at VHWUA have been ongoing for a number of years. The canal network properties have been captured and trial water releases have been calculated. The uptake of this new water release calculation method was however slow and not very successful. It was therefore decided to implement a new water release calculation method which seems to be very successful. The new method is based on the 6 hourly distribution sheet which was developed for LORWUA. A similar "spreadsheet" was developed with 12 hourly intervals which can be programmed to calculate sub-totals, totals, grand-totals and add user defined % losses. The new 12 hourly distribution sheet is shown in Figure 5.5 and the distribution sheet setup form is displayed in Figure 5.6.



Line	User	Q (m3/h)	MAR	Hours	Open	Su9 D	Su9 N	Mo10 D	Mo10 N	Tu11 D	Tu11 N	We12 D	We12 N	Th13 D
196		0	0											
200	SUB TOT[1]			96		0	0	650	650	650	650	650	650	500
205	LOSSGV(%)			96		0	0	124	124	124	124	124	124	90
206	TOTAL[1]			96		0	0	774	774	774	774	774	774	590
211	2FT(MM)					0	0	295	295	295	295	295	295	247
212		0	0											
215	1J6 C	0	0											
221		0	0											
225	VHP1/10	0	0											
226		0	0											
230	TOTAL[2]			96		0	0	1680	1492	2040	1872	1852	966	1856
235	LOSS TWV1(%)			96		0	0	269	224	306	318	315	174	316
240	GRAND TOT[1]			96		0	0	1949	1716	2346	2190	2167	1140	2172
244		0	0											
245	TWV1(MM)					0	0	260	240	293	281	279	183	279

Figure 5.5 12-Hourly distribution sheet



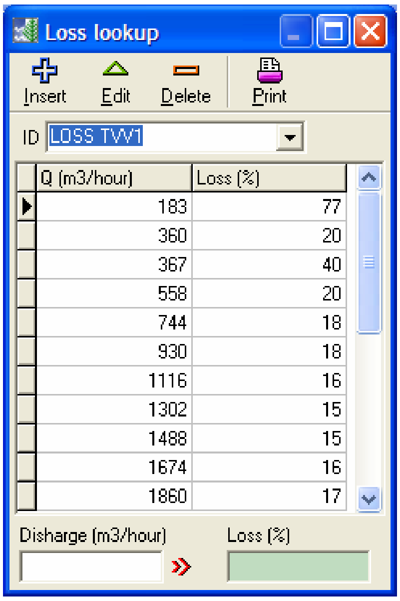
Line	User	Sub tot[1]	Total[1]	Grand tot[1]	Sub tot[2]	Total[2]	Grand tot[2]	Sub tot[3]	Total[3]	Grand tot[3]	Loss	(mm)
195	1J6 B	4										
196												
200	SUB TOT[1]	4	4								4	
205	LOSSGV(%)		4								4	
206	TOTAL[1]		4			1						4
211	2FT(MM)											4
212												
215	1J6 C					1						
221												
225	VHP1/10					1						
226												
230	TOTAL[2]			1		1					5	
235	LOSS TWV1(%)			1							5	
240	GRAND TOT[1]			1								5
244												
245	TWV1(MM)											5

Figure 5.6 12-Hourly distribution sheet setup form

The new 12 hourly distribution sheet has also been introduced to Loskop Irrigation Board and Hartbeespoort Irrigation Board. Both are in the process of capturing the initial setup for the distribution sheet. The distribution sheet is very flexible in the following ways:

- Three different totals that can be calculated for each Sub-total, Total and Grand total.
- The line numbers can be re-numbered to space them 5 numbers apart.
- Page breaks can be inserted.
- Measure plate readings are automatically generated using discharge tables.
- % Loss lookup tables can be created and linked to different totals.
- Distribution sheet summaries can easily be setup and printed.
- Distribution sheets can easily be copied between weeks and water years.
- Get direct access to water orders.
- Easily generate and link weekly time tables to a distribution sheet.

The % Loss lookup form is displayed in Figure 5.7 which is used to link a % loss to a variable flow rate in a canal. This method is an improvement to the previous approach where a fixed % was applied to all flow rates.



Q (m3/hour)	Loss (%)
183	77
360	20
367	40
558	20
744	18
930	18
1116	16
1302	15
1488	15
1674	16
1860	17

Figure 5.7 % Loss lookup table

The implementation of the 12 hourly distribution sheet at VHWUA was very successful. VHWUA has been using this method of water release calculation 100% for the last couple of months with major improvements in their water losses and water management. They actively took part in the development and give valuable feedback which already lead to planned extensions for the near future.

5.4.3. Water order form for LSRWUA

WAS currently has two different methods of water ordering. The first method is by means of the old water order form which uses 12 hourly day and night values. The second method is the use of meter readings. LSRWUA uses a different method to order water and it was necessary to add it as part of the WAS implementation. The new water order form uses a starting date and time and an ending date and time with a discharge specified in m^3/s. The total volume and duration are then calculated automatically. The new water order capturing screen can be seen in Figure 5.8. It has been developed and implemented at LSRWUA who tested it successfully with real data.

The development of the new water order form will only be used by LSRWUA at this stage. It adds however another water ordering method to the WAS program which gives Irrigation schemes more options to choose from if they decide to implement the WAS.

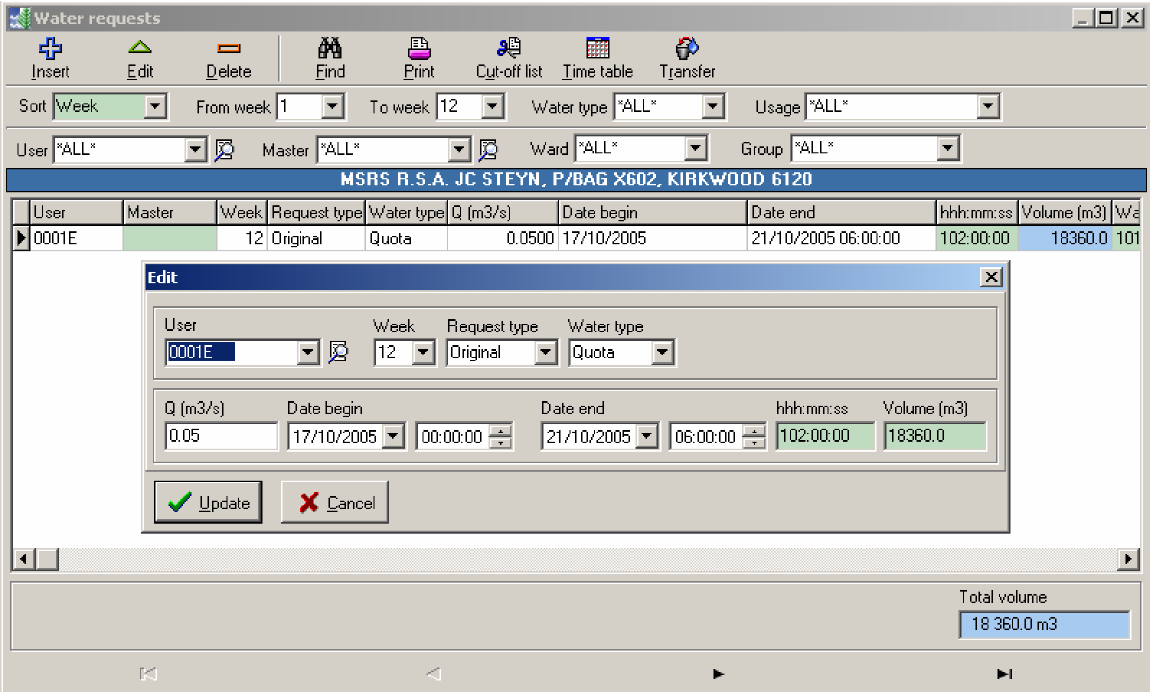


Figure 5.8 Date and time based water order form

5.5. Lower Sundays River WUA implementation and TT

Current release calculation method

Lower Sundays has a unique way of water ordering and distribution. They make extensive use of a SCADA system to set and control automatic gates throughout their scheme. SMS communication is also used to alert responsible persons of any alarm that was raised by the automatic controllers in the field. The calculation procedure of the water release module will probably need to be adapted for their needs once the calibration has started. Water orders are captured using the water order form as described in the previous paragraphs. Different set points are then determined for the automatic gates depending on the water distribution pattern and volumes.

Data capturing

A student was used initially to capture the canal network data without much success. Thereafter CSS was subcontracted to capture the canal network data which they completed in time. Data was captured using existing maps, field measurements and a geographic information system (GIS). All the data has been captured and verified as far as possible. Changes to some of the data will still be done during the final calibration stage. This will be done once Lower Sundays River WUA will start calibration and using the release module.

Calibration

Lower Sundays is still in the process of implementing and testing the accounts and water request modules of WAS. This is a priority for them and the calibration of the water release calculation will only become a priority once the other modules have been implemented successfully.

Discussion

The status of the WAS implementation at Lower Sundays at the start of this project was virtually nothing compared to what it is now at the end of the project. A massive amount of data has been captured, a new water order form has been developed and implemented and their personnel has been equipped to manage the WAS program in various ways. Interaction between Lower Sundays and NB Systems is active and they will definitely take the implementation to its full completion after this project has been finished.

5.6. Lower Olifants River WUA implementation and TT

Current release calculation method

Lower Olifants River WUA uses a 6 hourly distribution and a "rolbeurt" (revolving turn) system which has been added to WAS. According to the “rolbeurt” system farmers are not allowed to order water with the same starting day every week. The starting day is rolled over to the next day in the following week. The reason for this is to put the maximum amount of water into the canal without exceeding the Maximum Abstraction Right (MAR) as LORWUA has canal capacity problems during peak periods.

The total scheme is divided into a number of water wards (they call it sections) with a water control officer responsible for each ward. The water orders are captured every Thursday in WAS by the different water control officers. They have a number of computers on a network which means that the water orders can be captured simultaneously and in a shorted time period. The 6 hourly distribution sheet is then generated which is used to determine the release and settings for a number of control points at the start of each section.

Data capturing

All the canal network data has been captured from existing maps and measurements in the field. The data needed to be verified and LORWUA appointed a consultant specifically for this task and for the calibration. This was unfortunate not successful which means that the calibration of the release had to be put on hold.

Calibration

The calibration procedure will commence as soon as the canal data verification has been done.

Discussion

LORWUA made good progress since the start of the project. The 6 hourly distribution sheet has been developed during the course of the technology transfer project and implemented successfully. Feedback from the scheme is used to improve and fine tune the system as far as possible. The scheme management is keen to take the water release calculation procedure right to the end.

5.7. Loskop Irrigation Board implementation and TT

Current release calculation method

Loskop Irrigation Board is divided into a number of water wards which is managed by ward managers. Each ward manager runs the WAS program for his/her own water ward. The distribution sheets are calculated with WAS, but the sluice opening and closing times are calculated manually and using previous experience. Farm turnouts are opened beforehand (usually on a Saturday) according to the water requested by the farmer. Sluice settings for branching canals are changed according to experience and taking the total water demand into account.

Data capturing

Loskop Irrigation Board was subcontracted to capture the canal network data for both the Left and Right bank main canals. Figure 5.9 shows the data of the 141 canal that is branching off the Loskop left bank main canal. Data was captured using information from previous research projects, existing maps, field measurements and a geographic information system (GIS). All the data has been captured and verified as far as possible. Changes to some of the data will still be done during the final calibration stage. This will be done once Loskop Irrigation Board will start using the release module.

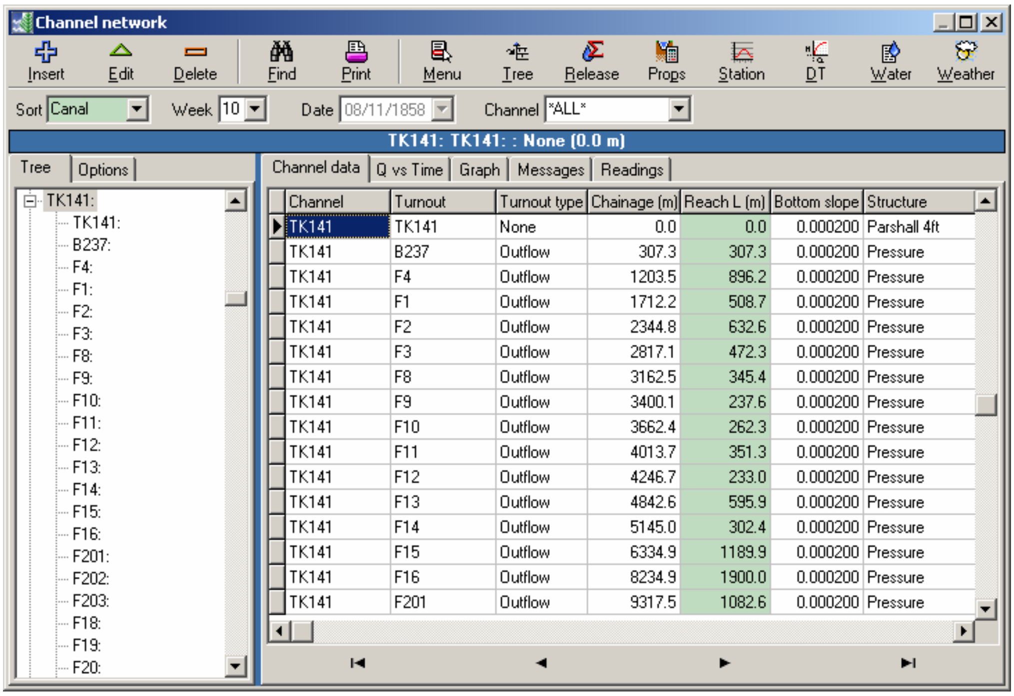


Figure 5.9 Loskop TK141 canal data

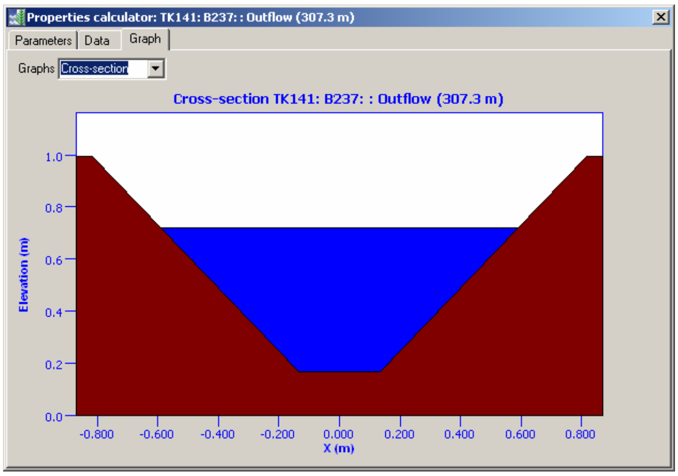
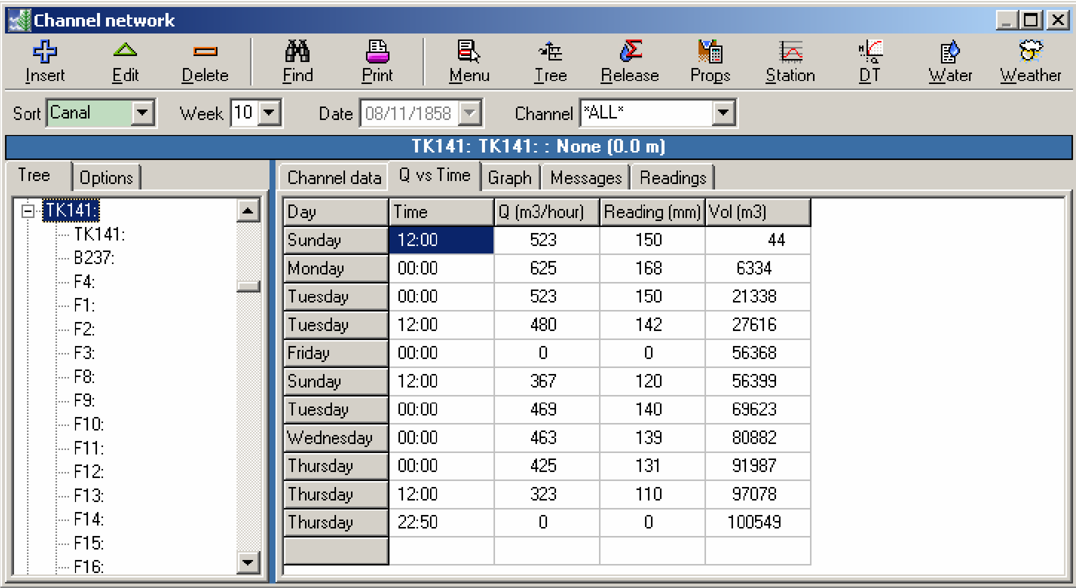


Figure 5.10 Cross-section of canal TK141

Calibration

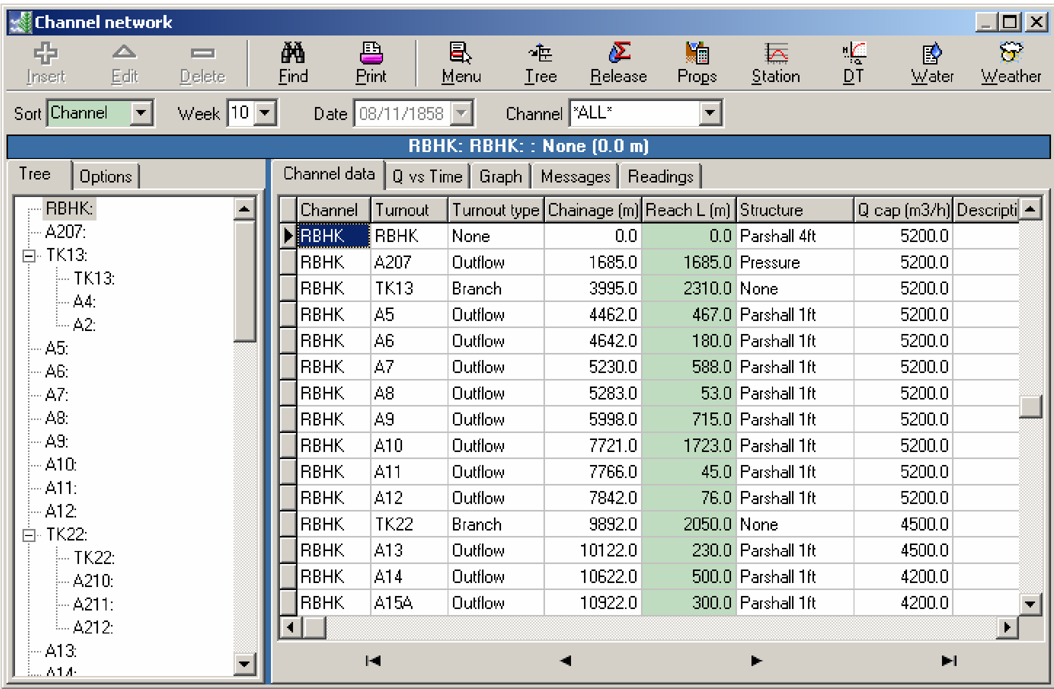
The calibration procedure needs to be undertaken in a specific order. The canal branches are done first followed by the main canal. The main canal cannot be calibrated before all the branches are completed. The release has been calculated successfully for all the canals on the Loskop scheme. Calibrations have been done on some of the canal branches. The feeling at Loskop is however to implement the 12 hourly distribution sheet and to follow the same route as Vaalharts Water User Association. In this case the canal branches are done using the 12 hourly distribution sheet calculations (see paragraph 3.2) and only the main canals will be done using the release module approach.

Everything has been installed and it is now up to the Loskop Irrigation Board personnel to test it and take it further. The project team will assist where possible.



Day	Time	Q (m3/hour)	Reading (mm)	Vol (m3)
Sunday	12:00	523	150	44
Monday	00:00	625	168	6334
Tuesday	00:00	523	150	21338
Tuesday	12:00	480	142	27616
Friday	00:00	0	0	56368
Sunday	12:00	367	120	56399
Tuesday	00:00	469	140	69623
Wednesday	00:00	463	139	80882
Thursday	00:00	425	131	91987
Thursday	12:00	323	110	97078
Thursday	22:50	0	0	100549

Figure 5.11 Calculated release for canal TK141



Channel	Turnout	Turnout type	Chainage (m)	Reach L (m)	Structure	Q cap (m3/h)	Descripti
RBHK	RBHK	None	0.0	0.0	Parshall 4ft	5200.0	
RBHK	A207	Outflow	1685.0	1685.0	Pressure	5200.0	
RBHK	TK13	Branch	3995.0	2310.0	None	5200.0	
RBHK	A5	Outflow	4462.0	467.0	Parshall 1ft	5200.0	
RBHK	A6	Outflow	4642.0	180.0	Parshall 1ft	5200.0	
RBHK	A7	Outflow	5230.0	588.0	Parshall 1ft	5200.0	
RBHK	A8	Outflow	5283.0	53.0	Parshall 1ft	5200.0	
RBHK	A9	Outflow	5998.0	715.0	Parshall 1ft	5200.0	
RBHK	A10	Outflow	7721.0	1723.0	Parshall 1ft	5200.0	
RBHK	A11	Outflow	7766.0	45.0	Parshall 1ft	5200.0	
RBHK	A12	Outflow	7842.0	76.0	Parshall 1ft	5200.0	
RBHK	TK22	Branch	9892.0	2050.0	None	4500.0	
RBHK	A13	Outflow	10122.0	230.0	Parshall 1ft	4500.0	
RBHK	A14	Outflow	10622.0	500.0	Parshall 1ft	4200.0	
RBHK	A15A	Outflow	10922.0	300.0	Parshall 1ft	4200.0	

Figure 5.12 RBHK canal network and data

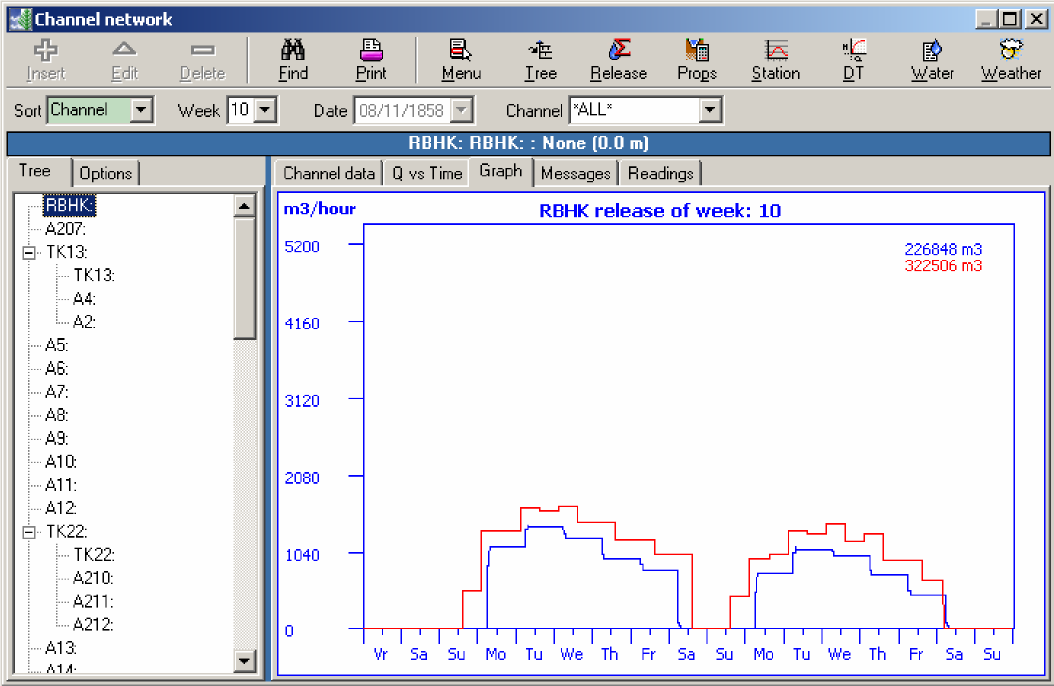


Figure 5.13 RBHK calculated release for week 10 and water year 2005/2006

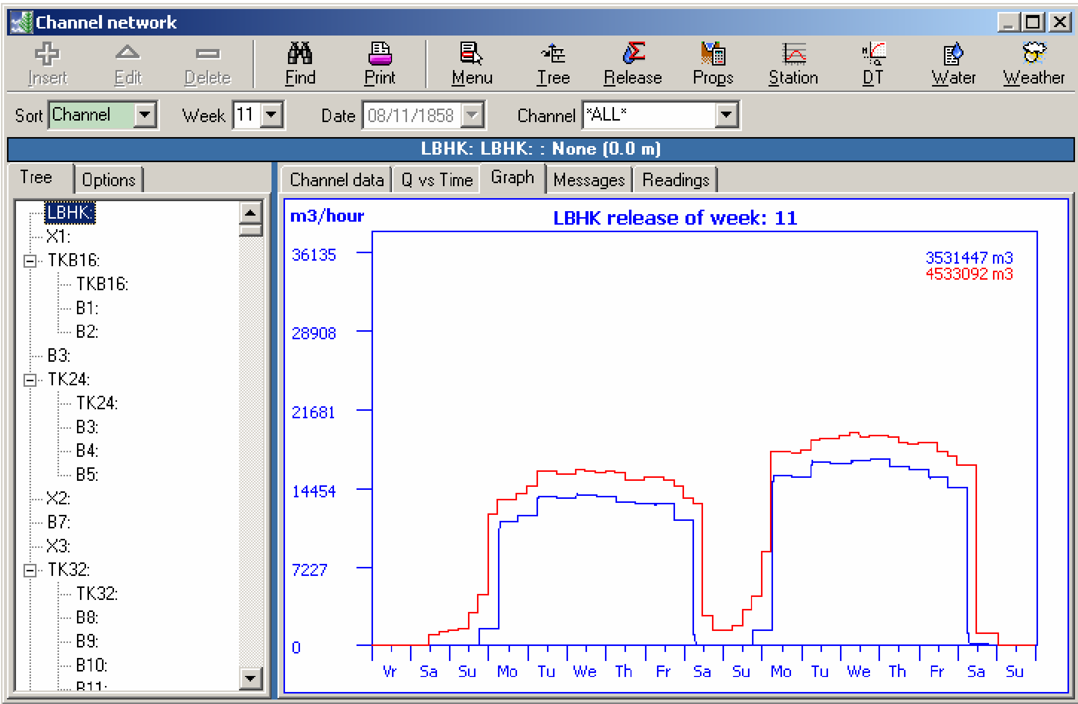


Figure 5.14 LBHK calculated release for week 11 and water year 2005/2006

Discussion

All the Loskop data that was needed to do the water release calibration in WAS has been captured and verified as far as possible. Some changes in the canal network data are expected during the final calibration phases. There were some delays with the measurements of the cross-sectional data in the field. A discussion with the Loskop personnel on the final operational procedures was done. They indicated a preference to use (try out) a combination of a 12 hourly distribution sheet (as described in paragraph 3.2) on the main canal branches in combination with the release calculation on the main canals only. This procedure proved to be more practical for the Vaalharts WUA which is discussed in the next chapter.

The calibration, initial training and trial runs at Loskop were done as far as possible. The next step is for the Loskop personnel to test the 12 hourly distribution sheets and after that test the results of the release calculation on the main canals.

5.8. Vaalharts WUA implementation

Current release calculation method

The Vaalharts WUA area is divided into a number of water wards. Water bailiffs are responsible to manage water in more than one water ward. A number of feeders (about 18) branch from the main canal into a number of community furrows and from their into irrigation plots. Water is delivered through pressure regulation sluices into each plot. Each feeder is managed by a “segsman” and the target time to deliver water at each sluice is at 07:00 in the morning.

The release calculation is done using a manual system in combination with an Excel spreadsheet that was developed at Vaalharts over a period of time. The lag times used on the main canal are based on previous experience with different flow rates. A constant flow rate is added to take water losses into account. Water orders for each feeder are added without taking lag times into account. This fact made it practical to implement a 12 hourly distribution sheet approach on all feeders which simplifies the release calculation.

Data capturing

The Vaalharts WUA had a massive amount of data that needed to be captured. Existing scheme maps were used as a basis to capture the canal network structure. The scheme manager Mr. J. Momberg also assisted with the initial capturing of sluices and their specific order on the canal network. Their water office personnel also assisted with the capture and verification of the sluices on the canal network. CSS was sub-contracted to capture and verify sluice chainage values, canal slopes and canal geometry. The availability of the GIS maps contributed to the delay in data capturing from CSS. All the data has been captured and verified as far as possible.

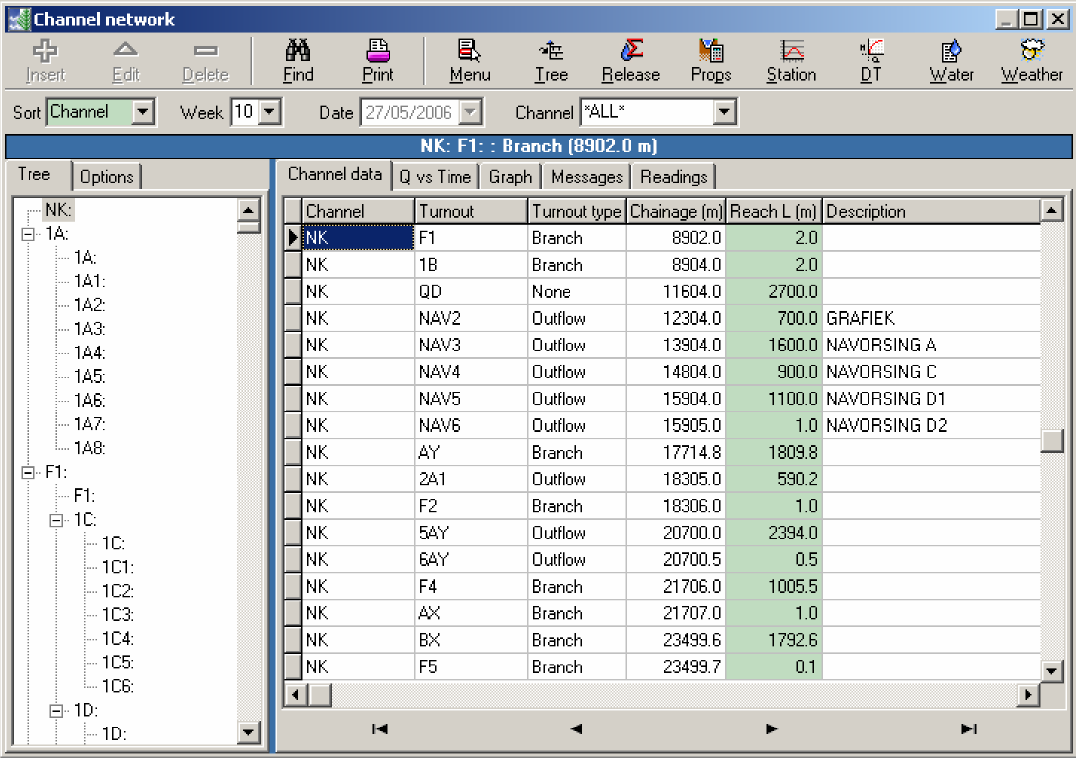


Figure 5.15 Vaalharts North canal data

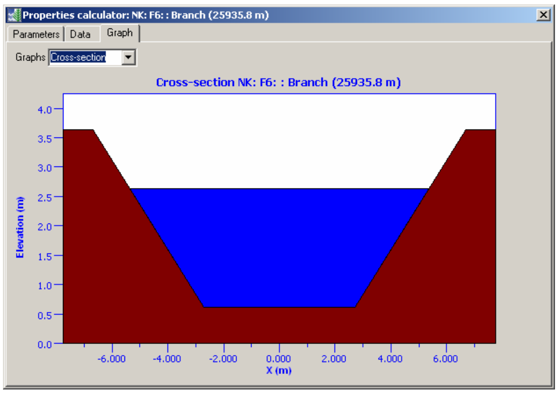


Figure 5.16 Cross-section of the North canal

Calibration

Much work has been done on the release calibration at Vaalharts. The main canal still needs to be calibrated once all the data on the feeders have been verified. A number of work sessions were held with their personnel in the water office during the data capturing and calibration. The initial results from the release calculation on the feeders led to the development of a 12 hourly distribution sheet (see Figure 5.17) which proved to be a better and a more practical solution in this case.

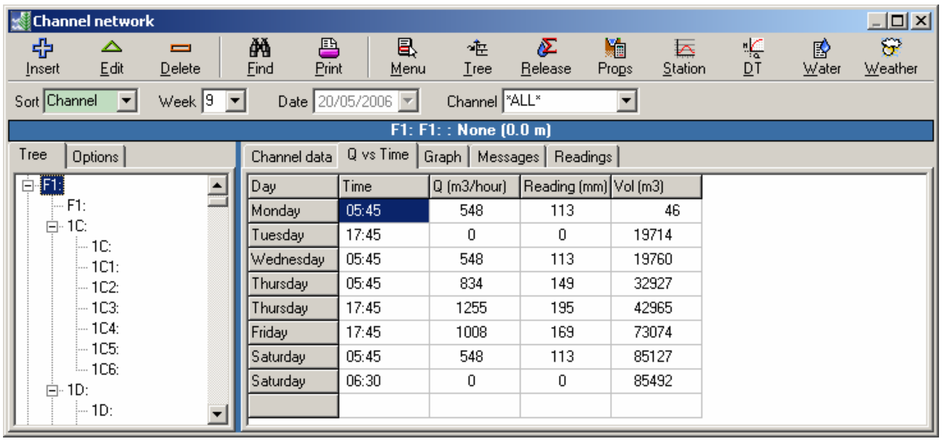


Figure 5.17 Calculated release for feeder 1

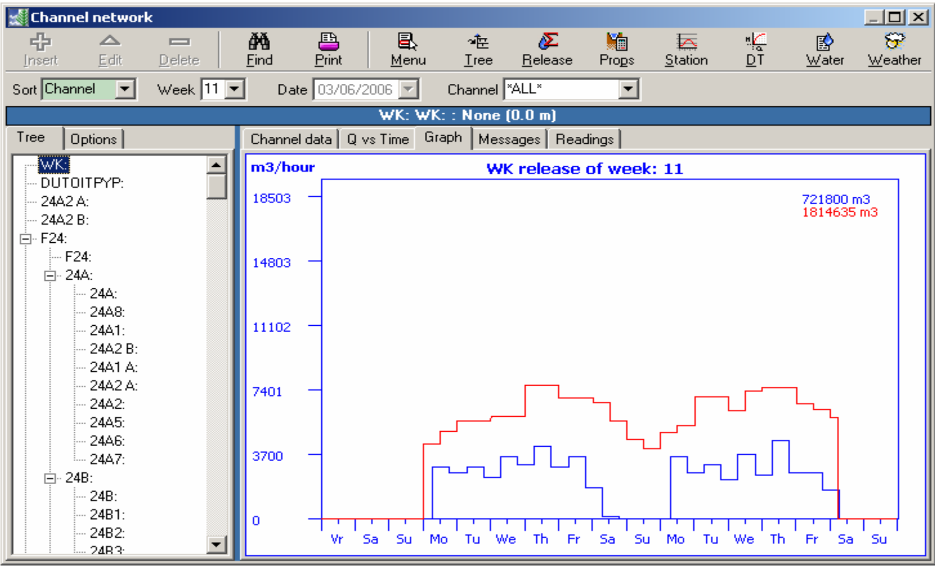
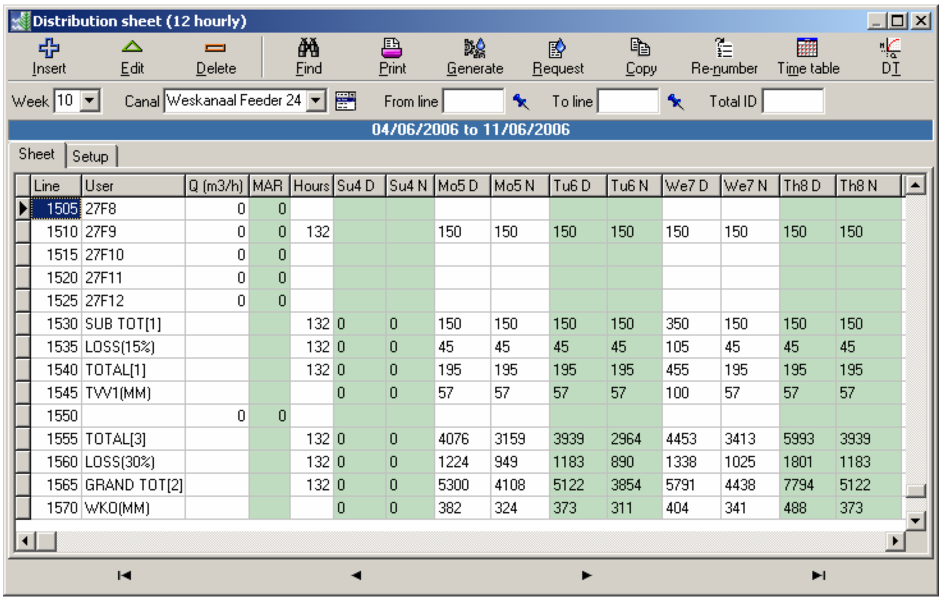


Figure 5.18 Calculated release for the West canal

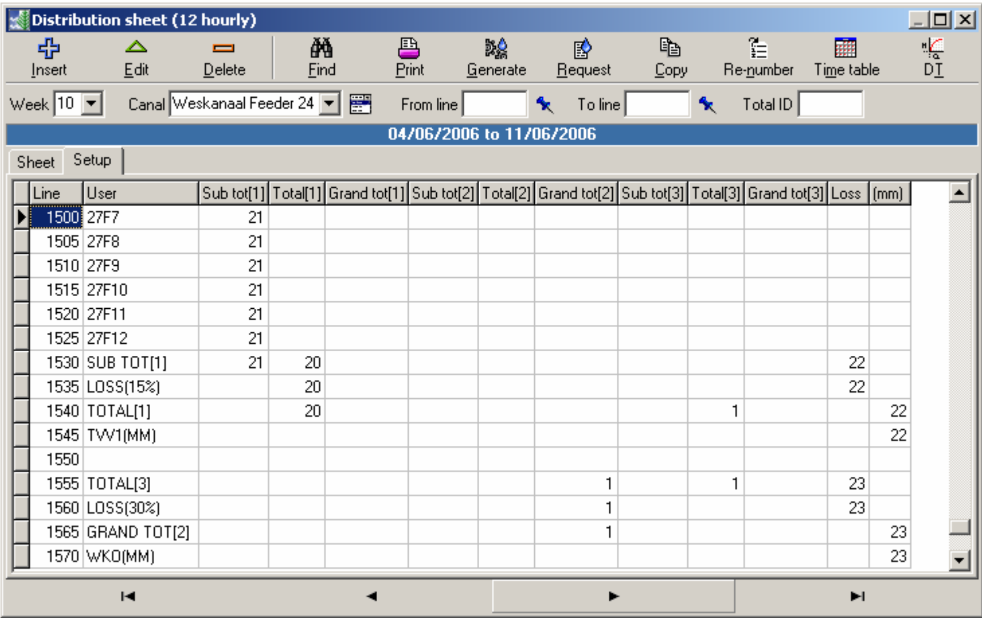
12 Hourly distribution sheets

The 12 hourly distribution sheet was specifically developed for Vaalharts WUA to solve their needs for water release calculation using the WAS program. This sheet calculates the release for a specified week for each feeder canal. It corresponds with their Excel method of water release calculation. The main difference is that the losses are added as a percentage of the flow rate and not as a fixed rate which is currently used. The percentage loss is automatically calculated and a discharge table can be linked to calculate the corresponding measuring plate reading for the specific feeder.



Line	User	Q (m3/h)	MAR	Hours	Su4 D	Su4 N	Mo5 D	Mo5 N	Tu6 D	Tu6 N	We7 D	We7 N	Th8 D	Th8 N
1505	27F8	0	0											
1510	27F9	0	0	132			150	150	150	150	150	150	150	150
1515	27F10	0	0											
1520	27F11	0	0											
1525	27F12	0	0											
1530	SUB TOT[1]			132	0	0	150	150	150	150	350	150	150	150
1535	LOSS(15%)			132	0	0	45	45	45	45	105	45	45	45
1540	TOTAL[1]			132	0	0	195	195	195	195	455	195	195	195
1545	TVV1(MM)				0	0	57	57	57	57	100	57	57	57
1550		0	0											
1555	TOTAL[3]			132	0	0	4076	3159	3939	2964	4453	3413	5993	3939
1560	LOSS(30%)			132	0	0	1224	949	1183	890	1338	1025	1801	1183
1565	GRAND TOT[2]			132	0	0	5300	4108	5122	3854	5791	4438	7794	5122
1570	WKO(MM)				0	0	382	324	373	311	404	341	488	373

Figure 5.19 2 Hourly distribution sheet

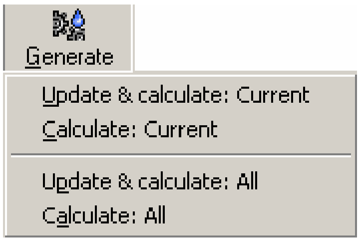


Line	User	Sub tot[1]	Total[1]	Grand tot[1]	Sub tot[2]	Total[2]	Grand tot[2]	Sub tot[3]	Total[3]	Grand tot[3]	Loss	(mm)
1500	27F7	21										
1505	27F8	21										
1510	27F9	21										
1515	27F10	21										
1520	27F11	21										
1525	27F12	21										
1530	SUB TOT[1]	21	20								22	
1535	LOSS(15%)		20								22	
1540	TOTAL[1]		20						1			22
1545	TVV1(MM)											22
1550												
1555	TOTAL[3]						1		1		23	
1560	LOSS(30%)						1				23	
1565	GRAND TOT[2]						1					23
1570	WKO(MM)											23

Figure 5.20 12 Hourly distribution sheet setup

The resulting release hydrograph of each feeder is used as an input to the release calculation of the main canal once the release is calculated for each feeder. This means that no calibration is necessary for the feeder canals which simplifies and speeds up the calculations. Figure 5.20 shows the distribution sheet setup for the Feeder 24 on the West canal. The setup is very flexible and it is programmed by the user for each distribution sheet.

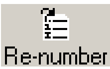
The following paragraphs describe some of the main features that were added to the 12 hourly distribution sheet to make it practical to work with.



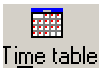
The **Generate menu** has four options to update and/or calculate distribution sheet/s. A distribution sheet can be updated and/or calculated during the generation procedure. When a specific distribution sheet is updated, it means that each off take on the distribution sheet is updated with the water order information in the database for the specified week. When a distribution sheet is calculated, it means that all the water orders are added according to the user defined setup of the specific distribution sheet. The setup of each distribution sheet is programmed by the user as can be seen in Figure 15.

- Update & calculate: Current: Update and calculate the current distribution sheet only.
- Calculate: Current: Re-calculate the current distribution sheet only.
- Update & calculate: All: Update and calculate the all the distribution sheets in the list.
- Calculate: All: Re-calculate all the distribution sheets in the list.

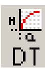
The **Request button** opens the water request form at the specific water order location.



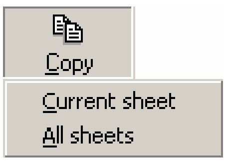
The **Re-number** button is used to renumber the lines of the current distribution sheet with an increment of 5. This is sometimes needed to make space for a new line to be inserted.



The **Time table button** gives easy access to the weekly time table form. The weekly time table control the dates that are displayed on the headers of the relevant columns on the distribution sheet.



The **DT button** gives easy access to the discharge table information which is used to read the measuring plate readings for a given flow rate. The discharge table is also used to read the % loss for a given flow rate. There is no limitation on the number of discharge tables that can be captured in WAS.



The **Copy menu** is used to copy the current or all distribution sheets to another week and/or water year. Both options open the Copy distribution sheet form as shown in Figure 5.16.

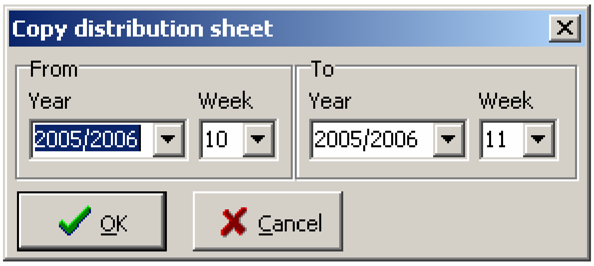


Figure 5.21 Copy distribution sheet form

Discussion

The implementation of the release module of the WAS program at the Vaalharts WUA has been an objective for many years without much success. The main reasons for that were a lack of human resources to capture the massive amount of data and a negative attitude from the water distribution personnel at Vaalharts who did not support the idea of the WAS program being used to calculate the water releases.

A break through has been made with this project and not only did we capture the geometry of the total canal network but we also managed to add a 12 hourly distribution sheet that has a similar look and feel of what they are currently doing. The 12 hourly distribution sheet also has a major impact on their water losses and water distribution management and control.

According to the Vaalharts WUA chief water control officer, the WAS system brought the operational losses down by ±12,4% during the implementation period. The water balances are now updated on a daily basis compared to a 6 weeks previously.

5.9. WAS exit strategy

The WAS program has the advantage that it is in use on a daily basis at the technology transfer case study areas which include:

- Loskop Irrigation Board
- Vaalharts WUA
- Oranje Riet WUA
- Lower Olifants WUA
- Lower Sundays River WUA

The different schemes are in regular contact with NB Systems for follow up training and support. They all have WAS maintenance agreements in place and the implementation and refinement of WAS will therefore automatically continue in the future.

Vaalharts WUA has already indicated their interest in further improvements to their water release calculation procedures due to the impact of the technology transfer project. The technology transfer project had a very positive outcome in this case, which will be taken further in the future.

6. SAPWAT TECHNOLOGY TRANSFER

6.1. Introduction

A key component of improving the efficiency with which irrigation water is applied relates to the management of irrigation systems. For irrigation to be efficient, the right amount of water needs to be applied at the right time. Irrigation farmers need information regarding crop water requirements so as to know what the “right” amount is for a given point in time (and for a given crop at a given location). The experience is that irrigation farmers do not wilfully waste water, but rather a lack of knowledge of the actual water requirements of crops is a major contributor to inefficient irrigation application. Structural limitations also contribute to inefficiencies, however the focus of SAPWAT model is to provide irrigators with information related to the crop water requirement, i.e. the “right” amount of water to apply.

SAPWAT can be used to estimate the total annual and monthly crop irrigation requirements which can then be compared to the water available to the area. This enables farmers and WUA managers to not only ensure that the “right” amount of water is applied at the right time, but also enables them to identify possible limitations in the conveyance and delivery infrastructure which could have negative consequences associated with the crops being stress in certain periods resulting from these limitations. SAPWAT can also be used to analyse various irrigation and cropping scenarios, e.g. the effect that the changing of crops or crop types or the shifting of planting dates could have on irrigation water supply and demand.

This document relates to the WRC deliverable 3.03. For this deliverable the SAPWAT model was used to simulate the crop water requirements of various crops, various irrigation systems and various scheduling options for the research areas forming part of the project. An undertaking of this nature provides the WUAs and farmers with information related to the crop water requirements. The information is valuable to farmers as it can enable them to improve their irrigation application. The information is also valuable to WUAs who can work out in advance what the probable water requirement will be within their schemes. This calculation is made possible utilising information about cropping patters (i.e. the nature of the crops that have been grown, and the time of the plantings), as well as a knowledge of the water distribution (e.g. canal) capacities. The WUA can warn its member base in advance if water demands are anticipated to exceed the ability of the system to supply the water.

6.2. Technology Transfer of Sapwat

Most of the WUA’s / IBs participating in the Technology Transfer project had already heard about SAPWAT before the commencement of the TT project, and some already had the modelled installed on their computers, and were already using the model. Mr Pieter van Heerden was the SAPWAT authority in the team, responsible for the transfer of technology associated with the model. Mr van Heerden visited the WUAs / IBs participating in the TT project, and show-cased the model. In addition to discussing the model, and its functionality, Mr van Heerden has also configured the SAPWAT model for the dominant crop and management practices in the participating WUAs / IBs. The model results were discussed (and validated) with the participating WUA’s / IBs. The implication is that a database of simulated crop water requirements exists for the dominant crops of the participating WUAs / IBs, which can easily be used by the WUAs / IBs, as well as by individual farmers. Some details of the dominant crops, and the crop water requirements of these crops (for given management practices), is detailed in the sections below.

6.3. The Cropping Patterns and Water Use of the WUAs / IBs

One of the tasks of the TT project was to find out details of the current cropping patterns of the participating WUAs / IBs. A summary of the cropping pattern of the WUAs / IBs is given below, and the crop water use requirements are detailed below.

6.3.1. Loskop

Cropping pattern surveys were done fairly recently, therefore the irrigation requirements should be fairly accurate.

Scheduled area: 16084 ha
Water quota: 7700 $m^3.ha^{-1}.a^{-1}$
Water use right: 123846800 $m^3.a^{-1}$ (i.e. 1238.5 MCM. a^{-1})
Water delivery limit: 25000000 $m^3.m^{-1}$ (i.e. 3000.0 MCM. a^{-1})
Total water use: 124483250 $m^3.a^{-1}$ (i.e. 1244.8 MCM. a^{-1})
Water balance: -636450 $m^3.a^{-1}$ (i.e. - 0.6 MCM. a^{-1})
Water use (%): 100.5%

Note:
MCM = Million Cubic Meters
The system is not limited by the canal capacity.

Table 6.1 Cropping Pattern of the Loskop Irrigation Board

Crop	Option	Irrigation	%
Citrus	Average	Drip	16.6
Cotton	Medium growers	Centre Pivot	12.0
Cotton	Medium growers	Sprinkler – moveable	12.0
Grapes	Table Medium	Drip	4.3
Maize	Short grower Early plant	Centre Pivot	0.0
Peaches	Long/late	Drip	0.1
Peas	General	Centre Pivot	2.0
Peas	General	Sprinkler – moveable	2.0
Peas	General	Centre Pivot	2.0
Peas	General	Sprinkler – moveable	2.0
Pecans	Estimate cover	Drip	0.0
Peppers	Spring plant	Centre Pivot	0.0
Peppers	Spring plant	Sprinkler – moveable	0.0
Potato	Medium growers Autumn/Winter p	Centre Pivot	1.0
Potato	Medium growers Autumn/Winter p	Sprinkler – moveable	1.0
Potato	Medium growers Autumn/Winter p	Centre Pivot	1.0
Potato	Medium growers Autumn/Winter p	Sprinkler – moveable	1.0
Potato	Medium growers Autumn/Winter p	Centre Pivot	1.0
Potato	Medium growers Autumn/Winter p	Sprinkler – moveable	1.0
Soybeans	Medium	Centre Pivot	1.0
Soybeans	Medium	Sprinkler – moveable	1.0
Tobacco	All areas	Centre Pivot	1.7
Tobacco	All areas	Sprinkler – moveable	1.6
Tobacco	All areas	Centre Pivot	1.7
Tobacco	All areas	Sprinkler – moveable	1.6
Vegetable	Summer	Centre Pivot	2.1
Vegetable	Summer	Sprinkler – moveable	2.0

Vegetable	Winter	Centre Pivot	2.1
Vegetable	Winter	Sprinkler – moveable	2.0
Wheat	Plant 05/25	Centre Pivot	14.0
Wheat	Plant 05/25	Sprinkler – moveable	13.6
			103.4

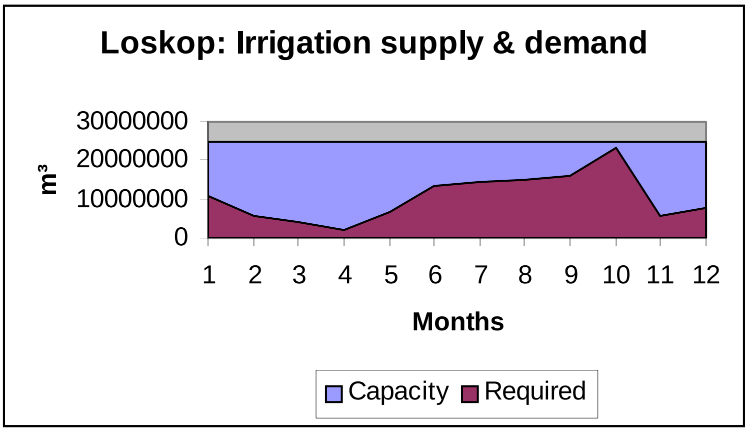


Figure 6.1 Potential monthly water supply compared to water required by cropping system

Total water use exceeds water use right by 0.5%. The supply infrastructure can satisfy monthly demand, but the safety factor for October is low with 92% of capacity being utilised.

6.3.2. Orange-Riet

Cropping pattern surveys were done fairly recently, therefore the irrigation requirements should be fairly accurate.

Scheduled area: 16903 ha
Water quota: 11000 $m^3.ha^{-1}.a^{-1}$
Water use right: 185933000 $m^3.a^{-1}$ (185.9 MCM. a^{-1})
Water delivery limit: 42595560 $m^3.m^{-1}$
Total water use: 234432000
Water balance: -48499000
Water use (%): 126

Table 6.2 Cropping pattern of the Oranje-Riet Irrigation Scheme

Crop	Option	Irrigation	%
BeansBus	Dry Short	Centre Pivot	1.4
Cotton	Medium growers	Centre Pivot	0.2
Cotton	Medium growers	Flood - channel supply	0.1
Fescue	Standard	Centre Pivot	1.5
Fescue	Standard	Flood - channel supply	0.5
Grapes	Wine Medium	Drip	1.7
Groundnut	Standard	Centre Pivot	1.4
Lucerne	Semi-dormant	Centre Pivot	7.1
Lucerne	Semi-dormant	Flood - channel supply	3.5
Maize	Short grower Early plant	Centre Pivot	22.3
Maize	Short grower Early plant	Flood - channel supply	11.2
Maize	Short grower Late plant	Centre Pivot	22.3
Maize	Short grower Late plant	Flood - channel supply	11.2
Olives	Estimate cover	Drip	0.1
Onion	Seeded	Centre Pivot	0.3
Peaches	Short/early	Drip	0.1
Pecans	Estimate cover	Drip	0.4
Potato	Medium growers Spring plant	Centre Pivot	1.7
Sunflower	Standard	Centre Pivot	0.6
Sunflower	Standard	Flood - channel supply	0.3
Vegetable	Summer	Centre Pivot	1.3
Wheat	Plant 06/05	Centre Pivot	27.9
Wheat	Plant 06/05	Flood - channel supply	13.9
			131.0

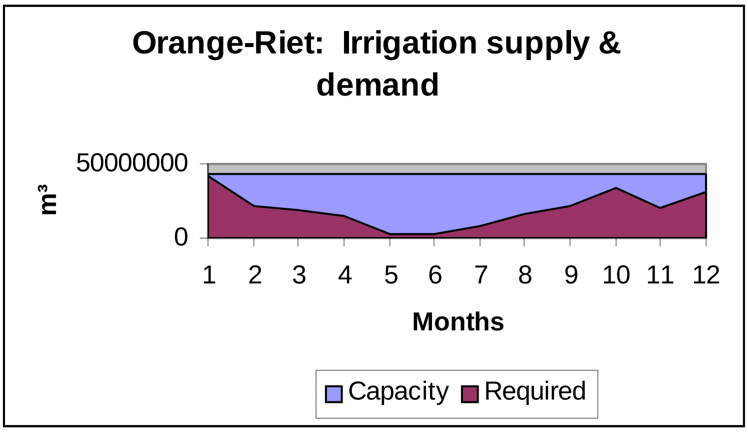


Figure 6.2 Potential monthly water supply compared to water required by cropping system

Total water use exceeds water use right by 26%. The supply infrastructure can satisfy monthly demand, but the safety factor for January is very low with 99% of capacity being utilised.

6.3.3. Gamtoos

Cropping pattern surveys were done fairly recently, therefore the irrigation requirements should be fairly accurate.

Scheduled area: 7431 ha
Water quota: 8000 $m^3.ha^{-1}.a^{-1}$
Water use right: 59440000 $m^3.a^{-1}$

Water delivery limit: 1493600 m³.m^{-1}
Total water use: 48323500
Water balance: 11116500
Water use (%): 81

Table 6.3 Cropping Pattern of the Gamtoos Irrigation Board

Crop	**Option**	**Irrigation**	**%**
BeansBus	Dry Short	Centre Pivot	
BeansBus	Green	Centre Pivot	1.3
BeansBus	Green	Centre Pivot	0.9
Beetroot	Summer crop	Centre Pivot	0.3
Beetroot	Summer crop	Centre Pivot	0.2
Beetroot	Summer crop	Centre Pivot	0.4
Beetroot	Winter crop	Centre Pivot	0.4
Broccoli	Main Autumn plant	Centre Pivot	0.1
Broccoli	Main Spring plant	Centre Pivot	
Broccoli	Main Summer plant	Micro	0.1
Broccoli	Main Winter plant	Centre Pivot	
Cabbage	Early Autumn plant	Centre Pivot	1.2
Cabbage	Early Spring plant	Centre Pivot	1.1
Cabbage	Early Summer plant	Centre Pivot	1.1
Cabbage	Early Winter plant	Centre Pivot	1.2
Carrots	Autumn plant	Centre Pivot	1.9
Carrots	Spring plant	Centre Pivot	1.6
Carrots	Summer plant	Centre Pivot	1.7
Carrots	Winter plant	Centre Pivot	1.7
Cauliflr	Main Autumn plant	Centre Pivot	0.8
Cauliflr	Main Spring plant	Centre Pivot	0.1
Cauliflr	Main Summer plant	Centre Pivot	0.3
Cauliflr	Main Winter plant	Centre Pivot	0.2
Chicory	Autumn plant	Centre Pivot	0.1
Chicory	Spring plant	Centre Pivot	1.1
Citrus	Average	Drip	22.5
Cucurbit	Spring plant	Centre Pivot	1.3
Cucurbit	Summer plant	Centre Pivot	1.8
Cucurbit	Winter plant	Centre Pivot	1.3
Fescue	Standard	Centre Pivot	7.2
Lettuce	Summer Crop	Centre Pivot	0.4
Lettuce	Summer Crop	Centre Pivot	0.4
Lettuce	Winter Crop	Centre Pivot	0.4
Lettuce	Winter Crop	Centre Pivot	0.4
Lucerne	Semi-dormant	Centre Pivot	4.1
Maize	Short grower Early plant	Centre Pivot	6.9
Past sum	Annual (grazing)	Centre Pivot	0.7
Peaches	Long/late	Drip	0.3
Potato	Medium growers Autumn/Winter p	Centre Pivot	10.8
Potato	Medium growers Spring plant	Centre Pivot	5.2
Potato	Medium growers Summer plant	Centre Pivot	5.2
Sweet corn	Main Spring plant	Centre Pivot	1.1
Sweet corn	Main Spring plant	Centre Pivot	0.6
Sweet corn	Summer	Centre Pivot	1.7
Tobacco	All areas	Centre Pivot	3.7

Tomatoes	Table Autumn/Winter plant	Centre Pivot	0.1
Tomatoes	Table Spring/Summer plant	Centre Pivot	0.2
Wheat	Plant 06/05	Centre Pivot	6.7
			100.8

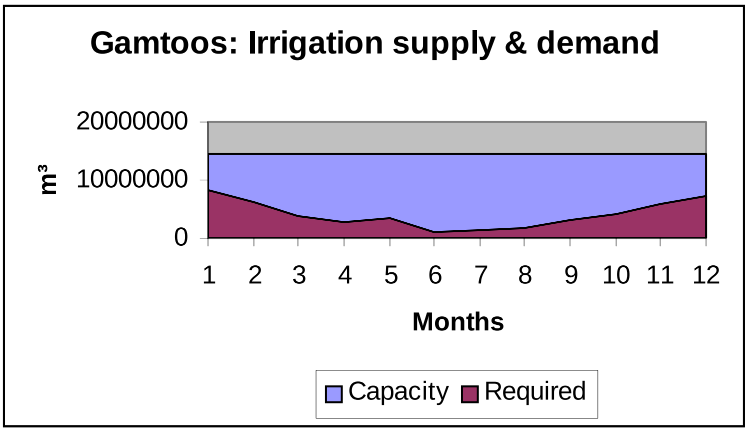


Figure 6.3 Potential monthly water supply compared to water required by cropping system

Total water use is about 81% of allocation. The supply infrastructure can satisfy monthly demand with ease.

6.3.4. Lower Sundays River

Cropping patterns surveys are out of date and therefore the irrigation requirements estimates might not be good.

Scheduled area: 17111 ha
Water quota: 9000 $m^3.ha^{-1}.a^{-1}$
Water use right: 153999000 $m^3.a^{-1}$
Water delivery limit: 25024837 $m^3.m^{-1}$
Total water use: 130757900
Water balance: 23241100
Water use (%): 85

Table 6.4 Cropping Pattern of the Lower Sundays Irrigation Board

Crop	Option	Irrigation	%
Citrus	Average	Drip	82.3
Lucerne	Semi-dormant	Sprinkler - moveable	12.2
Maize	Short grower Late plant	Sprinkler - moveable	0.9
Potato	Medium growers Spring plant	Sprinkler - moveable	0.0
Vegetable	Summer	Sprinkler - moveable	2.2
Vegetable	Winter	Sprinkler - moveable	2.1
Wheat	Plant 06/15	Sprinkler - moveable	0.8
			100.5

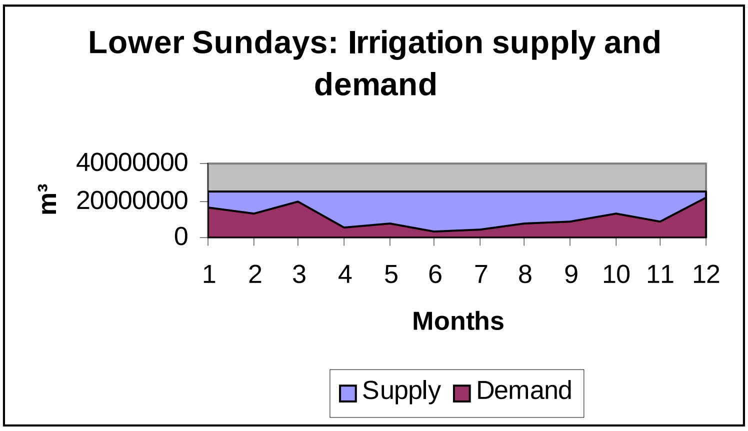


Figure 6.4 Potential monthly water supply compared to water required by cropping system

This WUA uses only about 85% of its allocated water. Present maximum system capacity utilisation is about 84% for December

6.3.5. Lower Olifants River

Cropping patterns surveys are out of date and therefore the irrigation requirements estimates might not be good.

Scheduled area: 9212 ha
Water quota: 12200 $m^3.ha^{-1}.a^{-1}$
Water use right: 112386400 $m^3.a^{-1}$
Water delivery limit: 19398000 $m^3.m^{-1}$
Total water use: 102743750
Water balance: 9642650
Water use (%): 91

Table 6.5 Cropping Pattern Lower Olifants River Water User Association

Crop	Option	Irrigation	%
Citrus	Average	Drip	31.2
Cucurbit	Spring plant	Drip	0.9
Cucurbit	Spring plant	Flood - channel supply	0.9
Cucurbit	Spring plant	Sprinkler - moveable	0.9
Grapes	Wine Medium	Drip	63.5
Grapes	Wine Medium	Flood - channel supply	10.6
Onion	Transplant Autumn	Drip	0.4
Onion	Transplant Autumn	Flood - channel supply	0.4
Tomatoes	Canning Early Spring plant	Drip	2.8
Tomatoes	Canning Early Spring plant	Flood - channel supply	1.2
Tomatoes	Table Spring/Summer plant	Drip	2.8
Tomatoes	Table Spring/Summer plant	Flood - channel supply	1.2
			116.8

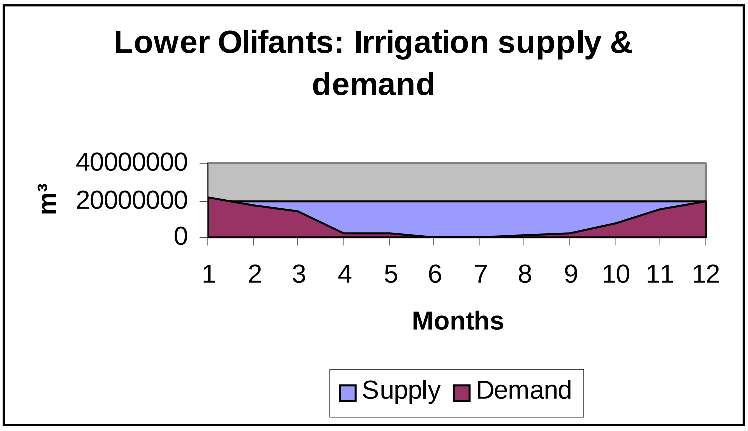


Figure 6.5 Potential monthly water supply compared to water required by cropping system

This WUA uses only about 91% of its allocated water. Potential demand during December-January exceeds supply capacity by about 1%.

6.3.6. Comparing the Crop Water needs between Water User Associations/Irrigation Boards

SAPWAT allows the user to assess the irrigation requirement of crops by taking into account the growth characteristics of the crop in a particular climate region, planting time, irrigation system and irrigation strategy. The preceding section details the cropping patterns of the participant WUAs and IBs. Appendix 1 contains the crop water use requirements for the dominant crops in each participating WUA / IB. This section contains a comparison of the crop water use requirements of two crops that are undertaking on most of the participating WUAs / IBs.

Two crops that could be used over the range of WUA areas included in the TT-project are citrus and maize, not necessarily the most important crops in each area, but the comparisons can highlight the differences that climate, rainfall, irrigation system and irrigation strategy can make in the irrigation requirements of crops. The crop irrigation needs for citrus are shown in Figure 6 (annual demand), and Figure 7 (monthly demands) respectively. Figure 8 and Table 1 detail the irrigation demands for maize.

SAPWAT enables the user to plan for irrigation water requirements under virtually any combination of irrigation system use and the linked irrigation management strategy that the local irrigation environment dictates. By being able to imitate what goes on in the fields or on an irrigation scheme. The user develops a better understanding of the local irrigation environment.

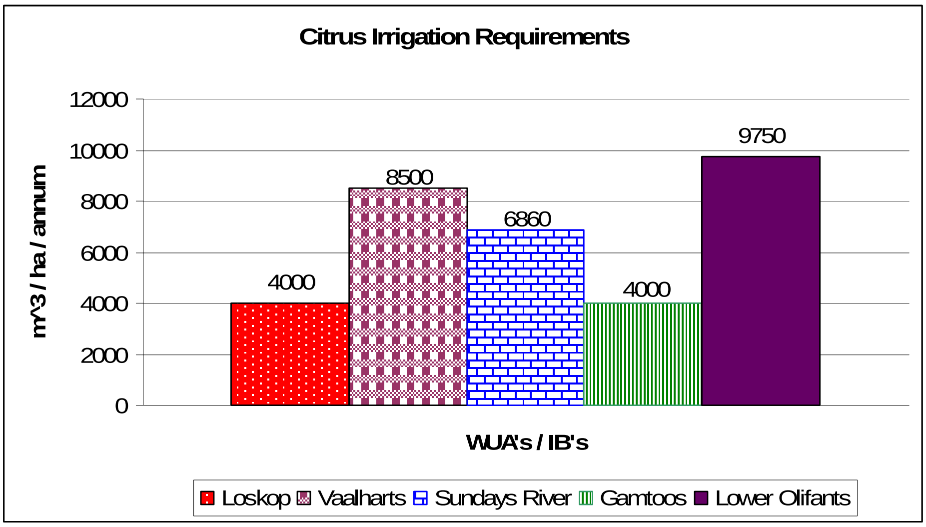


Figure 6.6 The annual irrigation requirement for citrus for the respective participating WUAs / IBs

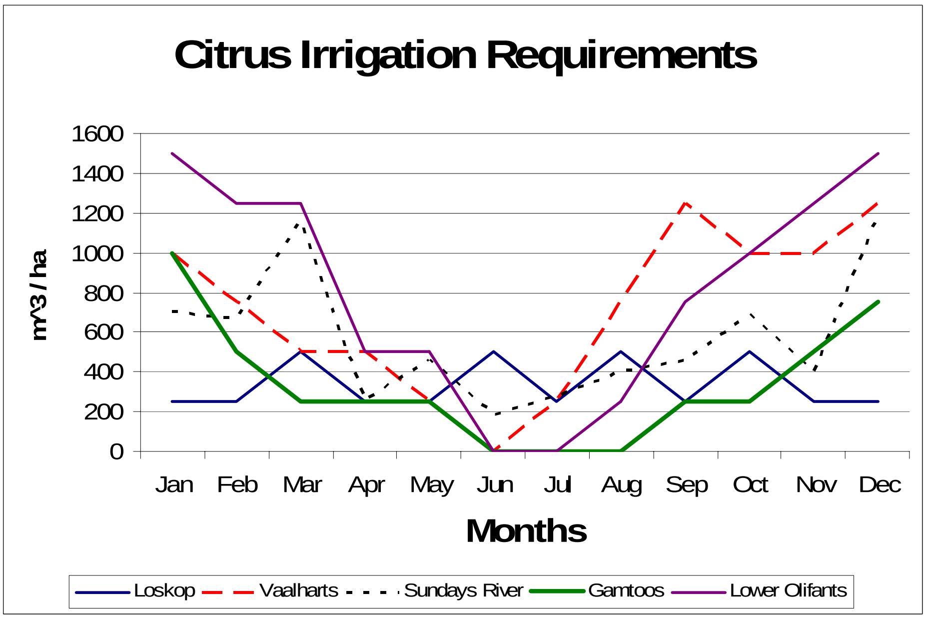


Figure 6.7 The monthly irrigation requirement for citrus per WUA / IB.

What is immediately apparent from the graph is the big differences in irrigation water demand as a result of a combination of different climates, rainfalls and the different irrigation strategies followed. These can be seen in the accompanying table.

A similar difference is noticeable in the case of maize. Here we also have different irrigation systems for a crop and the difference in irrigation requirement is immediately apparent when comparing the total irrigation requirement for the different systems.

What must also be kept in mind is that the total irrigation requirement is a function of irrigation system efficiency as well as the irrigation strategy. In most cases on irrigation schemes the reticulating infrastructure and the management there-of could very well force a sub-optimal irrigation strategy onto the irrigators, which could result in more irrigation water requirement that the differences in assumed system efficiencies would dictate.

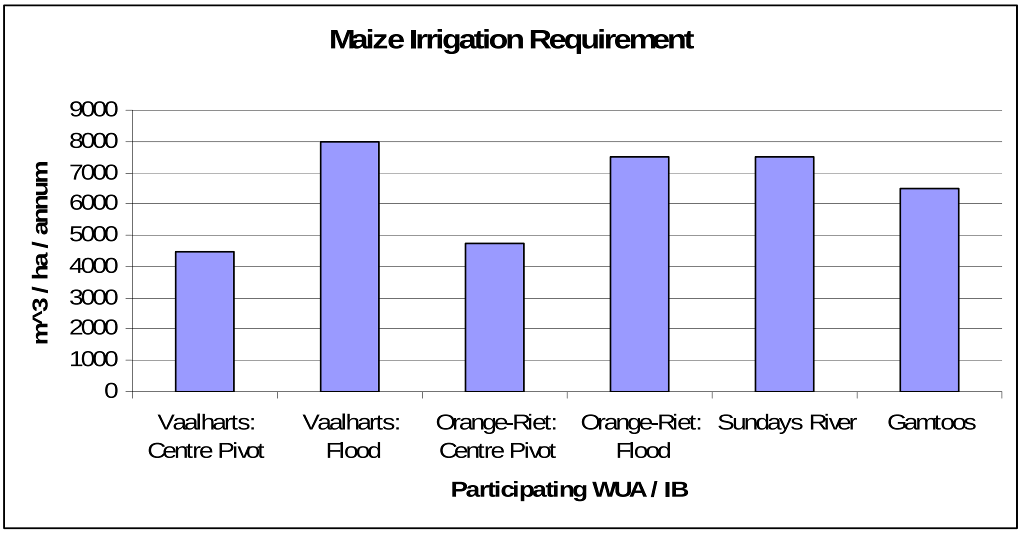


Figure 6.8 The average annual crop water use requirement of maize in the respective WUAs / IBs

Table 6.6 The monthly irrigation requirements for maize in the respective WUAs / IBs

WUA/IB	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Loskop	75	150	105	100	0	0	0	0	0	0	0	0	430
Vaalharts: Centre Pivot	1000	1000	1250	500	0	0	0	0	0	0	0	750	4500
Vaalharts: Flood	1500	2000	2500	1000	0	0	0	0	0	0	0	1000	8000
Orange-Riet: Centre Pivot	500	1000	1750	1500	0	0	0	0	0	0	0	0	4750
Orange-Riet: Flood	1000	1500	3000	2000	0	0	0	0	0	0	0	0	7500
Sundays River	1500	2250	2250	750	0	0	0	0	0	0	0	750	7500
Gamtoos	2500	2000	500	0	0	0	0	0	0	0	500	1000	6500

6.4. Irrigation needs of sugarcane for the Mhlathuze Catchment

One of the tasks undertaken by Mr van Heerden was to simulate the sugarcane irrigation requirements for the Mhlathuze Catchment area. The South African Research Institute (SASRI) currently make use of specialised sugarcane models (e.g. canesim) to simulate the crop water requirements of sugarcane. The SAPWAT simulation results are shown below. A comparison with the canesim simulation results was not undertaken, as this can be done by SASRI.

Table 6.7 Irrigation Requirements

Irrigation requirements (mm)

Date: 26/03/2007

Task: WRC K5/1481//4: TT-project

WMA / Primary river: 06: Usutu to Mlhatuze
WUA / Secondary river: Mhlatuze
Sub area / Tertiary river: Heatonville
Farm / Quaternary river:

Weather station: NKWALINI
Water use right (m^3): 0.000
Cultivated (ha): 1.000
Leaching (%): 0
Country:

Crop	Option	Start	Irrigation system	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Sugrcane	Autumn harvest	05/ 1	Sprinkler - moveable (70%)	100	125	125	150	100	100	125	0	0	25	75	100	1025
	Cover = 100%; Wetted area = 100%; Target Yield = Normal yield (75%); Soil = Medium; TAM = 140mm; Root depth = 1.50m Irrigation strategy: Fixed Depth @ 25mm; Cycle = At Percentage of Critical Depletion @ 50% or days; Stage I = Cycle 0 days @ 0mm; Stage II = Cycle 0 days @ 0mm; Stage III = Cycle 0 days @ 0mm; Stage IV = Cycle 0 days @ 0mm															
Sugrcane	Spring harvest	10/ 1	Sprinkler - moveable (70%)	0	0	0	25	75	125	150	125	100	125	150	125	1000
	Cover = 100%; Wetted area = 100%; Target Yield = Normal yield (75%); Soil = Medium; TAM = 140mm; Root depth = 1.50m Irrigation strategy: Fixed Depth @ 25mm; Cycle = At Percentage of Critical Depletion @ 50% or days; Stage I = Cycle 0 days @ 0mm; Stage II = Cycle 0 days @ 0mm; Stage III = Cycle 0 days @ 0mm; Stage IV = Cycle 0 days @ 0mm															
Sugrcane	Summer harvest	12/ 1	Sprinkler - moveable (70%)	125	75	0	0	0	25	150	125	100	125	150	150	1025
	Cover = 100%; Wetted area = 100%; Target Yield = Normal yield (75%); Soil = Medium; TAM = 140mm; Root depth = 1.50m Irrigation strategy: Fixed Depth @ 25mm; Cycle = At Percentage of Critical Depletion @ 50% or days; Stage I = Cycle 0 days @ 0mm; Stage II = Cycle 0 days @ 0mm; Stage III = Cycle 0 days @ 0mm; Stage IV = Cycle 0 days @ 0mm															

6.5. Further Development: SAPWAT3

SAPWAT3 like its predecessors Cropwat and the familiar SAPWAT program is a tool for use in irrigation policy development, planning, design, management and analysis. In common with its predecessors it is self-contained in that all the data required to run the program is included in the installation software and it is not necessary to seek data elsewhere. Similarly a minimum of computer literacy is required of the user.

SAPWAT3 is a considerable advance on SAPWAT. The historic data base that is the foundation on which future predictions are based now spans, in the case of South Africa, the 50 years from 1950 to 1999 on a daily identifiable calendar basis and includes full climatic and rainfall information. In addition runs of irrigation amounts that would have been required for a crop, in a specific locality can be run for one year only or for the full 50 years or for the period between any two specific dates. The climatic database has been developed by Prof Roland Schulze and was specifically provided on request to create a centroid weather station in each quaternary area. The program runs seamlessly from one year to the next and is not confined to average years or to a specific calendar year as is normally the case. This enables the user to rapidly assess the impacts of changing the quantity and timing of irrigation, the results achieved with alternative irrigation systems and the influence of soil type. SAPWAT3 has the potential to facilitate the meaningful development and packaging of the norms and standards required to evaluate and promote irrigation efficiency.

SAPWAT3 bases the calculation of crop evapo-transpiration on the internationally accepted methodologies published in FAO No56 including those recommended for non-standard situations. The existing SAPWAT program also used crop coefficients based on separating crop transpiration from soil evaporation but the algorithms used for this purpose when the program was developed utilised a methodology that differs from those utilised in FAO No 56 that were published later. While the existing SAPWAT crop coefficients were calculated in accordance with the basic principles of the FAO four-stage methodology the values were adjusted utilising research results, field surveys and experience to conform to real-life local practice. The FAO No 56 crop coefficients are calculated according to the standard procedures that depend on assumptions, ratio between day and night wind velocities for example, that may not be entirely applicable in all areas in South Africa so that a degree of calibration is still required that will differ somewhat from what was previously estimated to adjust the crop coefficients.

A more serious deficiency is adjustment of the calculated evapo-transpiration of crops that is the potential evapo-transpiration and not the actual value. SAPWAT partly compensates for this by making provision for crops that are planted at the density that results in cover at full canopy of leaf area indices of less than three. Additional compensation is provided in some versions by providing three levels of yield where maximum yield, by implication, results in potential evapo transpiration and provision is made by modifying the DU value for reducing the irrigation requirement when the yield is average or below average. Currently SAPWAT3 reduces the actual evapo transpiration if the user empirically edits the crop coefficient to reduce the third stage evapo transpiration. In some cases, values for high and average target yields have been provided to facilitate the process. It is hoped that the project that Prof Dirk Raes (one of the co-authors of FAO 56) and associates have undertaken to replace FAO No 33 will produce a methodology to cater for this need and will be suitable for incorporation in SAPWAT3. A promising discussion with Prof Raes was held recently in this regard.

It is important that SAPWAT3 output be assessed against the experience and knowledgeable judgement of practitioners and researchers. Where their are significant deviations the reasons must be sought by running the model in order to establish if there are inputs or assumptions that were not valid in the context of the evaluation. Such cases highlight where there should be modifications or editing of inputs. Output from the parallel irrigation efficiency project (WRC) will be very valuable. The DWAF WARMS database, (both registration and verification) contains a wealth of information on irrigation crops and water use. It is important to remember, however, that both the registration and the verification processes were to a large extent based on SAPWAT. Be this as it may, the figures have been agreed by each farmer concerned and to this degree are officially acceptable. Analysis of this data will be of mutual benefit to both the SAPWAT3 and irrigation efficiency projects. Similarly information on water and crop management as well as the yield levels attained in practice will be of benefit and visits by personnel from both projects should aim at commonality of data collection and interpretation.

It is one thing to cater for such aspects as the reduction of crop irrigation requirements as a consequence of non-water related production constraints that can influence the relationship between potential evapo-transpiration and actual evapo-transpiration but it is quite another matter to assess the impact of "irrigation efficiency", the transposition of net irrigation requirements to gross irrigation requirements. SABI have developed recommendations for these values but they do not take account of the impact of the variability of water distribution by irrigation equipment (CU and DU) or of the variability of the soils in a field. This is not acceptable and was catered for to an extent in the case of SAPWAT. It is proposed that recommendations be obtained from the recognised international specialists in this field and that these values be accepted as baseline data from which realistic values can be estimated. This would mean that SAPWAT3 would be anchored from one side by the internationally acknowledged methods for estimating potential crop evapo-transpiration and on the other by similarly authoritative and defensible irrigation efficiency approaches.

Much the same situation applies to on-scheme and on-farm water distribution losses. Once again it would be valuable if authoritative advice can be obtained and coupled to the data available in South Africa.

Against this background, SAWPAT3 can be used to set benchmarks for irrigation water requirement, not only as a single figure, but also give ranges of expected irrigation requirement by doing standard deviation analyses on up to 50 years of historic data. The ranges of irrigation water required does also give a better (statistical) indication of what capacity the designer should aim for in his design, for example, by designing not for the average, but for the requirement of one standard deviation above the average, he could be sure that his design will be able to supply enough irrigation water for about 84% of the time (years).

The calculation of efficiency factors, such as gross margin per unit water and intensity of land use, the efficiency of planned water use scenarios can be evaluated and a more efficient management scenario can be applied by the farmer to ensure a better land use and income per unit water.

6.6. Conclusions

The SAPWAT model was one of the models forming part of the Technology Transfer project. The model was already known to most of the participating WUAs / IBs. Mr van Heerden, being an authority in the use of SAPWAT, was tasked with the technology transfer of the SAPWAT model to the participating WUAs / IBs. As the model was already well known to the participants, Mr van Heerden configured the model to simulate the crop water requirements of the dominant crops in the participating WUAs / IBs, and the results were validated with discussions with the WUAs / IBs.

The SAPWAT model is being used widely in South Africa and internationally, and will continue to be in the future. The model is pre-packaged with weather data needed to drive the model, and is easy to set up and run. The SAPWAT model will mainly find its use for planning purposes, both by individual farmers, as well as WUAs / IBs. The model is also being further developed as part of another WRC funded project, which will facilitate the sustained use of the model in the year to come.

7. THE TECHNOLOGY TRANSFER OF SWB

7.1. Background

The Soil Water Balance (SWB) model is an irrigation-scheduling tool that is based on the improved generic crop version of the soil water balance model first described by Campbell and Diaz (1988). The model has since been improved and re-programmed with a user-friendly interface by researchers from the University of Pretoria, following several research projects funded by the WRC over many years (Annandale et al., 1996; Benadé et al., 1997; Annandale et al., 1999; Annandale et al., 2000; Annandale et al., 2002a; Annandale et al., 2002b; Annandale et al., 2002c; Benadé et al., 2002; Annandale et al., 2005; Annandale et al., 2007).

SWB is a real time, generic crop irrigation-scheduling model. It gives a detailed description of the soil-plant-atmosphere continuum. Crop water use is estimated by using a mechanistic and, therefore, universally valid approach. This has several advantages over the more empirical methods, which use different crop factors for different planting dates and regions. The use of thermal time to describe crop development also requires crop parameters, but these are transferable to other environments.

Databases are used to store crop, weather, field, water and soil parameter data. The crop database is populated with default crop parameters for a range of commonly irrigated crops in South Africa. This, together with the fact that several fields can be simulated simultaneously, makes it an ideal scheduling tool for large farmers, irrigation consultants or WUAs.

SWB calculates crop growth and soil water balance components using three units, namely the weather, soil and crop units. The SWB weather unit calculates Penman-Monteith grass reference daily evapotranspiration (ETo) according to the recommendations of the Food and Agriculture Organization (FAO) of the United Nations (Allen et al., 1998). In the soil unit of SWB, potential evapotranspiration (PET) is divided into potential evaporation and potential transpiration by calculating canopy radiant interception from simulated leaf area. This represents the upper limits of evaporation and transpiration, which will only proceed at potential rates if atmospheric demand is limiting. More often, supply of water to the soil surface or plant root system will be limiting. Soil water evaporation is simulated by relating the evaporation rate to the water content of the surface soil layer. In the case of transpiration, a dimensionless solution to the water potential based water uptake equation is used. This procedure results in a root density weighted average soil water potential, which characterizes the water supply capabilities of the soil-root system (Annandale et al., 2000). If actual transpiration is less than potential transpiration, the crop is assumed to be stressed and leaf area expansion will be reduced if the crop is still in the vegetative phase of growth. Therefore, there is feedback between the crop and the soil.

The multi-layer soil component of the model ensures a realistic simulation of infiltration and crop water uptake. A cascading soil water balance is used, and canopy interception and surface runoff are calculated after rain or overhead irrigation. In the crop unit, SWB calculates crop dry matter accumulation in direct proportion to transpiration corrected for vapour pressure deficit. It also calculates radiation-limited growth and uses the lesser of the two dry matter values. This dry matter is then partitioned into roots, stems, leaves and grain or fruits. Partitioning depends on crop phenology, which is calculated from thermal time and modified by water stress.

In cases where the input growth parameters for specific crops are not available, SWB can also follow the FAO crop factor approach. Soil water balance components are still calculated mechanistically, but the advantage of mechanistic feedback between the crop and soil is lost, as canopy growth is now assumed to depend only on calendar time.

At the end of a simulation, all results are tabulated and various output graphs are produced, including the soil water balance graph. Depending on the current deficit, the model will also recommend the next irrigation date and quantity, based on the irrigation frequency and timing options selected.

SWB Irrigation Calendars were also developed as an alternative to real-time irrigation scheduling. The SWB model now has the capability of generating site-specific recommendations of seasonal irrigation requirements, which can be printed out and supplied to the farmer. Irrigation calendars were specifically developed for resource-poor farmers who are without computers and access to real-time weather data. However, it is clear that commercial farmers could also benefit from this simpler management option. Calendars are not promoted as replacement for real-time scheduling, but rather as a site specific simplified application of the SWB model. Once farmers have mastered the basic irrigation scheduling principles, they could progress to real-time use of SWB for better irrigation management.

Previous technology transfer actions to promote the use of SWB amongst irrigators and irrigation advisors had limited success. Only a handful of irrigation consultants and individual farmers were known to use the SWB as a scheduling tool. In this project the main aim was to further promote the use of SWB through WUAs, that could possibly use the model to provide a scheduling service to their farmers.

7.2. SWB improvements

Following earlier technology transfer actions involving SWB, it was realized that further improvements were necessary in order simplify the model, especially for real-time scheduling. There would be no sense in trying to promote a model that was difficult or cumbersome to use to potential new users.

As a first step to identify possible improvements, an improved version of the model was given to six TT team members and colleagues, as well as two current users (irrigation consultants), to evaluate ease of use and potential problem areas. The objective was to try to address some of the constraints of running real-time simulations and they had to make recommendations with regard to possible simplifications to make daily simulation runs more convenient. From this feedback, it seemed that most users or potential users had problems right from the beginning to set up new fields, soils and weather files. The SWB team used this feedback to consider various options for improvement, which were implemented subsequently. These improvements are detailed below:

7.2.1. Change of database

From a programming point of view, the Paradox database previously used for in- and output data capturing no longer complied with the increasing complexity and volumes of data that have to be handled. As a consequence, the database often became unstable, and gave problems, both a programming and end-user point of view. It was, therefore, decided to do major re-programming that would allow the use of the Firebird database, which is also used in the WAS program. This action took up a substantial proportion of the budget and human resources, but the effort was considered essential to ensure a sustainable future for the SWB model.

7.2.2. Development of a single simulation setup input screen

Detailed inputs in the field and soil setup screens discouraged new users from setting up new simulations. There were apparently too many different screens and too much data per screen was required from the user. It was consequently decided to add a new, simplified setup screen that combined the most essential field, soil, irrigation management and weather inputs (Quick Setup screen, Figure 7.1).

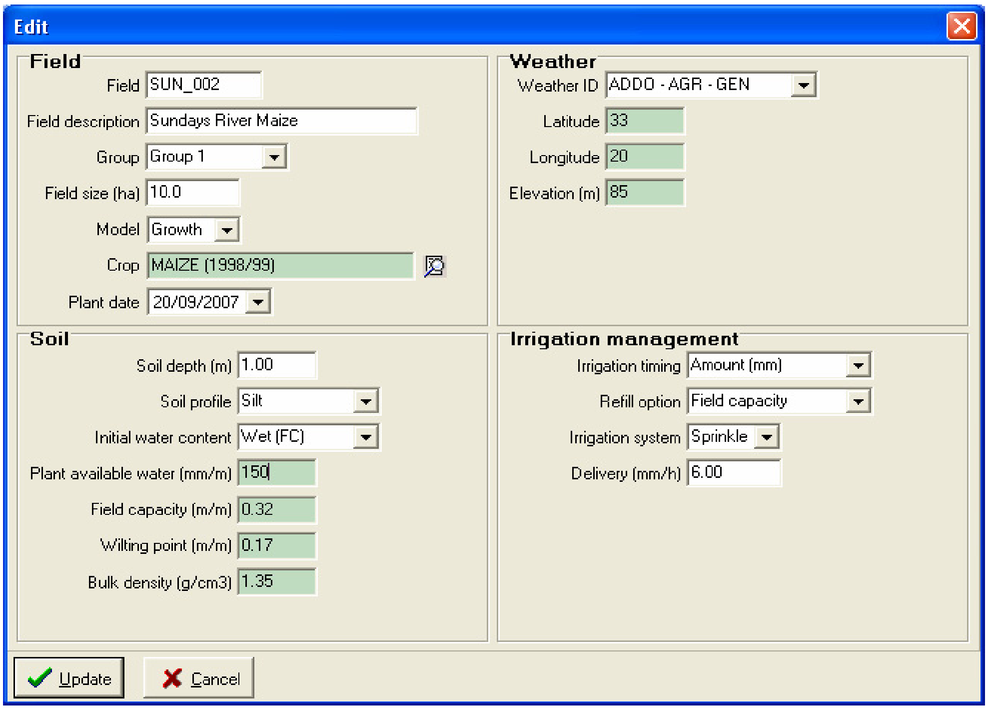
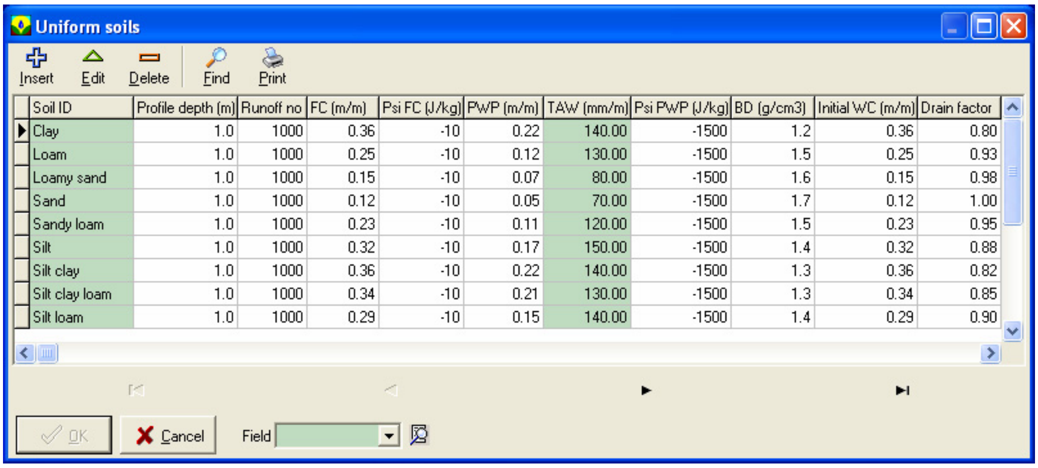


Figure 7.1 Example of the new Quick Setup screen, which combines Field, Soil, Irrigation management and Weather inputs

Only a limited number of inputs are now required, of which most can be selected from drop down menus. Default options are used for "hidden" inputs, which can later be manually changed in the Field and Soil Forms, should the users desire to do so. For example, it is assumed that a uniform soil profile applies and the model internally replicates the relevant soil properties to all soil layers, without the user being aware of this. Should the user later want to change the properties of some layers, it may be done manually in the detailed Soil Form.

7.2.3. Default soils

Users often do not have all the required input information per soil layer available. This made the setting up of new soils difficult and cumbersome. A database of the most commonly found soil groups in South Africa was added to the model. The same default soil types and soil parameter values used in SAPWAT are used, namely for sand, sandy loam, loamy sand, silt, silt loam, silt clay, silt clay loam, loam and clay (Figure 7.2). When a new field is created using the Quick setup screen, a soil can now simply be selected from the default soil drop down list (Figure 7.1).



Soil ID	Profile depth (m)	Runoff no	FC (m/m)	Psi FC (J/kg)	PWP (m/m)	TAW (mm/m)	Psi PWP (J/kg)	BD (g/cm3)	Initial WC (m/m)	Drain factor
Clay	1.0	1000	0.36	-10	0.22	140.00	-1500	1.2	0.36	0.80
Loam	1.0	1000	0.25	-10	0.12	130.00	-1500	1.5	0.25	0.93
Loamy sand	1.0	1000	0.15	-10	0.07	80.00	-1500	1.6	0.15	0.98
Sand	1.0	1000	0.12	-10	0.05	70.00	-1500	1.7	0.12	1.00
Sandy loam	1.0	1000	0.23	-10	0.11	120.00	-1500	1.5	0.23	0.95
Silt	1.0	1000	0.32	-10	0.17	150.00	-1500	1.4	0.32	0.88
Silt clay	1.0	1000	0.36	-10	0.22	140.00	-1500	1.3	0.36	0.82
Silt clay loam	1.0	1000	0.34	-10	0.21	130.00	-1500	1.3	0.34	0.85
Silt loam	1.0	1000	0.29	-10	0.15	140.00	-1500	1.4	0.29	0.90

Figure 7.2 New default Soil list in SWB from which soils can be selected.

7.2.4. Weather database improvements

The weather database (WDB) was also converted from Paradox to Firebird, for the same reasons mentioned for SWB. A complete weather database containing long-term daily temperature and rainfall data for almost 1000 stations in Southern Africa was imported into the WDB, using the data of Lynch (2004) and Schulze & Maharaj (2004). This feature is very useful for running long-term simulations in the planning mode and for generating Irrigation Calendars.

Additionally, a weather data generator was built into the WDB. This feature allows the generation of typical long-term weather data for any site, given that some historical long-term data is available for the generation of model parameters. The weather generator may also be used to fill in gaps in long-term historical weather data.

The importation of weather data into WDB proved problematic in the past due to the wide range of data formats available. To overcome this problem, a generic data import procedure was created. This allows the handling of almost any form of text data. A procedure for data export (to *.csv format) was also introduced.

7.2.5. SWB Planning for scenario modelling

As part of this project, the need was expressed to demonstrate to irrigators the necessity for, and advantages of, irrigation scheduling. These can best be demonstrated when models are used for running different irrigation management scenarios, which can give outputs of water usage and crop yield. These outputs are then used as inputs to economic models to assess the economic consequences of certain crop management strategies or scenarios. In this project, SWB was identified as the irrigation management model, while RISKMAN was to be used for economic assessments.

RISKMAN requires simulated yield and total water usage as inputs for different combinations of crop, soil and management. Due to variable temperatures and annual rainfall distribution per locality, simulation runs should be conducted over a number of years (20 to 50 years) to ensure reliable economic output data. In order to provide the required outputs necessary for economic analysis, several adjustments had to be made to SWB. Firstly, long-term weather data was needed for the most important irrigation areas in the country. This was facilitated by incorporating a complete database of daily long-term temperature (minimum and maximum) and rainfall data into the WDB (see point 7.2.d).

The user could now simply select the weather station closest to his area of interest when setting up a field. The number of scenario runs (years of simulation) can be varied by typing in the appropriate number of years next to *Generate scenarios* on the Run screen. Furthermore, the model outputs were expanded to also show a summary table of final yield and total water usage per simulated year, which can be used as direct inputs to RISKMAN.

To be able to analyze the effect of various irrigation management strategies on crop yield and water usage, the need arose to do specific field setups, which could be duplicated several times, where after minor changes in irrigation timing or refill options could easily be made for each of the new fields. Functionality was consequently developed to easily duplicate fields to comply with this requirement. As no irrigation data is usually available for long-term simulations, a function had to be developed to "auto irrigate" fields according to the irrigation timing and refill options selected.

To compare current farmer practices with scientific scheduling methods, the user must be able to cater for management options often applied by irrigators. These include options such as fixed frequency and amount of irrigation (e.g. 50 mm once a week), deficit irrigation and managed stress level, assuming a certain stress level in case of water scarcity, and consequent lower yields. The irrigation timing options were, therefore expanded to include *Stress percentage* and *Cumulative stress percentage* (in addition to the existing options of Amount, Depletion % and Interval). Similarly, the refill options were expanded to include *Fixed amount* (in addition to the existing options of Field Capacity, Leaching Requirement and Room for Rain) (Figure 7.3).

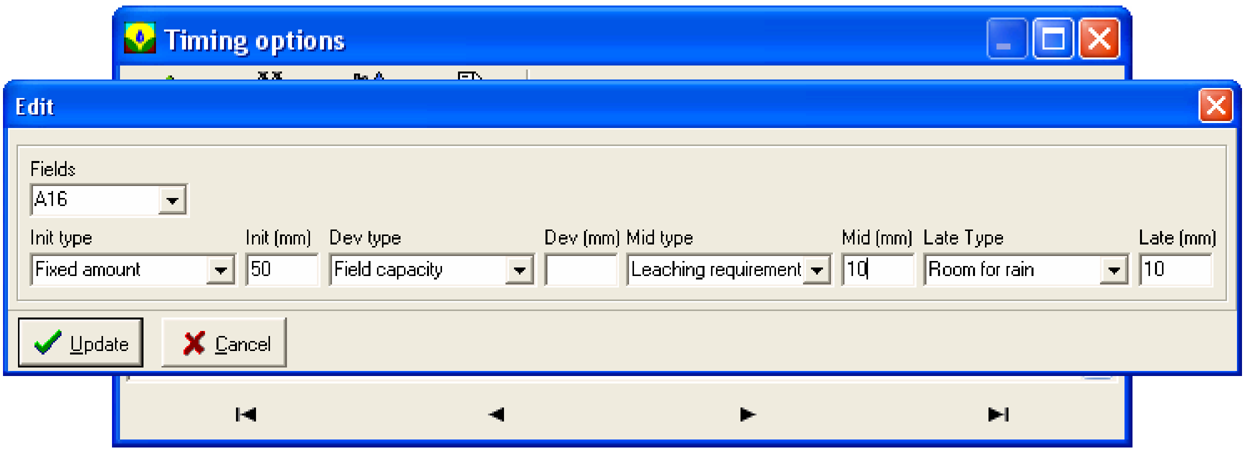


Figure 7.3 New irrigation timing options (top) and profile refill options (bottom) were added to SWB

7.3. Addressing specific WUA needs

The approach followed in this project was to promote the use of models through Irrigation Boards (IBs) or Water User Associations (WUAs). A preliminary list of potential IBs and WUAs that could be targeted for the technology transfer of models was identified when the terms of reference for the project was drawn up. The first marketing step was, therefore, to expose all the selected IBs or WUAs to all the different models covered in this project. Team members visited the IBs to inform them about the models and to give brief introductions to each model. After these initial discussions, IBs were asked to indicate which models they were interested in for possible use on their irrigation schemes. After feedback from the different schemes, the list of co-operating IBs was revised, based on the interest expressed. Only three of the nine selected schemes indicated that they were interested in the use of SWB as real-time scheduling tool. These were Loskop, Sunland and Gamtoos.

The actual technology transfer could unfortunately not commence before most of the development work described under 7.2 had been completed. Previous experience has shown that potential new users should not be confronted with model versions that still contain bugs, as these can be discouraging and they may loose faith and interest in the model. The first technology transfer actions were focused on Loskop and Sunland, as some consultants on these schemes were already familiar with SWB or they were currently using SWB. The consultants were supplied with the new improved SWB Pro version of the model for evaluation. Following this, useful feedback was received, that helped the team to iron out minor problems or to introduce further improvements to SWB. Indications were that SWB was actively used by some consultants, and they were encouraged to give continuous feedback and report problems to the team.

After the workshop held during November 2006 in Jefferies Bay, the Vaalharts WUA also expressed interest in the use of SWB as a scheduling tool.

7.3.1. Vaalharts Water User Association

Arrangements to visit Vaalharts were made in co-operation with the WUA. The visit to Vaalharts realised during early March 2007 and the technology was transferred to one young, enthusiastic farmer, who is already involved in assisting neighbouring farmers with scheduling. During the visit the use of SWB as real-time scheduling tool, as well as the use of RISKMAN as economic planning model, were demonstrated. SWB was implemented and the farmer was assisted in the setting up of new fields and the importation of weather data into SWB. Further follow-up actions are planned through the WUA in order to involve more interested consultants or individual irrigators.

7.3.2. Gamtoos Water User Association

Gamtoos WUA was visit during the last week of March 2007. During this visit, the SWB model was demonstrated to WUA staff and other interested irrigators. Only a limited number of farmers attended the presentation. No irrigation consultants were present. Informal discussions with WUA members and farmers suggested that the poor attendance by irrigators should probably not be seen as a lack of interest. Other factors probably played a role, including the fact that a very successful irrigation consultant already rendered a scheduling service on the scheme. Many irrigators, therefore, do not see the need for another scheduling tool or service. It was agreed that the WUA will inform the project team of any future interest.

7.3.3. Loskop Irrigation Board

The Loskop Irrigation Scheme was visited on 10 May 2007 and a proposal for SWB implementation was made to members of the board. It was decided, in principle, that the SWB model would be implemented on a trial basis and that the Irrigation Board will render a scheduling service to interested irrigators. A decision was also made that a person would be appointed to manage the GIS and SWB model for the scheme. The SWB model was consequently installed on one of the IB computers and demonstrated to the designated staff member.

The IB has decided in principle that the scheduling service will at first only be rendered on a limited scale to a few individual farmers. This will give staff the chance to first gain experience in the model and enable them to iron out teething problems. Furthermore, the idea was not to take business away from irrigation consultants already active in the area (using SWB or other scheduling tools), but rather to focus on irrigators who were currently not applying any scientific scheduling methods.

Some board members expressed interest in irrigation calendars for farmers who are not interested in real-time scheduling. It was, therefore, decided that standard calendars would be generated for some cash crops, using popular cultivars as well as typical planting dates and soil data for the area. These standard calendars will be kept at the IB offices and distributed to interested irrigators. An example of one of these calendars for Loskop is given in Figure 7.4

IRRIGATION CALENDAR

Farmer:
Crop: MAIZE II
Field: LOSKOP001
Plant Date: 08/01/2007

Irrig System: Pivot
Management Option: Field capacity
Irrigation Frequency Option: Amount (mm)

Date & Day	Irrigation requirement (IR) (mm)	Rain since previous irrigation (mm)	Recom-mended Irrigation amount = IR - Rain *
2 Feb 2007, Fri	25		
9 Feb 2007, Fri	26		
13 Feb 2007, Tue	25		
17 Feb 2007, Sat	29		
21 Feb 2007, Wed	29		
25 Feb 2007, Sun	29		
1 Mar 2007, Thu	29		
5 Mar 2007, Mon	29		
9 Mar 2007, Fri	28		
13 Mar 2007, Tue	28		
17 Mar 2007, Sat	26		
21 Mar 2007, Wed	25		
25 Mar 2007, Sun	25		
30 Mar 2007, Fri	31		
4 Apr 2007, Wed	30		
9 Apr 2007, Mon	29		
14 Apr 2007, Sat	28		
19 Apr 2007, Thu	28		
24 Apr 2007, Tue	26		
29 Apr 2007, Sun	25		
2 May 2007, Wed	12		

*** Notes**

- Record rain and empty gauge just before irrigation.
- Subtract rainfall from irrigation requirement to obtain the Irrigation amount.
- If IR - rain < 0, then skip the irrigation, i.e. irrigation amount = 0.

Figure 7.4 Example of SWB Irrigation Calendar generated for maize on a sandy loam soil at Loskop.

7.3.4. Lower Sundays River Water User Association

Discussions with Lower Sundays River WUA board members took place during May 2007. The SWB Pro model was again demonstrated to the board and the benefits of using the model were highlighted. The meeting was also attended by a consultant that previously operated on the scheme, using SWB.
The attending board members were positive about the use of SWB as scheduling tool on the irrigation scheme, but were not sure how it should be implemented. At present the WUA does not have the capacity to render a scheduling service to its users without appointing a person or hiring in the services of an independent consultant. This person will have the duties of managing the weather data base and running the model at the WUA office on behalf of irrigators. As any of these actions will have financial implications, the matter was to be discussed at a next board meeting before a final decision could be made.
Apart from the real-time scheduling service, the WUA was particularly interested in Irrigation Calendars as starting point for irrigators who do not currently schedule at all, especially for those who plant cash crops. Standard calendars for some crops could be generated for distribution to interested irrigators. These will be generated for most popular cultivars, using typical planting dates and soil data for the area. Additionally, site-specific Irrigation Calendars could be generated on request by the appointed WUA staff member or consultant. These farmers could even later progress to the real-time use of SWB, once they have mastered the basic irrigation scheduling principles.

7.4. Conclusions

SWB is a real time, generic crop irrigation-scheduling model. The model was primarily designed as a tool to help irrigators manage their irrigation water. SWB can, however, also be used to generate site-specific Irrigation Calendars for use by farmers who are not interested in real-time irrigation scheduling.

At the onset of this project a number of improvements to SWB were identified as priority before any technology transfer actions could take place. These improvements were necessary in order to facilitate easy setting up and use of the model. These included changes to the database, creation of a single simplified simulation setup screen, inclusion of default soil types and scenario modelling for economic analysis. The weather database was also improved and populated with long-term weather data for almost 1000 weather stations in Southern Africa for use in scenario modelling and Irrigation Calendars. The improved version of the model was then released as SWB Pro.

Only three of the nine selected schemes, namely Loskop, Sunlands and Gamtoos initially indicated any interest in the use of SWB as a real-time scheduling tool. After the Jefferies Bay workshop in November 2006, the Vaalharts WUA also expressed interest in SWB. At the end of this technology transfer project the level of SWB Pro implementation differed vastly between the various WUAs and IBs. At Loskop, for instance, a decision was made to appoint a person who could run the model and assist farmers with irrigation management, while some of the other schemes were still in the process of deciding how a scheduling service should be approached and implemented. Loskop IB and Lower Sundays River WUA also indicated keen interest in Irrigation Calendars as an alternative to irrigators not currently ready for real-time scheduling.
Although the implementation of SWB Pro probably lags behind that of most other models in this project, it is still believed that the process will continue even after this project has officially come to an end. The project team is also committed to continue support to those WUAs and IBs who are interest in the use of the SWB model.

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8. THE TECHNOLOGY TRANSFER OF RISKMAN

8.1. Background

RISKMAN is a risk simulation model that enables a decision-maker to choose between risky alternatives. The model has its origin in the whole farm simulation model developed by Oosthuizen and Meiring (1996) which was developed to facilitate decision support at the whole farm level taking risk into account. The building block of the comprehensive risk simulation model is an embedded enterprise budget generator which requires a lot of data input. The need for a less data intensive model that is able to evaluate the risk efficiency of alternative management strategies was soon realised. The original model by Oosthuizen and Meiring (1996) was programmed into two separate decision support systems FARMS and RISKMAN (Meiring, Oosthuizen, Botha and Crous, 2002). FARMS is a deterministic (without risk) representation of the original decision support system while RISKMAN retained the functionality of the risk simulations. The main advantage of RISKMAN is that it is not as data intensive as FARMS. The technology transfer of the FARMS system was undertaken by Botha, Oosthuizen and Meiring (2005) and took the form of courses that were presented to agricultural advisors. RISKMAN also formed part of the models that were integrated with WAS to establish an integrated information management system for irrigation water management (Benadé, Annandale, Jovanovic, Meiring and Crous, 2002). Although SWB also formed part of the integrated information system the need for an explicit link between SWB and RISKMAN is motivated to enhance the use of these two models by water managers, agricultural advisors and farmers to evaluate the risk efficiency of alternative irrigation water use strategies. The importance of risk management is increasing due to increased price volatility changing government policies and the dynamic unstable environment in which farmers have to make their decisions. Risk management has to do with the identification of alternative management options, quantification of the risk associated with these management alternatives on key output variables and using the information to make decisions.

RISKMAN provides decision support through a budgeting model that will simulate the impact of alternative management options on net operating receipts and net farm income using readily available data contained in enterprise budgets. Sample enterprise budgets may be obtained from the National Department of Agriculture (COMBUD, 1999). Several methods can be used to characterise the risk associated with irrigation quantity, crop yield, price variability and interest rate fluctuations. A link is also developed that enable the user to use the data from the irrigation planning scenarios simulated with SWB to characterize irrigation quantity and crop yield variability. Output from the risk simulations is presented in a table and graphical format to enhance interpretation of the results. Ultimately the choice between the management alternatives is very personal and will necessarily vary from person to person due to the person's attitude towards risk. As a result it is very difficult to make universal recommendations with regard to the choice between alternatives. RISKMAN utilises subjective expected utility theory (Hardaker, Huirne and Anderson, 1997) to recommend alternative management actions for decision makers with varying degrees of risk aversion.

Previous efforts to transfer the technology imbedded in RISKMAN did not result in the model being as widely used as for instance SAPWAT. However, the model is widely used within the scientific community. Based on previous technology transfer efforts, discussions with farmers, agricultural advisors and researchers some new developments were made to RISKMAN during the project to enhance its functionality with the aim of increasing use. Next these developments will be discussed in some more detail.

8.2. RISKMAN improvements

Typically decision-makers perceive the risk management as complex and do not know how to interpret recommendations made by the stochastic dominance analyses. Furthermore choice of risk aversion levels to base the recommendations on is difficult to rationalise and discourage the users of the model. Recommendations in RISKMAN are based on stochastic dominance with respect to a function (Meyer, 1977) which is based on pair wise comparisons of all the alternative management actions that are simulated. Since results of all pair wise comparisons are reported and the necessity of the technique to evaluate all possible pairs makes the results cumbersome and difficult to interpret. Researchers also indicated that due to the way the Delphi version of RISKMAN was programmed, it is impossible to reproduce the same results for the same inputs which reduce the creditability of the model. As a result several modifications were made to RISKMAN.

8.2.1. Procedural changes

In this section the changes that were made to the procedures used in RISKMAN is discussed. In order for the model to be creditable it is important that the user is able to reproduce his results of his simulations when the same data set is used. Advances in literature also made it possible to replace recommendations made by stochastic dominance with respect to a function which are difficult to interpret with stochastic efficiency with respect to a function (SERF) (Hardaker, Richardson, Lien and Schumann). The SERF procedure is much more transparent and produces a complete ranking of risky alternatives without the need to do the analyses pair wise.
After some consideration it was felt by the team members that the procedural improvements to RISKMAN needed to be validated in Excel before programming it in Delphi. The development of an Excel version of RISKMAN was also stimulated by the fact that some end-users indicated that it would be easier to integrate RISKMAN with their datasets that are already in Excel. During the development of RISKMAN Excel it became clear that the users preferred the layout of RISKMAN and therefore the layout was maintained. Interesting though, is that the users preferred the Excel version since more information is shown on one sheet which makes the relation between different data inputs more explicit.
The random number generator developed by (Richardson, Schumann and Feldman, 2006) was used in RISKMAN Excel to conduct the risk simulations. The random number generator is seeded which means that it is possible to reproduce your output with the same inputs. In order to increase the interpretability of the risk analyses SERF was programmed in Excel. SERF recommendations are based on the maximisation of certainty equivalents. A certainty equivalent represents the maximum sure amount a decision-maker is willing to accept which will make him indifferent between accepting the sure amount and accepting the risk. Figure 1 shows the certainty equivalents calculated for 3 alternative crop rotations for decision-makers with varying degrees of risk aversion.

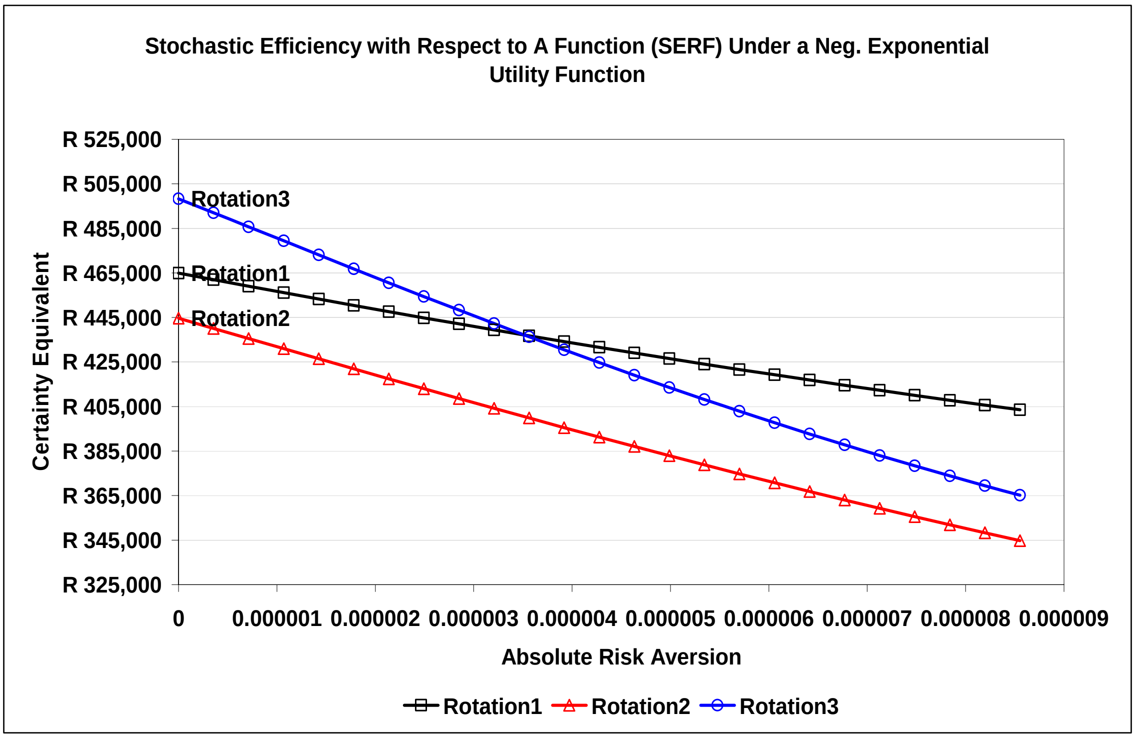

Figure 8.1 Sample output of the certainty equivalent graph used for determining the risk efficiency of alternative management options

The results indicates that rotation 2 will be least preferred by decision-makers since its certainty equivalent is lowest. The certainty equivalent lines of Rotation 1 and 2 crosses over which imply that some decision-makers will choose Rotation 1 and Rotation 3 by others. More specifically Rotation 1 will be the preferred option by more risk averse decision-makers and Rotation 3 by less risk averse decision-makers. The absolute risk aversion parameters used in the SERF analysis is based on the relative risk aversion of a decision-maker which typically varies between zero and four with a four indicating extreme risk averse behaviour (Hardaker *et al.*, 1997)

8.2.2. Linking RISKMAN with SWB

A specific objective of this project was the integrated technology transfer of RISKMAN and SWB. The project team responsible for the technology transfer of RISKMAN work closely with the team members responsible for the technology transfer of SWB to establish an integrated system to evaluate the risk efficiency of alternative irrigation management options. Firstly the RISKMAN team evaluated the available version of SWB. After the evaluation of the model it became clear that SWB was data intensive and that the model did not sufficiently allow for the simulation of pre-defined irrigation options. The model was subsequently improved to model the impact of alternative irrigation management options with historical weather data to quantify the production risk of each management alternative.

The link between SWB Pro and RISKMAN Excel can be described as loosely-coupled. SWB Pro is used to simulate the impact of alternative irrigation management options (quantities of water applied) on crop yield. The historically applied water and crop yields are exported to a CSV file format which is then imported into RISKMAN Excel. A macro was developed to facilitate data import and to automatically link it to the appropriate ranges in Excel. Functionality was also developed so that the user can run several scenarios in SWB before transferring the data to RISKMAN Excel.

8.3. Technology transfer actions

The technology transfer of RISKMAN Excel took place in conjunction with the technology transfer of SWB Pro at each of the interested WUA. The purpose of the joint technology transfer actions was to explicitly demonstrate the link between SWB Pro and RISKMAN Excel. Technology transfer actions took place at Vaalharts, Gamtoos, Loskop and the Lower Sundays River.

8.3.1. Vaalharts WUA

The first demonstration in Vaalharts was held early March 2007. The application of RISKMAN to evaluate the profitability of alternative irrigation scheduling strategies was shown to a young farmer who is also involved in assisting neighbouring farmers with scheduling. He indicated that he was very interested in using RISKMAN for planning purposes.
The second demonstration of RISKMAN in Vaalharts was during June 2007. It was held to the agronomist / agricultural economist of Senwes in Hartswater. He also forms part of a study group of farmers who meet on a regular basis. He is also busy developing computer models to assist those farmers who form part of the study group in decision making. He was very much interested in the use of RISKMAN for planning purposes and emphasised the importance of using information that is relevant to a specific farmer and not a group of farmers in order to do decision support. He argued that it will be easier to convince the farmers of the benefit of using RISKMAN if they can easily relate to the figures that are presented.

8.3.2. Gamtoos Water User Association

Gamtoos WUA was visited during the last week of March 2007. The demonstration was arranged to be held to WUA staff and other interested irrigators, however, only a limited number of farmers attended the technology transfer workshop. The attendants seemed interested in RISKMAN, however, their major concern was whether RISKMAN can also be employed in the case of permanent crops such as citrus. RISKMAN can also be used for permanent crops given that yield data is available for the alternative irrigation schedules.

8.3.3. Loskop Irrigation Board

The use of RISKMAN was demonstrated together with the use of SWB on 10 May 2007 to members of the Loskop Irrigation Board and some interested farmers. Some of the board members have more experience in using the original version of RISKMAN and were mostly concerned about the complexity of RISKMAN as a decision support system. The demonstration convinced them that the new Excel version is more users’ friendly, however, they felt that the application of the model is highly specialised. They expressed the need to thoroughly educate the person/consultant who will be responsible for using RISKMAN to assist farmers in their decision making process.

8.3.4. Lower Sundays River Water User Association

During May 2007 another demonstration was made to the Lower Sundays River WUA board members. Attendants were very much receptive to the use of RISKMAN to evaluate alternative irrigation schedules based on profitability. Attendants acknowledged that it may be an effective method to convince farmers to use water more efficiently if more efficient use of water may result in an increase in profit.

8.4. Conclusions

Within the course of the project the functionality of RISKMAN was increased and most significantly by the inclusion of procedures that are able to more clearly discriminate between risky alternatives. Most participants of the technology transfer actions acknowledge the importance of linking the economics and the risk inherent in agriculture to water use. However, they still perceive the application of RISKMAN as highly specialised. Most of the farmer participants lost interest in the model when they realise that they need to provide information regarding product price distributions and that the model is not forecasting product prices. Therefore the conclusion is that application of the model is hampered by the quantification of price risk. It is easier for farmers to control and predict possible outcomes of crop yield when compared to product prices.

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9. THE PROJECT EXIT STRATEGY

One of the key objectives of the project was to ensure the models would continue to be applied in a sustainable manner even after the completion of the study. This is a challenging objective since the history of similar technology transfer projects has illustrated that in reality most models have not been used sustainably after the completion of such projects. The research team examined some of the possible reasons as to why the models might not be used sustainably after the completion of the project. The key reasons that were identified include:

- The model/s forming part of the technology transfer project might not offer the users significant benefits to justify the continued use of the models after the technology transfer project completion. Initially the users may willingly participate in a technology transfer project in order to ascertain the benefits of the models, and the logistics of running the models independently.
- The models could possibly offer value to the end users, however the cost or expertise required to keep the model input data current (i.e. updated) over time might not be economically viable. This would result in the usage of the models being discontinued over time.
- It may be possible that the level of expertise required to drive the model/s may be too high for direct utilisation by the end-user. The preferred option may be for the end user of a specific model to employ the services of experienced consultants or the development specialists. However, the cost of the contracting the consultants or specialists would need to be acceptable when compared to the benefits associated with the service offered.

The research team then analysed the (i) current need for the TT models as well as (ii) the potential need for the models in the near future. It became clear that the current need for a few of the models associated with the TT project was very high, and once the models had been initially configured and the users had been trained, the probability for the models to be used sustainably after the completion of the project was very high. For some models, the user need is currently not high enough to immediately result in the sustained use of the model after the completion of the project. However, it is clear that the demand for the models is anticipated to grow substantially over the next few years, largely due to the completion of the Compulsory Licensing process in over-allocated catchments throughout South Africa. The compulsory licensing process results in the initial allocation of water use licenses. As many catchments are over-allocated, many existing water users, who are using water as "existing lawful users" as defined by the 1998 National Water Act, will have their entitlements curtailed (reduced) in order to bring the over-allocated catchments back into balance. Water will become a scarce resource, which will be very apparent to the water users. At this stage the benefits of the TT models will become very apparent, and it is anticipated that the models will be used to a far greater extent than is currently the case.

The question that then arises is, will the water users make use of the models themselves (i.e. directly), or will they make use of consultants or specialists, who then provide the users with the solutions they need. The latter business model is an outsource model, where the models are used indirectly by the water users, via expert consultants. The research team came to the conclusion that some of the TT models would probably be used directly by the water users (e.g. WAS and SAPWAT). However, the outsource model may be the preferred business model for many of the other models, largely due to the high level of skills required to operate the models well. From a business perspective, it may be more economical for the water users to contract the services of a consultant, than to employ a person who has the necessary skills to drive the models. This was an important observation since a number of the models forming part of the TT project have been developed by research organizations such as universities. It is often the case that although universities do offer expertise on a consulting basis, the researchers themselves often do not have time to promptly respond to the needs of the users. This observation, coupled with the feedback received when working with the WUAs and IBs participating in the project that some of the models were too academic in nature, and not easy to use, or not capable of providing outputs in the required format, resulted in a significant amount of model development.

Based on the above the following developments were undertaken to (i) ensure that the models did provide the information required by stakeholders, (ii) with the models being easier to set up and run, and (iii) for certain of the models better integrating with one another, and (iv) to ensure that the model outputs were in line with the needs of the users. The challenge that lies ahead to improve the working relationship between the developers of the model/s, and the persons who apply the models (either directly or indirectly), as it is plausible that as the user needs mature, further developments are requested to the model to either simplify the process of setting up the model, or to increase the functionality of the model. What complicates this relationship is that academic institutions may not be interested in cosmetic developments to their models (which may in fact be very important to the users of the models). There is often a danger that academic institutions include way too much complexity in the models, which makes the model unwieldy to use practically.

The strategy to include a GIS component in the project will also contribute to the models being used sustainably over time, for the reason being that GIS will only be of real benefit to the WUAs and IBs if the data contained in the GIS is kept current. Bear in mind that much of this data can be used to drive (in part) the models of the TT project. Having access to current data will facilitate the continued use of the models, either directly by the water users, or indirectly through consultants. The interest shown by the participating WUAs and IBs was very high, exceeding the expectations of the research team. Formal GIS training courses were held to train the participating WUAs and IBs in the use of the GIS, which were also well attended. The training was provided by GIS specialists, for the reason being that after the completion of the project, it would be possible for the participating WUAs and IBs to receive advice and support from the specialists.

When looking at the models that are currently being used most sustainably throughout South Africa, the WAS and SAPWAT models come to the fore. These models were initially developed in academic environments, but have since been further developed by consultants, who make it there business to support the software, and to continually develop the software to meet the users needs. In the course of the project ACRU, SWB and RISKMAN have been further developed to be more attractive to be used by consultants, and/or by the water users directly. As was mentioned before, the user needs for many of the models is anticipated to grow significantly over the next few years. It is hoped that the developments undertaken in the course of the project will promote the attainment of the objective for the models to be used sustainably (albeit directly or indirectly by the water users). The proof of the pudding is in the eating, and the attainment of the objective for the models to be used sustainably will need to be reviewed in a few years time.

User manuals have been developed for most of the models forming part of the TT project. User manuals for ACRU and for SAPWAT were not produced as both these models are currently being further developed as part of other WRC projects. The user manuals for the WAS, SWB-Pro, Weather Database, AAMG and RISKMAN models are downloadable off the World Wide Web, from the following sites:

Model	**Download from the URL:**
AAMG	www.cphwater.com
RISKMAN	University of the Free State
SWB-PRO	www.nbsystems.co.za
WAS	www.nbsystems.co.za
Weather Database	www.nbsystems.co.za

10. DISCUSSION AND CONCLUSIONS

The objective to successfully implement and technology transfer the ACRU, WAS, SAPWAT, SWB and RISKMAN models in an integrated manner to seven participant commercial irrigation schemes has been successfully achieved. None of the 7 participating WUAs and IBs showed an interest in all the models associated with the TT project, but in most cases high interest was shown in the use of a select few of the models. The GIS component of the project was very popular with the participating WUAs and IBs, which was of great benefit to the project, as the GIS formed the key source of input data for the respective models associated with the TT project.

The interaction between the research team and members of the participating WUAs and IBs resulted in a process of technology transfer (in other words a dual flow of information and capacity building). The research team began to appreciate some of the practical challenges faced by the WUAs and IBs, which often required integrated solutions (which were often beyond the scope of a single model associated with the TT project). The need for integrated decisions, as well as the call for the models to be more user-friendly, and better tailored for their user needs, resulted in a number of developments being undertaken to many of the models forming part of the TT project, including:

- The ACRU rainfall-runoff model was integrated with the MIKE BASIN node-and-channel network model, thereby unlocking functionality in both models. The integrated system lends itself to the testing of various licensing scenarios (e.g. landuse scenarios as well as operating rule scenarios), on the assurance of supply to various water users in catchments. This development may be of particular interest to water users in catchments that are currently over-allocated, or catchments that are approaching a state of being fully allocated. The Loskop Irrigation Board and the Irrigation Boards in the Mhlathuze Catchment are located in over-allocated catchments. As such the ACRU-MIKE BASIN combination of models was configured for these catchments, which can now be used by stakeholders to test various scenarios to address the over-allocation in the catchments.
- The SWB model was quite significantly further developed from an information technology point of view, in that the database was migrated from a paradox database, to a sequel database (Firebird). In addition to that, the front end to the model was significantly simplified, and via the use of pre-packaged soil and weather data for South Africa, the model is able to automatically configure the SWB for a default set-up, after the user has selected his/her area of interest. It is still possible for the user to tailor the model inputs, should the default data not be suitable. This development may seem cosmetic to outsiders, however, what it has enabled is an easier integration of SWB with WAS (as WAS also uses a SQL database).
- The SWB model has been renamed to the SWB-Pro model, which allows the new SQL version to be differentiated from the Paradox Database version. The SWB-Pro, pre-packed with historical weather data, is able to be used for planning purposes, as well as for real-time scheduling. With respect to the planning functionality of SWB-Pro, the model was further developed to generate various irrigation schedule scenarios automatically, the output of which is to be used by the RISKMAN model. The development of SWB-Pro to better integrate with RISKMAN has promoted the sustainability with which the model will used, as the developers of RISKMAN are very encouraged by this development, as it allows many complex irrigation scenarios to be configured and run very easily, which can then easily be fed into the RISKMAN model.
- The functionality of the WAS release module has been further developed in the course of the project in response to the user needs of the participant WUAs and IBs. A need for a new distribution sheet was identified at LORWUA and VHWUA and a need for a new type of water order form was identified at LSRWUA. The modified release modules were then configured

and installed for the respective WUAs & IBs showing an interest for this module, and the feedback received has been very favourable, with reports of significant improvements in the efficiency with which water is released in the canals. In the course of the project Dr Benade (the developer of WAS) was awarded an international award for improving water conservation in the irrigation field. In addition to the award, the Department of Water Affairs and Forestry have indicated that they would like WAS to be used as the standard software with which WUAs and Irrigation Boards prepare their disposal reports. Both these considerations will promote the sustained use of the model in time to come.

- The SAPWAT model was not further developed in the course of the TT project since another, independent, WRC project had been initiated for this very purpose.
- The RISKMAN model, which was originally coded in Delphi, has been migrated to an Excel version. The reason for this migration relates to the fact that farmers are more familiar and thus comfortable with Excel spreadsheets. The SWP-Pro was developed to generate outputs which can easily be read by the Excel version.

The respective models forming part of the project were technology transferred to those WUAs and IBs which showed a high level of interest in the use of the model/s. The research team configured and installed the models for which a high user need was indicated. Effect was given to the process of technology transfer in the form of personal on-site meetings, where the researcher responsible for the respective model show-cased the model (model inputs and outputs), and discussed various scenarios with the member/s of the WUA or IB. In certain cases the members of the IB / WUA requested amendments to be made to the model to better meet their user needs. This was done in most cases.

It is believed that the project has been a success, and that the technology transfer initiative will not be wasted. It is clear that the current demand for some of the models is higher than for others. However, the research team are of the opinion that the demand for all the models will continue to grow over time (quite significantly) due to the increasing scarcity of water in South Africa. It is anticipated that once the Compulsory Licensing process has been completed in the over-allocated catchments in South Africa, the scarcity of water will become far more apparent to water users, and the demand for the models forming part of the TT project will increase substantially. It is viable that the WUAs and IBs that formed part of the TT project will become islands of expertise in South Africa, which will provide valuable assistance to other WUAs and IBs. It is also very likely that the market for consultants, who have expertise in the use of the models, will grow over time. It is imperative that the research organisations foster healthy working relationships with the consultants, and with the end users, as it is likely that there will be a continual call for model improvements and amendments.

11. RECOMMENDATIONS

Some suggested recommendations that can be made include the following:

1. To further develop the ACRU – MIKE BASIN model combination to also include RISKMAN. The reasons for this are:
    a. The SWB-Pro is currently unable to simulate catchment operating rules. Operating rules impact on the quantity of water available to the water user, particularly when restrictions are imposed)
    b. The SWB-Pro is unable to simulate return-flows.
2. As many of our catchments are over-allocated, water resource managers will want to assess the hydro-economic impacts of various operating rules, and license allocation decisions on water users. The ACRU-MIKE BASIN linkage is a useful platform to work from. What is missing is the economic component, which is the RISKMAN model. The alternative will be to further develop the SWB-Pro model, but this may be significantly more complex than the option being tabled.
3. The SWB-Pro currently does not give any consideration to short-term rainfall forecasts. Ideally the model should be further developed to incorporate the use of short term rainfall forecasts, which may influence the scheduling advice generated from the model.
4. It is recommended that the WRC and/or DWAF provide funding to support a technical user support unit, which continues supporting the use of the models associated in the Technology Transfer project. Although the Technology Transfer project was successful, it targeted only 7 WUAs / IBs, which is a very small percentage of the total number of WUAs and IBs in the country. At some stage all water users will require assistance in the management of their water, be it a catchment scale, scheme scale, or field scale. An organisation such as erstwhile Computing Centre for Water Research (CCWR) would be a suitable organisation for this purpose.
5. A tool which can be added to GIS as an extension should be developed for assisting WUAs with canal maintenance. The GIS is very visual in facilitating an improved understanding of the issues to users.

12 APPENDIXES

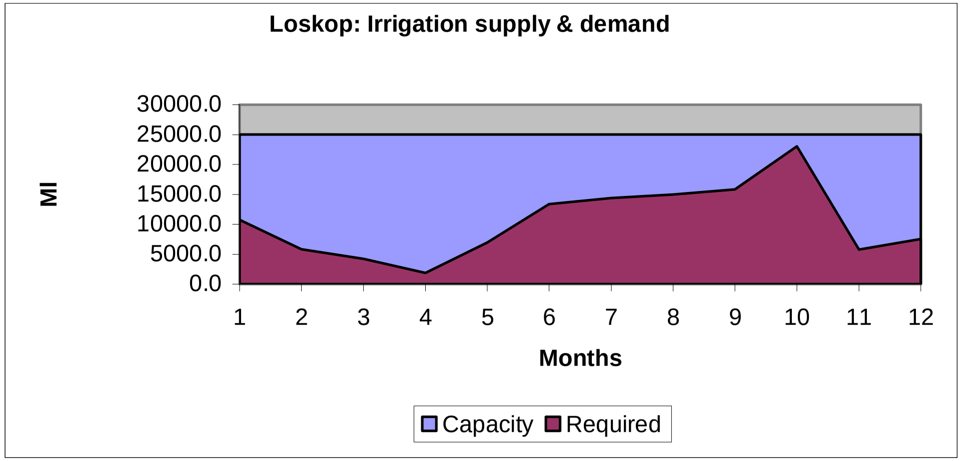
12.1 SAPWAT runs

The following tables indicate the crop, crop option, irrigation system, crop percentage in cropping pattern, area planted, as well as monthly and total irrigation requirements for the WUA irrigation areas of Loskop, Vaalharts, Orange-Riet, Gamtoos, Lower Sundays and Lower Olifants in Ml

LOSKOP

Crop		Irrigation	Land use		Megaliter													
CROP	CROP OPTION	SYSTEM	%	HA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Citrus	Average	Drip	16.6	4150	1037.5	1037.5	2075	1037.5	1037.5	2075	1037.5	2075	1037.5	2075	1037.5	1037.5	16600
Cotton	Medium growers	Centre Pivot	12	3000	2850	900	0	0	0	0	0	0	0	2250	1800	2250	10050
Cotton	Medium growers	Sprinkler - moveable	12	3000	4500	1500	0	0	0	0	0	0	0	1500	750	1500	9750
Grapes	Table Medium	Drip	4.3	1080	270	270	270	270	270	270	270	0	270	270	270	270	2970
Maize	Short grower Early plant	Centre Pivot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peaches	Long/late	Drip	0.1	30	7.5	7.5	7.5	0	7.5	7.5	7.5	0	7.5	7.5	7.5	7.5	75
Peas	General	Centre Pivot	2	500	0	0	0	0	250	500	625	250	0	0	0	0	1625
Peas	General	Sprinkler - moveable	2	500	0	0	0	0	250	375	750	250	0	0	0	0	1625
Peas	General	Centre Pivot	2	500	0	0	0	0	125	375	625	500	0	0	0	0	1625
Peas	General	Sprinkler - moveable	2	500	0	0	0	0	250	500	750	500	0	0	0	0	2000
Pecans	Estimate cover	Drip	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peppers	Spring plant	Centre Pivot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peppers	Spring plant	Sprinkler - moveable	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potato	Medium growers Autumn/Winter plant	Centre Pivot	1	250	0	0	0	0	187.5	375	375	412.5	125	0	0	0	1475
Potato	Medium growers Autumn/Winter plant	Sprinkler - moveable	1	250	0	0	0	0	187.5	500	500	625	125	0	0	0	1937.5
Potato	Medium growers Autumn/Winter plant	Centre Pivot	1	250	0	0	0	0	0	187.5	500	500	500	175	0	0	1862.5
Potato	Medium growers Autumn/Winter plant	Sprinkler - moveable	1	250	0	0	0	0	0	312.5	500	500	625	125	0	0	2062.5
Potato	Medium growers Autumn/Winter plant	Centre Pivot	1	250	0	0	0	0	0	0	312.5	550	612.5	500	62.5	0	2037.5
Potato	Medium growers Autumn/Winter plant	Sprinkler - moveable	1	250	0	0	0	0	0	0	187.5	500	625	500	125	0	1937.5
Soybeans	Medium	Centre Pivot	1	250	125	437.5	562.5	0	0	0	0	0	0	0	0	187.5	1312.5
Soybeans	Medium	Sprinkler - moveable	1	250	125	250	250	0	0	0	0	0	0	0	0	375	1000
Tobacco	All areas	Centre Pivot	1.7	413	0	0	0	0	0	0	0	0	516.25	413	413	516.25	1858.5

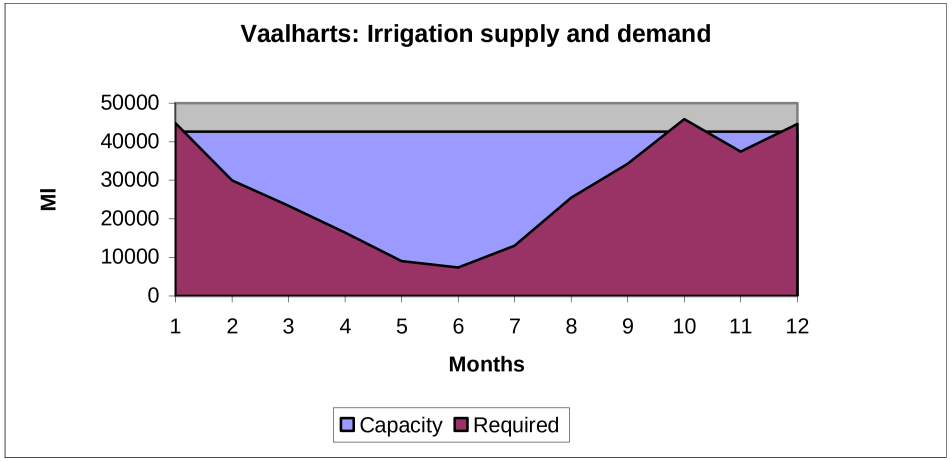
Tobacco	All areas	Sprinkler - moveable	1.6	412	0	0	0	0	0	0	0	0	1030	412	412	412	2266
Tobacco	All areas	Centre Pivot	1.7	413	289.1	495.6	103.25	0	0	0	0	0	0	0	206.5	82.6	1177.05
Tobacco	All areas	Sprinkler - moveable	1.6	412	267.8	412	206	0	0	0	0	0	0	0	123.6	61.8	1071.2
Vegetble	Summer	Centre Pivot	2.1	513	641.25	256.5	0	0	0	0	0	0	0	384.75	307.8	461.7	2052
Vegetble	Summer	Sprinkler - moveable	2	512	640	256	0	0	0	0	0	0	0	640	256	384	2176
Vegetble	Winter	Centre Pivot	2.1	513	0	0	384.75	307.8	461.7	641.25	513	513	0	0	0	0	2821.5
Vegetble	Winter	Sprinkler - moveable	2	512	0	0	384	256	640	1024	512	0	0	0	0	0	2816
Wheat	Plant 05/25	Centre Pivot	14	3500	0	0	0	0	1575	2800	3500	4375	5250	7000	0	0	24500
Wheat	Plant 05/25	Sprinkler - moveable	13.6	3400	0	0	0	0	1700	3400	3400	3400	5100	6800	0	0	23800
Total			103.4	25860	10753.15	5822.6	4243	1871.3	6941.7	13342.75	14365	14950.5	15823.75	23052.25	5771.4	7545.85	124483.25
Capacity					25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	0



VAALHARTS

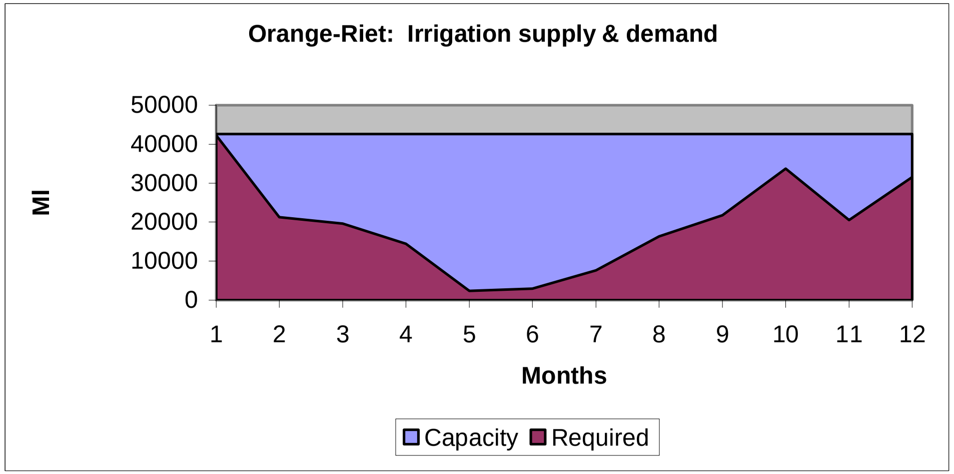
Crop		Irrigation		Land use							Megaliter					
CROP	CROP OPTION	SYSTEM	%	HA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Barley	Plant 06/05	Centre Pivot	2.2	525	0	0	0	0	0	262.5	262.5	656.25	525	1181.25	393.75	0	3281.25
Barley	Plant 06/05	Flood - channel supply	3.1	720	0	0	0	0	0	720	720	1800	1440	1800	360	0	6840
Citrus	Average	Drip	4.3	1005	1005	753.75	502.5	502.5	251.25	0	251.25	753.75	1256.25	1005	1005	1256.25	8542.5
Citrus	Average	Flood - channel supply	5.9	1380	2760	1380	1380	1380	1380	0	690	2070	2760	3450	2760	3450	23460
Cotton	Medium growers	Centre Pivot	2.6	615	768.75	615	615	0	0	0	0	0	0	307.5	461.25	615	3382.5
Cotton	Medium growers	Flood - channel supply	4.4	1020	2550	2040	1530	510	0	0	0	0	0	1020	1530	2040	11220
Grapes	Wine Medium	Flood - channel supply	4.9	1140	1710	570	570	570	0	0	0	1140	1140	2280	1710	2280	11970
Groundnt	Standard	Centre Pivot	2.8	645	1612.5	1451.25	645	0	0	0	0	0	0	322.5	967.5	1773.75	6772.5
Groundnt	Standard	Flood - channel supply	4.4	1020	2040	2040	2040	0	0	0	0	0	0	510	1530	2550	10710
Groundnt	Standard	Centre Pivot	2.6	603	753.75	603	603	603	301.5	0	0	0	0	0	0	301.5	3165.75
Groundnt	Standard	Flood - channel supply	3.3	780	1950	1560	1560	1560	780	0	0	0	0	0	0	780	8190
Lucerne	Semi-dormant	Centre Pivot	4.6	1065	0	0	0	0	0	532.5	798.75	1065	1331.25	2396.25	798.75	0	6922.5
Lucerne	Semi-dormant	Flood - channel supply	6.4	1500	0	0	0	0	0	1500	2250	3000	3750	3000	1500	0	15000
Maize	Short grower Early plant	Centre Pivot	2.4	570	1425	855	0	0	0	0	0	0	0	285	997.5	1425	4987.5
Maize	Short grower Early plant	Flood - channel supply	3.6	840	1680	1260	0	0	0	0	0	0	0	840	1680	2100	7560
Maize	Short grower Late plant	Centre Pivot	1.7	405	405	405	506.25	202.5	0	0	0	0	0	0	0	303.75	1822.5
Maize	Short grower Late plant	Flood - channel supply	2.6	600	900	1200	1500	600	0	0	0	0	0	0	0	600	4800
Olives	Estimate cover	Flood - channel supply	6.2	1440	4320	2880	2160	1440	1440	0	0	720	2160	2880	2880	4320	25200
Peas	General	Centre Pivot	1.5	350	0	0	0	437.5	175	175	87.5	0	0	0	0	0	875
Peas	General	Flood - channel supply	3.1	720	0	0	0	720	720	720	360	0	0	0	0	0	2520
Plums	Medium	Micro	4.1	963	1444.5	481.5	240.75	240.75	0	0	0	481.5	963	1444.5	1685.25	1685.25	8667
Wheat	Plant 06/15	Centre Pivot	2.5	585	0	0	0	0	0	438.75	585	585	731.25	877.5	585	0	3802.5
Wheat	Plant 06/15	Flood - channel supply	3.6	840	0	0	0	0	0	420	840	1680	2100	1680	840	0	7560
Barley	Plant 06/05	Centre Pivot	6.8	465	0	0	0	0	0	465	465	581.25	465	1046.25	348.75	0	3371.25
Barley	Plant 06/05	Flood - channel supply	10.6	720	0	0	0	0	0	720	1440	1800	1440	3240	1080	0	9720
Grapes	Wine Medium	Drip	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grapes	Wine Medium	Flood - channel supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundnt	Standard	Centre Pivot	7.5	510	637.5	510	510	1020	510	0	0	0	0	0	0	255	3442.5
Groundnt	Standard	Flood - channel supply	11.5	780	1950	1560	1560	1560	780	0	0	0	0	0	0	1560	8970

Lucerne	Semi-dormant	Centre Pivot	15.9	1080	1890	810	810	540	540	0	540	1080	1620	1890	1620	1890	13230
Lucerne	Semi-dormant	Flood - channel supply	22.1	1500	3750	2250	1500	1500	750	0	0	2250	2250	3750	3750	3750	25500
Maize	Short grower Late plant	Centre Pivot	5.3	360	360	810	900	270	0	0	0	0	0	0	0	270	2610
Maize	Short grower Late plant	Flood - channel supply	7.9	540	810	1080	1350	540	0	0	0	0	0	0	0	540	4320
Olives	Estimate cover	Flood - channel supply	21.2	1440	4320	2880	2160	1440	1440	0	0	720	2160	2880	2880	4320	25200
Pecans	Estimate cover	Flood - channel supply	22.1	1500	4500	1500	750	750	0	750	1500	1500	3750	5250	4500	5250	30000
Pecans	Estimate cover	Micro	12.6	855	1282.5	427.5	0	0	0	0	213.75	641.25	1068.75	1282.5	1496.25	1282.5	7695
Wheat	Plant 06/15	Centre Pivot	8.2	555	0	0	0	0	0	277.5	416.25	1387.5	1387.5	416.25	0	0	3885
Wheat	Plant 06/15	Flood - channel supply	11.5	780	0	0	0	0	0	390	1560	1560	1950	780	0	0	6240
Total			246	30416	44824.5	29922	23392.5	16386.25	9067.75	7371.25	12980	25471.5	34248	45814.5	37359	44598	331435.25
Capacity					42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	0



ORANGE-RIET

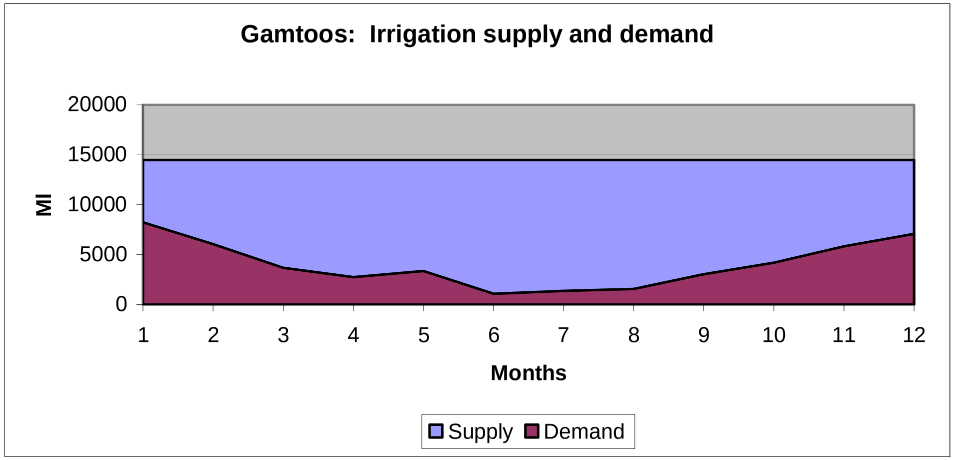
Crop		Irrigation		Land use							Megaliter						
CROP	CROP OPTION	SYSTEM	%	HA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
BeansBus	Dry Short	Centre Pivot	1.4	303	151.5	606	378.75	0	0	0	0	0	0	0	0	0	1136.25
Cotton	Medium growers	Centre Pivot	0.2	52	143	104	65	13	0	0	0	0	0	13	26	52	416
Cotton	Medium growers	Flood - channel supply	0.1	26	104	91	52	13	0	0	0	0	0	13	26	39	338
Fescue	Standard	Centre Pivot	1.5	317	713.25	475.5	396.25	317	317	0	158.5	317	475.5	634	634	713.25	5151.25
Fescue	Standard	Flood - channel supply	0.5	105	420	210	210	157.5	157.5	0	105	157.5	262.5	262.5	367.5	315	2625
Grapes	Wine Medium	Drip	1.7	358	268.5	179	89.5	0	0	0	0	0	0	179	268.5	268.5	1253
Groundnt	Standard	Centre Pivot	1.4	289	939.25	505.75	433.5	0	0	0	0	0	0	72.25	216.75	722.5	2890
Lucerne	Semi-dormant	Centre Pivot	7.1	1483	3707.5	1853.75	1112.25	1112.25	1112.25	0	741.5	1483	1853.75	2595.25	2595.25	2966	21132.75
Lucerne	Semi-dormant	Flood - channel supply	3.5	741	2593.5	1482	1111.5	741	741	0	741	1111.5	1482	1852.5	2223	2223	16302
Maize	Short grower Early plant	Centre Pivot	22.3	4690	15242.5	3517.5	0	0	0	0	0	0	0	1172.5	3517.5	12897.5	36347.5
Maize	Short grower Early plant	Flood - channel supply	11.2	2345	11725	3517.5	0	0	0	0	0	0	0	1172.5	3517.5	9380	29312.5
Maize	Short grower Late plant	Centre Pivot	22.3	4690	2345	4690	8207.5	7035	0	0	0	0	0	0	0	0	22277.5
Maize	Short grower Late plant	Flood - channel supply	11.2	2345	2345	3517.5	7035	4690	0	0	0	0	0	0	0	0	17587.5
Olives	Estimate cover	Drip	0.1	16	24	16	12	8	4	0	0	0	0	0	8	20	92
Onion	Seeded	Centre Pivot	0.3	68	0	0	85	68	68	34	68	85	17	0	0	0	425
Peaches	Short/early	Drip	0.1	12	18	12	9	9	3	3	0	0	3	9	15	18	99
Pecans	Estimate cover	Drip	0.4	78	117	58.5	0	0	0	0	0	0	78	97.5	117	136.5	604.5
Potato	Medium growers Spring plant	Centre Pivot	1.7	366	549	0	0	0	0	0	0	0	0	549	915	1098	3111
Sunflwer	Standard	Centre Pivot	0.6	131	65.5	98.25	229.25	163.75	0	0	0	0	0	0	0	0	556.75
Sunflwer	Standard	Flood - channel supply	0.3	65	65	97.5	162.5	130	0	0	0	0	0	0	0	0	455
Vegetble	Summer	Centre Pivot	1.3	273	750.75	204.75	0	0	0	0	0	0	0	204.75	204.75	682.5	2047.5
Wheat	Plant 06/05	Centre Pivot	27.9	5856	0	0	0	0	0	1464	2928	7320	10248	14640	2928	0	39528
Wheat	Plant 06/05	Flood - channel supply	13.9	2928	0	0	0	0	0	1464	2928	5856	7320	10248	2928	0	30744
Total			131	27537	42287.25	21236.5	19589	14457.5	2402.75	2965	7670	16330	21739.75	33714.75	20507.75	31531.75	234432
Capacity					42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	42595.56	0


Orange-Riet: Irrigation supply & demand
Ml
50000
40000
30000
20000
10000
0
1 2 3 4 5 6 7 8 9 10 11 12
Months
Capacity
Required

GAMTOOS

Crop		Irrigation	Land use								Megaliter						
CROP	CROP OPTION	SYSTEM	%	HA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
BeansBus	Dry Short	Centre Pivot		3	0	0.75	1.5	3	1.5	0	0	0	0	0	0	0	6.75
BeansBus	Green	Centre Pivot	1.3	132	33	99	132	0	0	0	0	0	0	0	0	0	264
BeansBus	Green	Centre Pivot	0.9	87	0	0	0	0	0	0	0	0	0	21.75	65.25	152.25	239.25
Beetroot	Summer crop	Centre Pivot	0.3	26	6.5	19.5	32.5	6.5	0	0	0	0	0	0	0	0	65
Beetroot	Summer crop	Centre Pivot	0.2	21	0	0	0	0	0	0	0	15.75	26.25	31.5	5.25	0	78.75
Beetroot	Summer crop	Centre Pivot	0.4	39	9.75	0	0	0	0	0	0	0	0	9.75	29.25	87.75	136.5
Beetroot	Winter crop	Centre Pivot	0.4	37	0	0	9.25	9.25	27.75	9.25	0	0	0	0	0	0	55.5
Broccoli	Main Autumn plant	Centre Pivot	0.1	13	0	0	0	3.25	9.75	6.5	3.25	0	0	0	0	0	22.75
Broccoli	Main Spring plant	Centre Pivot		3	0	0	0	0	0	0	0	0	0	1.5	4.5	5.25	11.25
Broccoli	Main Summer plant	Micro	0.1	13	0	6.5	6.5	9.75	3.25	0	0	0	0	0	0	0	26
Broccoli	Main Winter plant	Centre Pivot		3	0	0	0	0	0	0	0.75	2.25	3.75	1.5	0	0	8.25
Cabbage	Early Autumn plant	Centre Pivot	1.2	123	0	0	0	30.75	61.5	61.5	61.5	0	0	0	0	0	215.25
Cabbage	Early Spring plant	Centre Pivot	1.1	105	52.5	0	0	0	0	0	0	0	0	26.25	78.75	210	367.5
Cabbage	Early Summer plant	Centre Pivot	1.1	105	0	26.25	78.75	78.75	26.25	0	0	0	0	0	0	0	210
Cabbage	Early Winter plant	Centre Pivot	1.2	123	0	0	0	0	0	0	30.75	61.5	153.75	61.5	0	0	307.5
Carrots	Autumn plant	Centre Pivot	1.9	189	0	0	0	47.25	141.75	94.5	94.5	47.25	0	0	0	0	425.25
Carrots	Spring plant	Centre Pivot	1.6	163	203.75	0	0	0	0	0	0	0	0	81.5	163	285.25	733.5
Carrots	Summer plant	Centre Pivot	1.7	173	0	86.5	129.75	129.75	86.5	0	0	0	0	0	0	0	432.5
Carrots	Winter plant	Centre Pivot	1.7	165	0	0	0	0	0	0	41.25	123.75	123.75	206.25	82.5	0	577.5
Cauliflr	Main Autumn plant	Centre Pivot	0.8	82	0	0	0	61.5	82	20.5	82	41	0	0	0	0	287
Cauliflr	Main Spring plant	Centre Pivot	0.1	6	9	0	0	0	0	0	0	0	0	6	10.5	10.5	36
Cauliflr	Main Summer plant	Centre Pivot	0.3	26	0	19.5	39	13	26	6.5	0	0	0	0	0	0	104
Cauliflr	Main Winter plant	Centre Pivot	0.2	16	0	0	0	0	0	0	12	16	16	24	12	0	80
Chicory	Autumn plant	Centre Pivot	0.1	12	6	0	0	3	6	0	0	9	15	15	18	18	90
Chicory	Spring plant	Centre Pivot	1.1	110	165	192.5	165	110	82.5	55	27.5	0	0	27.5	82.5	55	962.5
Citrus	Average	Drip	22.5	2250	2250	1125	562.5	562.5	562.5	0	0	0	562.5	562.5	1125	1687.5	9000
Cucurbit	Spring plant	Centre Pivot	1.3	134	234.5	167.5	0	0	0	0	0	0	0	67	67	201	737
Cucurbit	Summer plant	Centre Pivot	1.8	183	0	45.75	137.25	91.5	137.25	91.5	0	0	0	0	0	0	503.25
Cucurbit	Winter plant	Centre Pivot	1.3	128	0	0	0	0	0	0	0	64	96	96	192	160	608

Fescue	Standard	Centre Pivot	7.2	720	1260	1080	720	540	540	0	0	180	720	720	1080	1260	8100
Lettuce	Summer Crop	Centre Pivot	0.4	42	0	0	0	0	0	0	21	31.5	52.5	52.5	0	0	157.5
Lettuce	Summer Crop	Centre Pivot	0.4	42	73.5	0	0	0	0	0	0	0	0	31.5	63	73.5	241.5
Lettuce	Winter Crop	Centre Pivot	0.4	42	31.5	52.5	63	31.5	0	0	0	0	0	0	0	0	178.5
Lettuce	Winter Crop	Centre Pivot	0.4	42	0	0	0	21	31.5	31.5	31.5	0	0	0	0	0	115.5
Lucerne	Semi-dormant	Centre Pivot	4.1	405	708.75	506.25	405	101.25	202.5	0	0	101.25	303.75	405	506.25	607.5	3847.5
Maize	Short grower Early plant	Centre Pivot	6.9	685	1712.5	1370	342.5	0	0	0	0	0	0	0	342.5	685	4452.5
Pastsum	Annual (grazing)	Centre Pivot	0.7	65	113.75	65	65	0	0	0	0	0	0	16.25	16.25	97.5	373.75
Peaches	Long/late	Drip	0.3	30	37.5	22.5	7.5	0	0	0	0	0	0	15	30	45	157.5
Potato	Medium growers Autumn/Winter p	Centre Pivot	10.8	1074	0	0	0	268.5	805.5	537	805.5	537	0	0	0	0	2953.5
Potato	Medium growers Spring plant	Centre Pivot	5.2	524	0	0	0	0	0	0	0	0	262	655	1179	917	3013
Potato	Medium growers Summer plant	Centre Pivot	5.2	524	0	131	393	524	524	0	0	0	0	0	0	0	1572
Swtcorn	Main Spring plant	Centre Pivot	1.1	106	0	0	0	0	0	0	0	0	26.5	53	185.5	132.5	397.5
Swtcorn	Main Spring plant	Centre Pivot	0.6	56	126	70	0	0	0	0	0	0	0	0	14	56	266
Swtptato	Summer	Centre Pivot	1.7	165	371.25	330	206.25	82.5	0	0	0	0	0	0	41.25	41.25	1072.5
Tobacco	All areas	Centre Pivot	3.7	370	832.5	647.5	185	0	0	0	0	0	0	0	92.5	277.5	2035
Tomatoes	Table Autumn/Winter plant	Centre Pivot	0.1	6	10.5	0	0	0	0	0	0	3	6	6	10.5	15	51
Tomatoes	Table Spring/Summer plant	Centre Pivot	0.2	16	0	8	12	12	12	12	12	0	0	0	0	0	68
Wheat	Plant 06/05	Centre Pivot	6.7	670	0	0	0	0	0	167.5	167.5	335	670	1005	335	0	2680
Totals			100.8	10054	8247.75	6071.5	3693.25	2740.5	3370	1093.25	1391	1568.25	3037.75	4198.75	5831.25	7080.25	48323.5
Capacity					14493.6	14493.6	14493.6	14493.6	14493.6	14493.6	14493.6	14493.6	14493.6	14493.6	14493.6	14493.6	0


Gamtoos: Irrigation supply and demand
Ml
20000
15000
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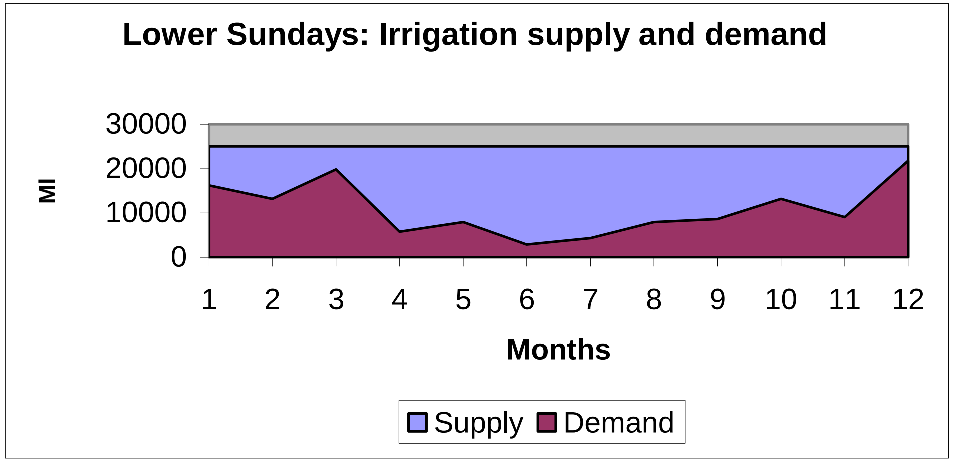
11
12
Months
Supply
Demand

LOWER SUNDAYS

Crop		Irrigation	Land use							Megaliter							
CROP	CROP OPTION	SYSTEM	%	HA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Citrus	Average	Drip	82.3	13950	9792.9	9290.7	16223.85	3557.25	6417	2580.75	3878.1	5524.2	6347.25	9611.55	5635.8	16586.55	95445.9
Lucerne	Semi-dormant	Sprinkler - moveable	12.2	2061	5152.5	3091.5	3091.5	2061	1030.5	0	0	2061	2061	3091.5	3091.5	4122	28854
Maize	Short grower Late plant	Sprinkler - moveable	0.9	155	232.5	348.75	348.75	116.25	0	0	0	0	0	0	0	116.25	1162.5
Potato	Medium growers Spring plant	Sprinkler - moveable	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vegetble	Summer	Sprinkler - moveable	2.2	374	1028.5	467.5	0	0	0	0	0	0	0	187	280.5	935	2898.5
Vegetble	Winter	Sprinkler - moveable	2.1	363	0	0	181.5	0	453.75	272.25	272.25	272.25	0	0	0	0	1452
Wheat	Plant 06/15	Sprinkler - moveable	0.8	140	0	0	0	0	0	0	210	105	210	315	105	0	945
Totals			100.5	17043	16206.4	13198.45	19845.6	5734.5	7901.25	2853	4360.35	7962.45	8618.25	13205.05	9112.8	21759.8	130757.9
Capacity					25024.837	25024.837	25024.837	25024.837	25024.837	25024.837	25024.837	25024.837	25024.837	25024.837	25024.837	25024.837	0



LOWER OLIFANTS

Crop		Irrigation	Land use								Megaliter						
CROP	CROP OPTION	SYSTEM	%	HA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Citrus	Average	Drip	31.2	3341.52	5012.28	4176.9	4176.9	1670.76	1670.76	0	0	835.38	2506.14	3341.52	4176.9	5012.28	32579.82
Cucurbit	Spring plant	Drip	0.9	96.39	216.8775	168.6825	24.0975	0	0	0	0	0	0	0	120.4875	144.585	674.73
Cucurbit	Spring plant	Flood - channel supply	0.9	96.39	433.755	337.365	48.195	0	0	0	0	0	0	0	240.975	289.17	1349.46
Cucurbit	Spring plant	Sprinkler - moveable	0.9	96.39	289.17	240.975	48.195	0	0	0	0	0	0	0	240.975	240.975	1060.29
Grapes	Wine Medium	Drip	63.5	6800	10200	6800	6800	0	0	0	0	0	0	3400	6800	8500	42500
Grapes	Wine Medium	Flood - channel supply	10.6	1135.26	2838.15	2838.15	1702.89	567.63	0	0	0	0	0	1135.26	2270.52	2838.15	14190.75
Onion	Trnsplnt Autumn	Drip	0.4	42.84	0	0	0	0	21.42	32.13	21.42	42.84	53.55	32.13	0	0	203.49
Onion	Trnsplnt Autumn	Flood - channel supply	0.4	42.84	0	0	0	0	85.68	42.84	64.26	85.68	107.1	64.26	0	0	449.82
Tomatoes	Canning Early Spring plant	Drip	2.8	299.88	824.67	449.82	0	0	0	0	0	0	0	0	299.88	749.7	2324.07
Tomatoes	Canning Early Spring plant	Flood - channel supply	1.2	128.52	706.86	449.82	0	0	0	0	0	0	0	0	321.3	578.34	2056.32
Tomatoes	Table Spring/Summer plant	Drip	2.8	299.88	674.73	749.7	599.76	0	0	0	0	0	0	0	374.85	449.82	2848.86
Tomatoes	Table Spring/Summer plant	Flood - channel supply	1.2	128.52	578.34	578.34	514.08	0	0	0	0	0	0	0	385.56	449.82	2506.14
Totals			116.8	12508.43	21774.8325	16789.7525	13914.1175	2238.39	1777.86	74.97	85.68	963.9	2666.79	7973.17	15231.4475	19252.84	102743.75
Capacity					19398	19398	19398	19398	19398	19398	19398	19398	19398	19398	19398	19398	0