An assessment of the economic water use efficiency and productivity of the upstream and downstream catchments' agricultural production, South Africa

A case study of the Baviaanskloof and Gamtoos Valley, Eastern Cape, South Africa

M.Sc. Thesis by Annah Ndeketeya

June 2012

Irrigation and Water Engineering Group

WAGENINGEN UNIVERSITY
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Master thesis Irrigation and Water Engineering submitted in partial fulfillment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands

Annah Ndeketeya

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Supervisors:

Dr.ir. Gerardo van Halsema
Irrigation and Water Engineering Group
Wageningen University
The Netherlands
www.iwe.wur.nl/uk

Odirilwe Selomane
Living Lands
Eastern Cape
South Africa
www.earthcollective.net/livinglands

Facilitated by:
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Abstract

Water scarcity is a problem that is threatening the world and pressure is growing for the agricultural sector to cut its water use. This has given rise to the interest in water use and efficiency in water management studies. With the aim of assessing the productivity of Baviaanskloof valley after serious land degradation, a study was carried out to determine the economic and physical water use efficiency for the year 2010 and the results were compared to the downstream catchment, the Gamtoos Valley. Water productivity for the year 2011 was also calculated for the Baviaanskloof using actual crop water use from Cropwat simulation. Data was collected from November 2011 up to February 2012. Interview with farmers and personnel from the Gamtoos Irrigation Board (GIB) were done to get information on water use, crops cultivated, yields, prices, costs and cropping seasons. In some cases the bucket method was used to validate the figures on water use obtained from the farmers. Using irrigation data on use from farmers and other soil, crop and weather parameters from the Agricultural Research Council the Cropwat model was run to simulate the actual crop water use and to determine the amount of over/under irrigation. All the raw data was then analyzed using the formulas': eWUE= net income/total water use, WUE=yield/total water use, WP=Yield/ actual water use. Comparisons were made per catchment from plot level to farm level then at basin level. Some differences were noticed among farmers and the reasons varied from yield, water use and net income. Major differences were noticed between the two catchments. The eWUE was 1.99 and 6.81R/m^3 for Baviaanskloof and Gamtoos respectively. For the common crops maize and potatoes the eWUE was higher again for Gamtoos than for Baviaanskloof: for potatoes it was mainly because of low yields (10t/ha) compared to 35t/ha from Gamtoos whilst in maize it was due to high water use of about 1200mm used by the Baviaanskloof farmers whereas the other farmers used only 420mm. The water productivity was higher than the WUE for the Baviaanskloof for most crops. The range between WP and WUE was huge for maize, potato, wheat and tobacco whilst it was slight for the seed vegetables. This shows there is a lot of room for improvement. From the results the recommendation is for farmers to focus more on high value crops. The results also showed that the total amount of water currently used for crop production is enough to irrigate approximately 271 hectares of citrus hence it is feasible for farmers to change to citrus production from a water availability standpoint. However, strong organisation and linkages especially with downstream farmers and GIB are needed to improve the agricultural practices in the upstream area. Further exploration still needs to be done to see what other land use options can be adopted in the area and the costs and benefits.

Key Words: economic WUE, physical WUE, water productivity, Cropwat simulation

Table of Contents

List of Figures

List of Tables

Acronyms

ARC	Agricultural Research Council
DWAF	Department of Water Affairs
Eta	actual Evapotranspiration
ETo	reference Evapotranspiration
eWUE	economic Water Use Efficiency
FAO	Food and Agriculture Organisation
GIB	Gamtoos Irrigation Board
NMM	Nelson Mandela Municipality
PRD	Partial Root zone Drying
PRESENCE	Participatory Restoration of Ecosystem SErvices & Natural Capital in the Eastern Cape
RAM	Readily Available moisture
RDI	Regulated Deficit Irrigation
TAM	Total Available moisture
WUA	Water Users Association
WUE	Water Use Efficiency
WP	Water Productivity

CHAPTER 1: INTRODUCTION

Water scarcity is becoming a major problem in many areas, thereby threatening agricultural production and livelihoods. With the issue of climate change it is anticipated that the problem of water shortage will increase in the future. (Sakthivadivel and Makin 2003) estimated that by 2020 approximately 75% of the world's population will live in areas experiencing physical or economic water scarcity. Agriculture being the main user of fresh water resources, it is a challenge for the sector to derive better measures of making efficient use of the available resources. This problem of water has also resulted in a lot pressure in the agricultural sector to increase water use efficiency. Some studies also emphasise increasing water productivity (A. H. Kassam . 2007). However, this is difficult to measure due to the complications in determining actual evapotranspiration (Eta). It is difficult to reliably measure or estimate all the components of the water balance in order to solve it for Eta.

This study was carried out from November 2011 to February 2012, to compare the eWUE between the upstream and downstream of a semi- arid area in South Africa. The findings of the study can provide a baseline to explore opportunities for increasing system-wide WUE and WP to avoid water scarcity and maintain livelihoods in the areas.

Water use efficiency (WUE) is a broad concept that can be defined in many ways. It can be defined as the yield of harvested crop product achieved from the water available to the crop through rainfall, irrigation and the contribution of soil water storage. This research considered only irrigation water applied as input for the calculation of WUE. Improving WUE in agriculture will require an increase in crop water productivity (an increase in marketable crop yield per unit of water removed by plant) and a reduction in water losses from the plant rooting zone of the soil, a critical zone where adequate storage of moisture and nutrients are required for optimizing crop production (FAO 2008).

Water productivity is used exclusively to denote the amount or value of product over volume or value of water used for plant growth or transpiration. One common approach is the 'crop per drop' which focuses on the amount of product per unit of water. The key principles of improving water productivity are to: (i) increase the marketable yield of the crop for each unit of water transpired by it; (ii) reduce all outflows (e.g. drainage, seepage and percolation), including evaporative outflows other than the crop stomatal transpiration; and (iii) increase the effective use of rainfall, stored water, and water of marginal quality (FAO 2003)

Both water productivity and WUE may be assessed in different ways, like physical WUE/ productivity whereby you use yield biomass as a numerator, nutritional WUE/ productivity and economic WUE/ productivity. This study will focus on economic water use efficiency which looks at the income (Yield * unit price) obtained per water consumed.

There is confusion in many studies between Water Use Efficiency (WUE) and Water Productivity (WP). In some studies they refer to WUEcrop and WUE_{ET} and these definitions should equate to WP (production/ Eta). This however brings a lot of difficulty in differentiating the two. In their paper (Gerardo E. van Halsema 2011) argued that it is 'better to reserve the concept of WP as a measure of productivity of the crop physiological process of biomass production and yield formation related to *actual water consumption* and use WUE for any measurement of *gross water application* that can be accounted for'. Therefore in this study, the gross water applications shall be used in determining WUE and actual crop water use for WP.

In an effort to meet the above principles of improving water productivity, many studies of water productivity are being done all over the world. (Enrique Playa´n 2006) did a study in Spain to come up with modernisation ways and optimisation of irrigation systems so as to increase productivity. More studies have been done on assessing crop productivity for different crops.

1.1 Background to the study

This study was commissioned by Living Lands a South African Not-for-Profit -Organisation with the vision of reversing degradation and guiding the restoration of 'living landscapes'. The organisation operates within the PRESENCE (Participatory Restoration of Ecosystem SErvices & Natural Capital in the Eastern Cape) which is a collaborative learning network aimed at guiding regional ecosystem management and the restoration of 'living landscapes'. As the secretariat and coordinator, Living Lands mainly facilitate and set up the PRESENCE network.

For the past years, it has been coordinating the Water for Food and Ecosystems (WFE) project in the Baviaanskloof area. The Baviaanskloof is the major water catchment in the Eastern Cape (Foundation 2012) and it supplies agricultural water to the Gamtoos valley and Kouga Dam which supplies drinking water to the Nelson Mandela Municipality. The area is facing various land and water problems which have had detrimental effects on agriculture. From previous studies and activities carried under the WFE programme, it has been discovered that farmers across the BMR are increasingly facing economic hardship, and consequently placing greater pressure on the limited natural resources utilised for conventional farming practices. These have led to, and will continue to lead to, expanding land degradation. As a result, the organisation is exploring the option of developing a PES market in the Baviaanskloof such that farmers choosing to reduce their water use can be assisted in the transition to other activities through payments from downstream farmers for the water services.

This research was carried out in the Baviaanskloof and the downstream Gamtoos valleys in South Africa.

1.1.1 Baviaanskloof Valley

The Baviaanskloof is a 75 km long valley between two mountain ranges in the Eastern Cape Province (South Africa). The area is a biodiversity hotspot and recognised as a unique World Heritage Site because of its beauty and biodiversity which has global importance (Jansen 2008). The average annual rainfall is about 300mm and is temporal and very erratic. The largest area, 60% is used as nature reserve and the other portion for agriculture and small settlements. Most of the Western Baviaanskloof is owned by 12 private farmers and typical farm sizes are between 1000 and 3000 ha. The main agricultural activity is livestock production of which the most common are goats and sheep, and ostrich to a lesser extent. For the small irrigated portion, the main crops are maize, onion- and carrot seeds, and alfalfa and groundwater is used.

1.1.2 Gamtoos Valley

The Gamtoos Valley falls within Kouga Local Municipality in the Cacadu District Municipality. It is a continuation of the Baviaanskloof valley downstream of the Kouga Catchment and lies between the parallel east-west running Baviaanskloof Mountains and lies south of the Groot

Winterhoek Mountains in the western region of the Eastern Cape Province. The Gamtoos Valley is approximately 70 km in length. This forms the downstream part of the study and it is intensively cultivated mainly with citrus (22.5%) and potatoes (20.5%). The farmers use water from the Kouga Dam which is released under strict protocol and operated by the Gamtoos Irrigation Board (GIB). Mainly drip and centre pivot systems are used for irrigation and there are water meters to determine the volume applied. In the Gamtoos valley, in the upper part there is more citrus cultivation and fewer vegetables and in the lower part there is more vegetable cultivation than citrus. This is mainly because there is more wind down valley and it damages the citrus and affects their quality hence they won't be good for export.

Figure 1. Showing locations of the Baviaanskloof and Gamtoos catchments

Source: (Jansen 2008)

1.2 Problem Statement

South Africa is a water scarce country and it is anticipated that by 2020 the country will be having critical shortages (Masondo 2011) if the whole population is adequately supplied. It also has the lowest rainfall proportion in the world (8.6%) that can be converted to reusable runoff (Agterkamp 2009). The looming crisis calls for increased attention to efficient use of water and productivity to ensure maximum beneficial use of the resource.

In addition to the national crisis the Baviaanskloof also has faced its own local issues. Unsustainable agricultural practices such as overgrazing of animals like goats and sheep have led to land and water problems in the Baviaanskloof. The denuded ground leads to loss of agricultural productivity, soil erosion, reduced water supply, increased water treatment costs and reduces the lifespan of dams (Zylstra 2008). The area also experiences erratic and low rainfall which does not improve the water supply situation. As a result of low rainfall, farmers resort to irrigation for agricultural production.

In the downstream Gamtoos Valley, irrigated agriculture is more intense and has already been going on for a long time, whereas for the upstream it is different. Also for the past few years now, many studies in the Baviaanskloof were only related to nature conservation and ecosystem issues but none really focused on agricultural production. A critical issue in the upstream areas is that the farms are now not economically viable largely related to the overgrazing and overstocking of goats, sheep and cattle for meat and mohair production (Blanksma 2011). Currently 55% of the thicket biome in the Western Baviaanskloof is severely degraded (Blanksma 2011).There is now no grass or thicket and the soils are of poor structure hence not very sustainable.

In the downstream areas, during dry years severe water shortages are experienced and farmers have to reduce the planted area and prioritize water supply to the permanent crops (citrus). Sometimes farmers within the Gamtoos valley practice water trading in which water will be sold at a rate of R4/ m^3 which is quite high compared to the normal rate of R0.25/m^3 (Joubert 2011)[i].

The Nelson Mandela Municipality's (NMM) supply has already reached the demand and they are almost in equilibrium however, the city is expanding and population increasing but the water supply is not. Therefore in the near future the problem of water will be worse if no measures are taken. In one of the possible solutions to try and solve this problem, the NMM has proposed to buy out water rights from the Baviaanskloof farmers. However, GIB personnel believe that there aren't substantial water supplies in the Baviaanskloof. They argue that the reason why agriculture is not so much intensive in the Baviaanskloof is because there is very little water to irrigate rather than that the farmers are not interested or inefficient.

Thus the importance of this project is to first determine the water use efficiency of the two catchments and see if the hypothesis or predictions are correct. It helps especially to see the extent of the differences (if any) between the upstream and downstream.

The study also aims to compare the economic water use efficiency of the optional/alternative land uses practices farmers can take to bring income, or if these are not available, to see which crops have a better eWUE and can do better in the area.

Thus this project aims to assess the economic impact of stopping irrigation agricultural practices in the upstream area and using the water for the downstream part where irrigation agriculture is much more advanced and of 'better production'.

In order to do this, it is of importance to first see the WUE of the two areas which will help to determine the economic impact of the reallocation of water.

1.3 Objectives

1.3.1Main Objective

The main objective is to quantify and assess the differences in economic water use efficiency of the upstream and downstream crops that is the Baviaanskloof and Gamtoos Valley, respectively and see how it differs from the water productivity.

1.3.2 Specific Objectives

To determine actual crop water use for the different crops by use of the CropWat model

To determine the economic water use efficiency of the crops downstream and upstream

To assess if there is a significant difference in the economic water use efficiency of the upstream and downstream

Compare WUE and WP for selected the different crops

To assess why drip irrigation is used on citrus irrigation only and not on other crops

To suggest more sustainable options for future land management in the Baviaanskloof based on the available water resources

1.3 Research Questions

1.3.1 Main Research Question

What is the economic water use efficiency of the Gamtoos and Baviaanskloof catchment and how does it compare with the water productivity?

1.3.2 Sub Questions

- What are the major crops are cultivated in the area and what is the growing season
- What is the quantity of water used in the Baviaanskloof for agriculture
- How do the different irrigation systems/ farms work?
- What is the volume of water delivered to the field?
- What are the soil characteristics of the field or area?
- What is the yield harvested for each field and crop?
- What is the unit farm gate price per kg of each crop?
- Which are the land use options that the farmers can take?
- What are differences between the Gamtoos and Baviaanskloof?

1.4 Restrictions

Some challenges were faced during the project that resulted in some slight changes. The weather data received from the Gamtoos valley did not have the sunshine and wind speed data therefore the simulation was not done for that area. Thus water productivity was only calculated for the Baviaanskloof. Due to lack of equipment, time and accessibility it was not possible to do field measurements and therefore had to use secondary data from interviews of which most were estimates as the farmers did not keep records. The main focus was on economic WUE to be able to compare between the two catchments since the crops cultivated were different. However the physical WUE was also calculated

CHAPTER 2: LITERATURE REVIEW

2.0 Research Framework

2.1 Rationale

As we approach the next century, more than a quarter of the world's population or a third of the population in developing countries lives in regions that will experience severe water scarcity (Amarasinghe 2001). This problem is mainly associated with climate change, population growth, food demand, and competition for water resources. Irrigation consumes or depletes over 70% of the total developed water supplies of the world. Many people believe that existing irrigation systems are so inefficient that most, if indeed not all, of future needs for water by all the sectors could be met by increasing the efficiency of irrigation and transferring the water saved in irrigation to the domestic, industrial and environmental sectors (Amarasinghe 2001). In addition the proportion of fresh water available is decreasing (Raes 2009) in part due to pollution of water resources. This all has resulted in a lot pressure for the agricultural sector, which is the major contributor to food security. The same authors highlighted that for this reason sustainable methods to increase crop water productivity are gaining importance in arid and semi-arid regions. Increased water productivity plays a major role in reducing competition for scarce water resources, increasing total crop production and making water available for other human and ecosystem uses (Acheampong 2008). However water productivity studies can be very cumbersome especially by trying to find the exact value for evapotranspiration. As a result water use efficiency studies have also be done to evaluate and ensure efficient use of water. There is a lot of confusion as many researchers exchange the terms water use and water productivity. In order to make a clear distinction, these will be discussed separately.

2.2 Water use efficiency

Water use efficiency of a leaf is defined as biomass accumulation, expressed as carbon dioxide assimilation, total crop biomass or crop grain yield, compared to total water input to the system (Sinclair et al, 1983). It can also be generally defined as (mass of product)/ (water applied or available) in kg m^{-3} or kg kg^{-1}. Both definitions are based on output per input and give emphasis on the output derived from water use.

$$\text{Water Use Efficiency} = \frac{Output\ derived\ from\ water\ use}{Water\ Input}$$

Economic WUE (USD/m3) is also defined as the economic value of all agricultural activities per one unit of available water supply within a command area (Burt 2002) which in this case irrigated inflow is used. It is calculated as follows.

$$\text{Economic WUE} = \frac{\text{Yield} * \text{Farm gate price}}{\text{Water used } (\text{m}-3)}$$

The water balance component evapotranspiration (*ET)* comprises non-productive evaporation (*E*) of water from the soil surface and productive transpiration (*T*) of soil-stored water by the plant. Evaporation of free water from leaf surfaces, interception evaporation, adds to non-productive evaporation (FAO 2003). The denominator is also just a gross amount of water available at field level but the actual evapotranspiration utilised by the crop is still undetermined. As a result water use efficiency represents an efficiency parameter of water utilization at farm level.

The concept of WUE is very broad and it encompasses many processes that take place in the field. Barrett Purcell & Associates developed a framework that considers all hydrological aspects of an irrigation system (figure1). From the figure it is clear how broad the concept is and covers many aspects of ecohydrology, farm and water management. For this project focus is on the upper part of the framework thus crop WUI, total input. As indicated in the diagram the main factors affecting crop production at this point are the management, climate soils, varieties, water quality etc. The issue of WUE also requires an understanding of the whole system and not only at a field level.

Scale of WUE

Spatial scale is very important in water use efficiency studies. The level at which the research is carried out contributes to how you define water saving as a result of WUE. As stated by Bouwer etal, 1984 (Helen Fairweather) "The upper irrigation project's inefficiency is the lower project's water source". Looking at a basin scale it is possible for the inefficiencies from the upstream to result in reuse in the downstream areas hence the water use efficiency for the basin as a whole is good. If people in the upstream part however, employ different methods to increase their efficiency and use the saved water to cultivate more areas it means no water will be available for use downstream. In that case therefore WUE is high at field scale (upstream) but at basin scale it can be a nightmare. Thus for the WUE studies it is important to assess the whole system in order to say something about efficiency and real water savings. WUE is a scale and context dependant measure of water efficiency and does not differ much from Irrigation efficiency. Irrigation efficiency is a term used to relate the volume of water delivered to the field to that beneficially used (Edkins 2006). Any changes that are done at a certain scale will impact the other level thus it is a more localised measure of efficiency.

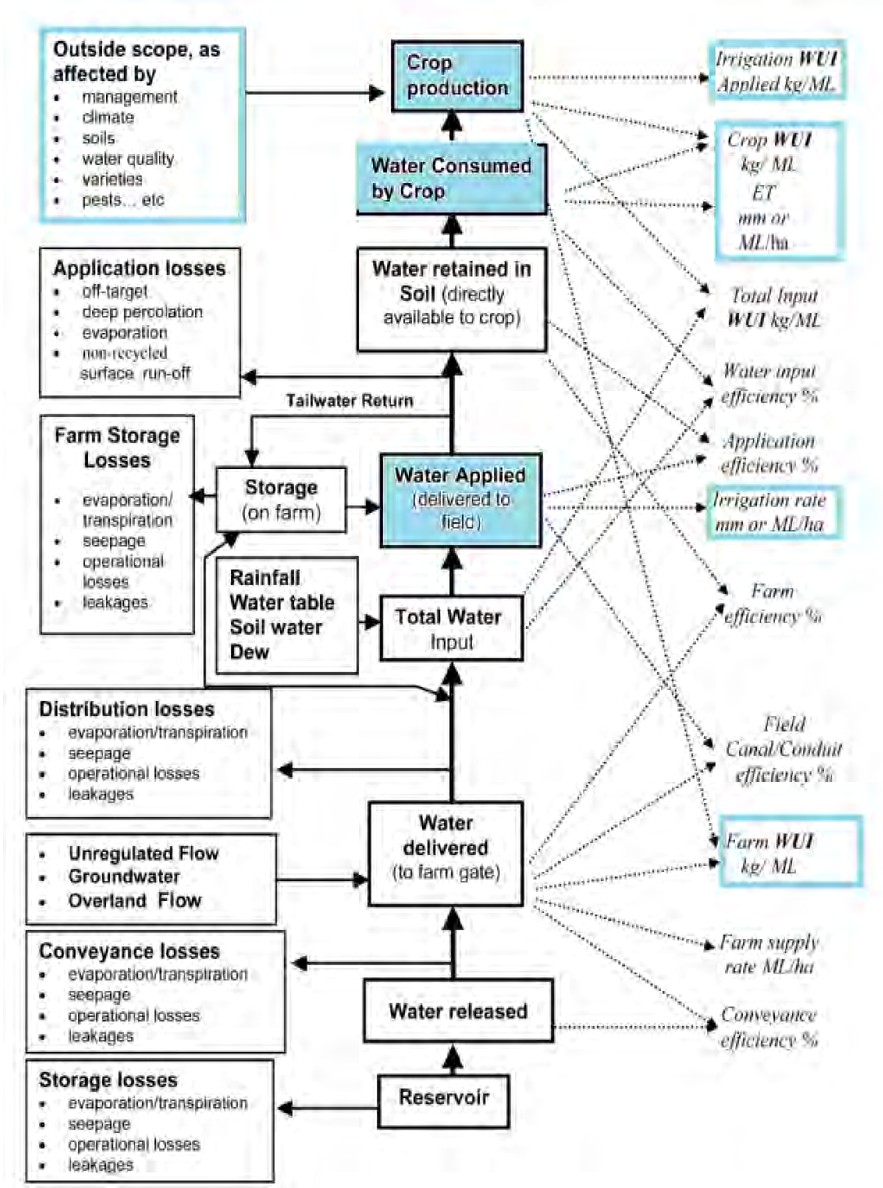


Figure 2. 1: Framework for water use efficiency.

Source: (Helen Fairweather)2003

*The factors highlighted on the graph are the once considered or calculated in this study. Some other factors like distribution, conveyance losses are not considered. These are also most important in flood irrigation. In the Gamtoos case for instance water meters were at the field hence the water recorded was the exact amount delivered to the field and/or crops hence no conveyance losses. Also note that the units in the diagram are different from the ones used in this study.

2.2.1 Ways to improve Water use efficiency

Conserve water- proper practices such as mulching should be implemented to minimise losses like deep percolation, runoff, seepage, evaporation and transpiration by weeds.

Promote maximum crop growth- cultivate high yielding varieties well adapted to the local conditions. It can also be achieved by assuring good growing conditions through pest and disease management, proper timing of planting, fertilisation, irrigation, harvesting. Thus from

the beginning of the season to the end proper management should be done to increase water use efficiency.
FAO, 1997

Improve irrigation technologies- this can be done by use of drip irrigation, supplementary irrigation and deficit irrigation. However this is very much scale dependant as shall be explained later.

Improve fertility- in some parts of Sub Saharan Africa the soils are of low fertility and this makes it difficult to absorb and hold water. As a result improving the fertility will change the nutrient status and organic matter water content of the soil. This results in the soil being able to hold more water and an improvement in the WUE.

2.3 Water productivity

(FAO 2003)defines the term water productivity as the amount or value of product over volume or value of water depleted by the plant, of which the value of the product might be expressed in different terms (biomass, grain, money). (David Molden: 2009) defines water productivity as the ratio of the net benefit from crop, forestry, fishery, livestock, and mixed agricultural systems to the amount of water required to produce those benefits. Both definitions are based on output per input and give emphasis on the output derived from exact crop water use. It is important to note the difference with WUE, that the denominator for WP is only that water beneficially used for evapotranspiration by the crop whilst for WUE it is all the water applied. The best approach to assess water productivity is by assessing water input and water output (Hugh Turral) In more simple ways the water productivity can be represented as:

$$CWP = \frac{Actual\ Yield}{Evapotranspiration(actual)} \text{ Kg m}^{-3}$$

(Iskandar Abdullaev 2004)

The output can be in terms of crop biomass, nutritional value, social values and income from yield depending on what you are more interested in. this research will be comparing different areas with different crops hence the economic productivity will be the one to be assessed;

$$economic\ WP = \frac{Actual\ Yield * farm\ gate\ price}{Evapotranspiration(actual)}$$

Water productivity is dependent on other factors like crop genetic material, water management practices, agronomic practices and economic and policy incentives to produce (Sakthivadivel and Makin 2003).

2.3.1 Scales of water productivity

The consideration of scales is relevant when defining the concept of water productivity (Acheampong 2008). Different science experts participate at different scales and there are particular interests in respect to each scale. The table below summarises the different scales and their respective experts and interests.

Table 2. 1. Scales of water productivity

	Crop/Plant	Field	Farm	Irrigation System	Basin
Processes	Water and nutrient uptake and use, photosynthesis	Tillage fertilizer application, Mulching	Distribution of water to fields, maximising 0&M , income	Distribution of water to farms, fees, drainage	Allocation across uses, regulation of pollution
Scientific Interests	Breeders, Plant crop, physiologists	Soil scientists	Agricultural engineers, agricultural economists	Irrigation engineers, social scientist	Economists, hydrologists, engineers
Production terms	Kg	kg	Kg.$	S	$value
Water terms	Transpiration	Transpiration, evaporation	Evapo-transpiration. Irrigation water supply	Irrigation deliveries, depletion, available water	Available water

O&M-operation and maintenance

(David Molden 2003)

WUE versus WP

The difference between WUE and water productivity lies in the denominator, for which the later takes into account only the actual evapotranspiration (Eta) water used by the crop for physiological conversion process for biomass production and yield formation. However, there is a lot of confusion between these two as some studies refer to WUE as WP, but WUE refers to gross water applications which may be a greater volume of water than is actually used by the crop.

The other challenging thing is that it is difficult to quantify Eta; mostly the water balance approach as follows

$Eta = I + P - R - D - \Delta S$,

Where rainfall (R) and drainage (D) are negligible and the evapotranspiration (Eta) will be irrigation (I) and rainfall minus the change in soil moisture. This method is haphazard and needs accurate and precise measurements of change in storage (ΔS) by use of lysimeters, modelling or neutron probe. In many WP studies as a result of inaccurate calculation of ΔS, WUE is calculated instead (Gerardo E. van Halsema 2011). Thus, great caution needs to be taken to distinguish between the two. The best is as suggested by the same authors to reserve WUE for gross applications and WP for actual water consumed.

Water productivity can be a way of dealing with the issue of basin closure. If there is an increase in water productivity, thus more yields per the same amount of evapotranspiration then it means some water can be conserved for use further downstream. Thus, conservation will be equal to reallocation of water which helps to improve the WUE of the whole system. On the other hand also, understanding the use of water and its consumption helps find ways to improve the productivity and determine redistribution for the whole system to increase overall productivity (A.H. de C. Teixeira 2 0 0 7).

Knowing the WP and WUE for a field or basin is a way of determining ways to improve on efficiency of water use. If the WP is greater than the WUE then it reflects that more water is applied than is used by the crop. The magnitude difference between the values shows the extend to which more water is used. This can then help irrigation engineers/ managers and/ or farmers to come up with ways to improve efficiency and increase the productivity.

2.4 Water accounting at field level

The concept of water accounting at field level is a way of better understanding the denominator of the general equation for water productivity (David Molden 2003). Water accounting is based on the water balance approach which considers inflows and outflows from basins or fields (Molden 1997). The art of water accounting is to classify water balance components into water use categories that reflect the consequences of human interventions in the hydrologic cycle.

What is of importance is to estimate the flows across domain boundaries within a certain period. For this reason there should be a clearly defined scale. This research focuses on plot, field and basin scale and there are particular processes that are important at this level. Water enters the system by rain, subsurface flow and irrigation. Depletion is through the processes of transpiration and evaporation and the remainder is surface runoff and soil storage (outflow). At field scale it cannot be said that the outflow is depletion as it can be recaptured downstream for re use (Sakthivadivel and Makin 2003). The depletion of water by evaporation and transpiration is beneficial as the water is used to support crop growth. The figure below shows the processes of water accounting at a field level.

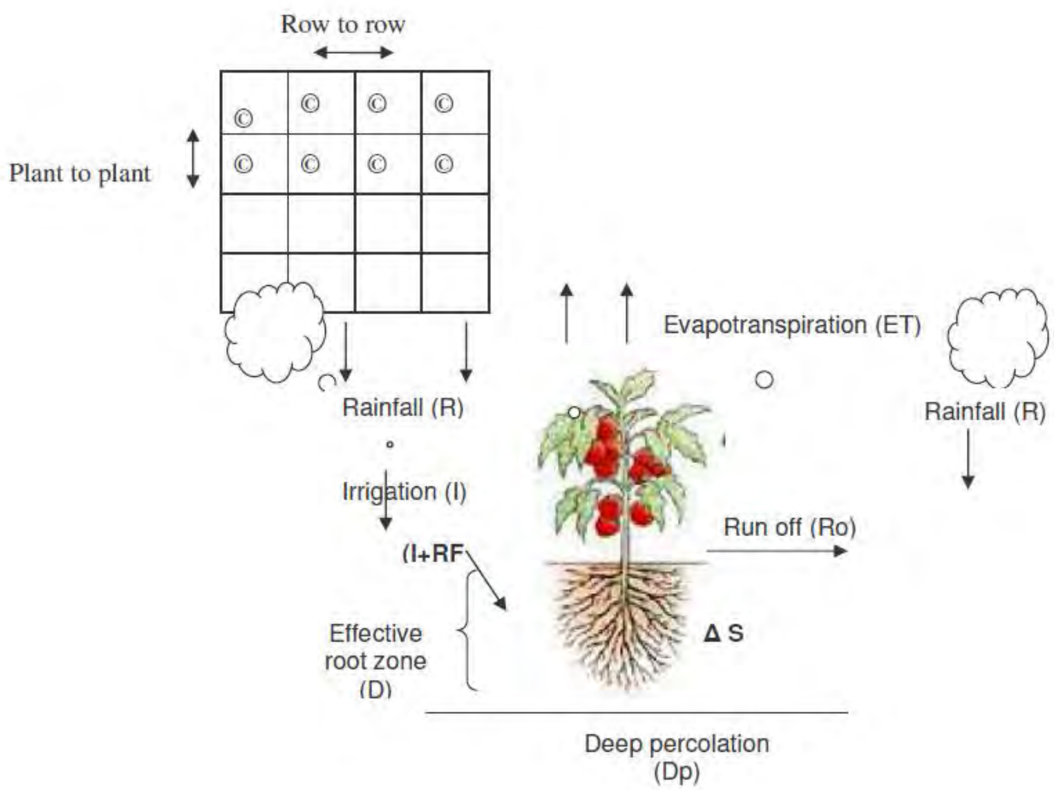


Figure 2.2 Water accounting processes at plot level

Source: (K.Palanisami 2006)

2.5 Crop per Drop

"We need a Blue Revolution in agriculture that focuses on increasing productivity per unit of water - more crop per drop" was a strong call made by the former UN Secretary General Kofi Annan in 2000. This has increasingly led to the challenge to produce more food with scarce water resources and increasing water productivity (Acheampong 2008).

The crop is the numerator of the equation and it can be referred to in different ways like: more kg per unit of evapotranspiration, more production per irrigation water delivered more welfare per drop of water consumed in agriculture. All of these are important and just like for water flows consideration of scale is important. At field scale farmers are interested at the mass of the produce. In water scarce periods farmers employ strategies to maximise their produce, such processes of interest include nutrient application, water conservation, soil tillage practices and other management practices.

2.6 CROPWAT model

CROPWAT is a computer program for irrigation planning and management, developed by the Land and Water Development Division of FAO (M. Smith 2002). Its basic functions include the calculation of reference evapotranspiration, crop water requirements, and crop and scheme irrigation. It uses the FAO (1992) Penman – Montieth method for calculating reference crop evapotranspiration (M. Smith 2002). The most recent version is the Cropwat 8.0 based on DOS version which will be used in this study. All calculation procedures used in CROPWAT 8.0 are based on the two FAO publications of the Irrigation and Drainage Series, namely, No. 56 and No. 33 (FAO 2011).

This model was chosen based on its flexibility for the simulation of different crops under a variety of climatic conditions, ability to simulate ET, availability of and easy access to the model and minimum data requirements.

2.6.1 Model Inputs

Climatic, soil, crop data as well as irrigation and rainfall data are used to calculate the ET.

- **Climate Data**
  Minimum and maximum temperature, air relative humidity, sunshine duration, wind speed at 2m high, monthly rainfall
  The above input will be entered in the Climate/ Eto module when running the simulation and rainfall also has the rainfall module.

- **Crop Data**

  Sowing data, crop ET coefficient (Kc), length of growing season and stages (see below), critical (soil moisture) depletion level (p), yield response factor, kc

  Length of growing season and growth stage

  - ***Initial stage*****:** this is from the planting date up to the point there is approximately 10% ground cover

- *Development stage*: this is from 10% ground cover up to effective full cover which is normally occurring at the initiation of flowering
- *Midseason stage*: this is from effective full cover to the beginning of maturity often indicated by beginning of age, senescence/ yellowing of leaves and browning of the fruit such that Etc is reduced relative to ETo.
- *Late season*: last stage from the maturity to harvest or full senescence
  FA0, 2004

2.6.2 Crop Coefficient

Crop coefficients (Kc) are used with reference crop evapotranspiration (ETo) to estimate specific crop evapotranspiration rates. The crop coefficient is a dimensionless number (usually between .1 and 1.2) that is multiplied by the ETo value to arrive at a crop ET (ETc) estimate. The resulting ETc can be used to help an irrigation manager schedule when irrigation should occur and how much water should be put back into the soil (CIMIS 2009). The values vary by crop type, growth stage and even cultural practices.

2.6.3 Yield response factor

The response of yield to water supply is quantified through the yield response factor (ky) which relates relative yield decrease (1-Ya/Ym) to relative evapotranspiration deficit (1-ETa/ETm) (M. Smith 2002).

The information will be recorded on the crop module for dry crop in the CropWat model.

- Soil Data

Initial available soil moisture, maximum infiltration rate, maximum rooting depth, total available soil water content (Stancalie D 2003)

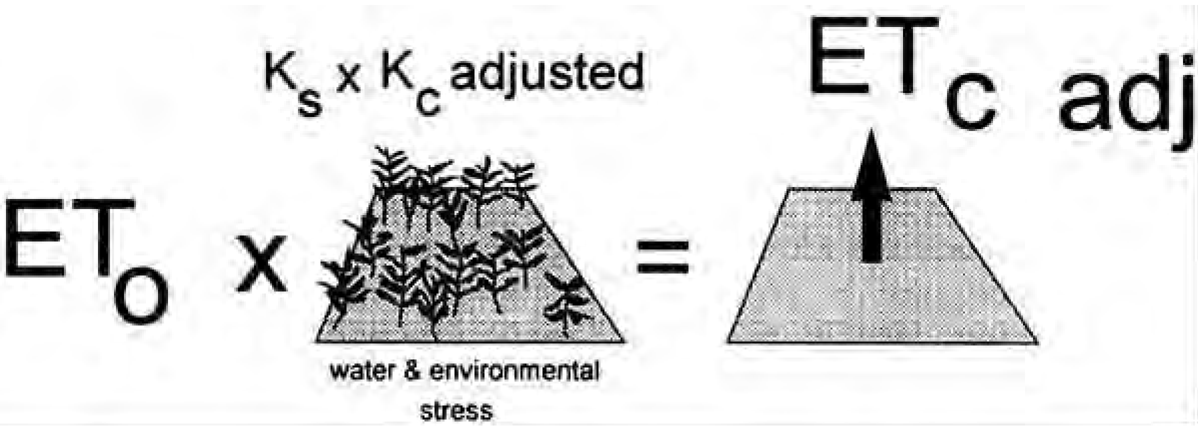
The calculation of reference crop evapotranspiration is based on Penman Montieth equation. The FAO Penman-Monteith method to estimate ETo is:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad \text{(eqn1)}$$

Where:

ETo = reference evapotranspiration [mm day-1]
Rn = net radiation at the crop surface [MJ m-2 day-1]
G = soil heat flux density [MJ m-2 day-1]
T = mean daily air temperature at 2 m height [°C]
U2 = wind speed at 2 m height [m s-1]
es = saturation vapour pressure [kPa]
ea = actual vapour pressure [kPa]
es - ea = saturation vapour pressure deficit [kPa]
= =slope vapour pressure curve [kPa °C-1]
and
a = psychrometric constant [kPa °C-1].

Source: (Nazeer 2010)



When assessing the ET rate, additional consideration should be given to the range of management practices that act on the climatic and crop factors affecting the ET process.

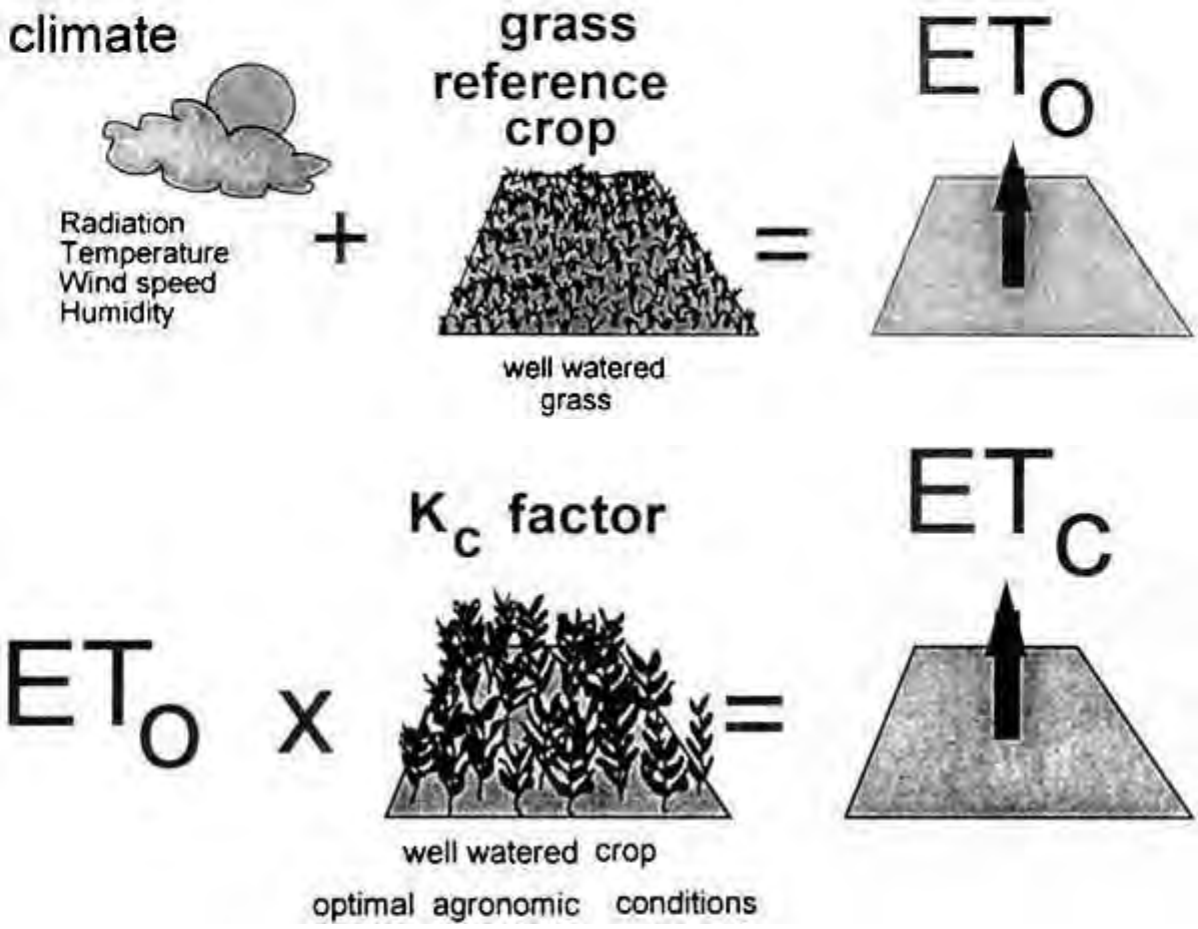


Figure 2.3: Showing crop evapotranspiration under different conditions

Source: (FAO 1998)

The second equation will be used calculate Etc so as to account for different management, different irrigation systems. The reduction coefficient Ks shall be used based on the local conditions and the adjusted Kc fed into the model. Ks is dependent on the available soil moisture and ranges between 0 and 1.

With inputs of water supply, soil water retention and infiltration characteristics and estimates of rooting depth, a daily soil water balance is calculated, predicting water content in the rooted soil by means of a water conservation equation, which takes into account the incoming and outgoing flow of water.

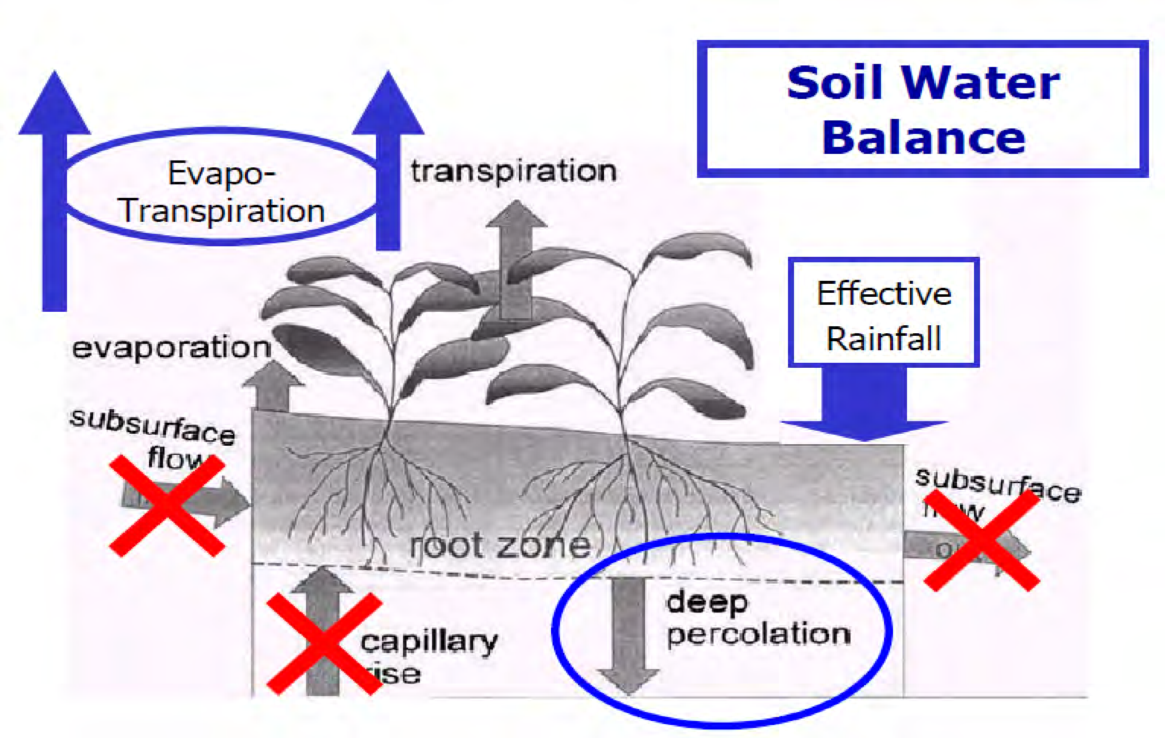


Figure 2.4. Showing the soil water balance components

(FAO 1998)

The subsurface flow, capillary rise marked with red above are difficult components of the balance to account for. Together with deep percolation these will not be considered in this study. Deep percolation also requires more sophisticated methods to quantify.
The CROPWAT model facilitates the estimate of the crop evapotranspiration, irrigation schedule and agricultural water requirements with different cropping patterns for irrigation planning.

2.7 Other Programs

To try to find data that is more local specific I also looked for another programme for Southern Africa, SAPWAT. It was however not possible to download and use it for simulation. I managed to use it to determine the lengths of crop growth stages as this could be done on the website. More information about the operation and principles of the Sapwat programme is explained below.

SAPWAT
This is a planning and management tool that relies on the extensive South African climate and crop database and is used for estimating crop water requirements in South Africa. http://www.sapwat.org.za/sdata1.php. It extends the facilities provided by CROPWAT and is a tool that can facilitate "designing for management". Its development dates back to the Green Book of 1985, which was used in South Africa for many years to estimate crop irrigation requirements.

OutputData

Regions	St.1	St.2	St.3	St.4	Kc	Fv Max	Fv End	Fv Start	Per.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Des
Highveld	30	30	60	1	1.15	1.15	90	0.01	0	.	.	.	.	.	.	.	.	.	Y	Y	Y
Middelveld	30	30	60	1	1.15	1.15	90	0.01	0	Y	Y	Y	Y	Y	.	.	Y	Y	Y	Y	Y
Lowveld/N.KZN	30	30	60	1	1.15	1.15	90	0.01	0	Y	Y	Y	Y	Y	.	.	Y	Y	Y	Y	Y
N.Cape/Karoo	30	30	60	1	1.15	1.15	90	0.01	0	.	.	.	.	.	.	.	.	.	Y	Y	Y
KZN/E.Cape (cool)	30	30	60	1	1.15	1.15	90	0.01	0	.	.	.	.	.	.	.	.	.	Y	Y	Y
E.Cape (hot)	30	30	60	1	1.15	1.15	90	0.01	0	.	.	.	.	.	.	.	.	Y	Y	Y	Y
Winter Rain	30	30	60	1	1.15	1.15	90	0.01	0	.	.	.	.	.	.	.	.	.	Y	Y	Y

Figure 2.5 showing SAPWAT example

The first window shows you a panel of different crops that are cultivated in Southern Africa. When you select the crop it gives you an option (if any) for example, early or late crop or short, medium or long variety. After selecting the best option the best output is displayed in another table.

Please select the relevant Crop & Option

CROP	A-grass-ref Almonds Apple Apricot Asparagus Avocado Babala Bananas Barley Beans_Dry	OPTION	[no Crop selected]

2.8 Water Use Efficiency of crops

2.8. 1 Water use efficiency of Citrus

Citrus is a perennial crop and requires water throughout the year. Recent irrigation studies on young citrus plants, that are correctly monitored and scheduled, have shown a water use of 2-5 mega litres per hectare annually. Water stress can affect citrus at each development stage. In general, water stress in the early fruit development stage will have a greater effect on decreasing fruit size than at the later stages of growth and development (Steven Falivene 2004). In order to improve the water use efficiency the main strategy is to ensure that water is not applied beyond the root zone. Possible ways could be by i) Use regular deficiency irrigation (RDI) and partial root zone drying (PRD) techniques, ii) Use subsurface drip irrigation and iii) Use drought tolerant rootstocks.

It is crucial to avoid water stress during critical periods in citrus production. The figure below shows critical periods in development stages of citrus.

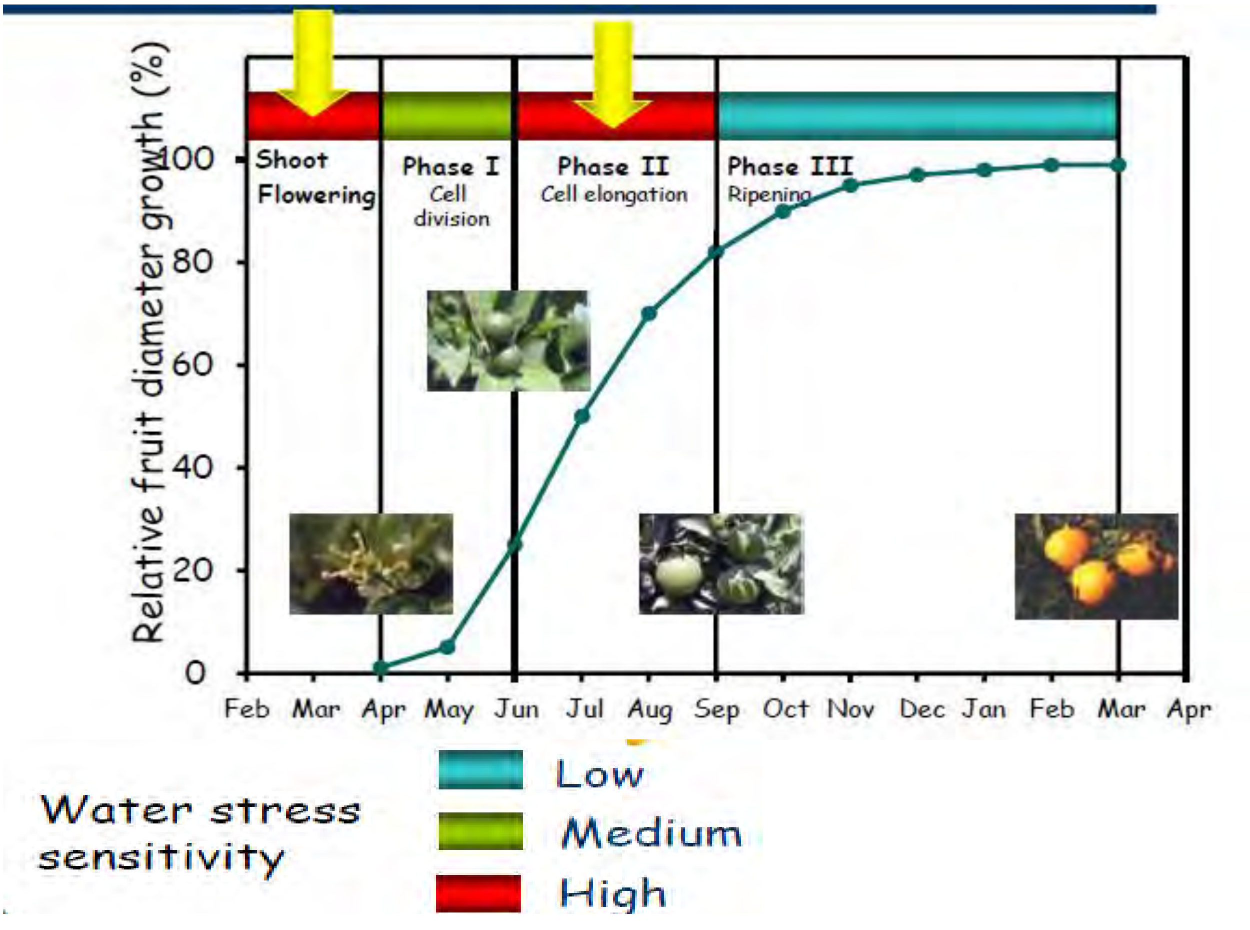


Figure 2.6: Showing the critical growth stages and water stress in citrus *(Pérez-Pérez nd)*

2.8.2 Water use efficiency of onions *(Allium cepa)*

Bulb and dry matter production of onions are very much dependant on the application of adequate water. Like many other crops the crops should not experience water deficit as this will cause low productivity especially during bulb development stage. During the vegetative and ripening periods, the crop appears to be less sensitive to water deficit. Excessive irrigation during the vegetative period can lead to a delayed and reduced bulb development (Abdullah Kadayifci 2005). Evapotranspiration rates are also greatly dependent upon the climatic conditions of the area, under cases of adequate irrigation supply (Borivoj Pejić 2011).

2.8.3 Water use efficiency Potatoes *(Solanum tuberosum)*

The potato stands out for its productive water use, yielding more food per unit of water than any other major crop hence its high nutrition productivity (FAO 2008).

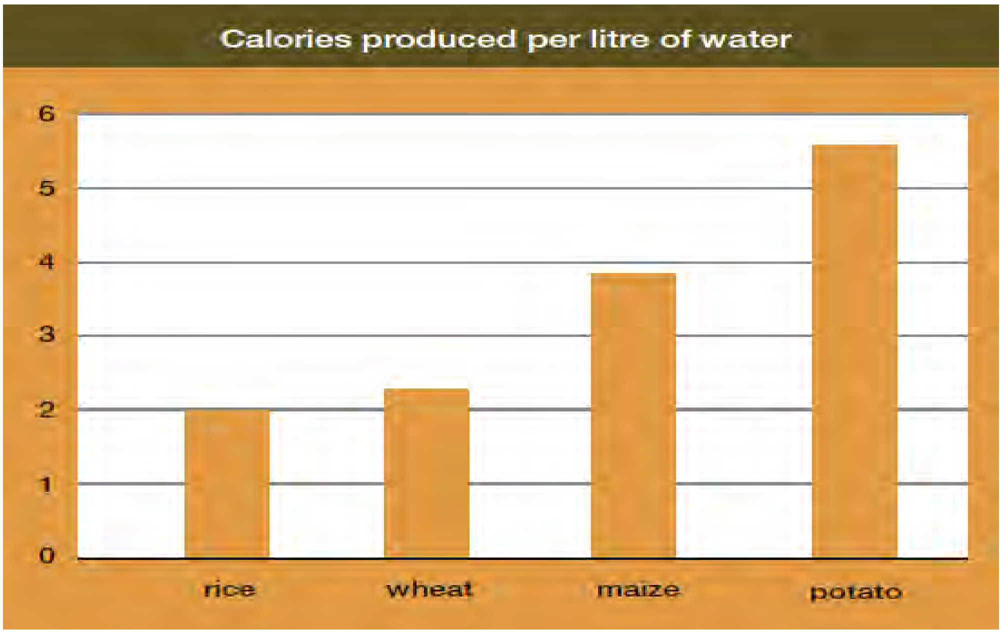


Figure 2. 7: Showing nutritional productivity of potatoes compared to other major crops.

Source: (FAO 2008)

The potato is shallow rooted and sensitive to mild water deficit. Reduction in water applied also greatly reduces the tuber yield. The water productivity of potatoes is generally low in hot climates than in cooler ones (Bowen 2003). The most sensitive phases are the stolonization and beginning of tuberlization phases (A.S.M. Amanullah 2010). Soil quality also has a major effect on tuber yield and this include soil factors like soil moisture content and strength. This is so because the soil quality affects the water movement and hence availability to the crop (Seyed Hamid Ahmadia 2010). Soil moisture and hydraulic characteristics of coarse sand may affect the yield negatively as water movement towards the roots could be too low during high evaporative demand and thus influence root growth and elongation (Jensen et al., 1998).

2.8.4 Water use efficiency in alfalfa/ Lucerne (*Medicago sativa)*

Alfalfa is a high water use crop because it has a long growing season, a deep root system, and a dense mass of vegetation (Bauder 2005). There is a linear relationship between dry matter production and water use in alfalfa of which the slope is expressed as WUE. Water use efficiency is highest when the water supplied to plants by irrigation, precipitation, or ground water approximates evapotranspiration. Alfalfa grown under semiarid conditions should be watered lightly and frequently to attain high yields and high WUE (I. A. M. Saeed 1997).

2.8.5 Water Use Efficiency of Carrot seeds (*Daucus carota L.*)

Water stress during root development also causes cracking of the roots, which also become hard. It has been reported that the maximum water use per day is 0.15 inches (3.81mm) for carrots when they reach a marketable size. Like for many other crops, after the carrots reach peak growing point the water use also declines (Edward C. Martin 2009). In a study carried out in Sidney, Austalia where they irrigated carrots with 100 and 150% Epan treatments they obtained a WUE that ranged from 1. 2 to 1.32 kg/m^3 (Ludong 2008).

2.8.6 Water use efficiency of Maize (*zea mays*)

Maize is a C 4 plant which makes it more efficient in use of water use than perennial grass crops like rye. The WUE of maize is approximately double that of other C3 crops grown at the same site and conditions. In New South Wales, the water use efficiency produced from both irrigation and rainfall was estimated to be 3.4 and 2.4kg/m^3 in the two year experiment carried out by (Edraki *et al.* 2003), these values were in consistency with later findings of 2005 (Kerry Greenwood 2005).

2.9 Comparing Factors affecting water productivity upstream and downstream

Farming Intensity

The downstream area, the Gamtoos Valley is characterised by more intensive production of mainly citrus and some vegetables. There is now a long history of cultivation in this area and more sophisticated methods are used for agricultural monitoring. Therefore it will be expected from this study that this area will have high water productivity. In the upstream part, Baviaanskloof however, agriculture is not very intensive and mainly seed potatoes and onions, and vegetables are grown together with livestock production.

Irrigation systems

Another issue is in the downstream areas mainly drip irrigation is used to irrigate whereas in the upstream part it is sprinkler irrigation. From studies done drip irrigation usually result in a higher productivity than sprinkler irrigation (F. A. Al-Said 2012).

Organisation

Farmers in the Gamtoos Valley get consultancy, support and advice from the GIB and consultancy from DFM and Netafim, who are both speciliazied in smart agricultural solutions. This helps them manage their farms and water applications. They also receive water from the Kouga Dam with fixed known allocations every year and all the maintenance of water infrastructure is done by the GIB. The Baviaanskloof farmers however have to maintain their own water sources which mainly depend on rainfall. There is no irrigation board or extension service helping them with advice or any kind of support.

Crops cultivated

In terms of the different crops, I expect the citrus to have a high WUE since it is cultivated under drip irrigation which has a better efficiency. Also because it seems agriculture is more intense hence better practices are likely to be implemented. I also expect potatoes to have a high WUE/WP as they have been indicated in many studies as a crop with high water use efficiency compared to other crops.

It is of importance to know the differences between the two catchments such that recommendations can be given for best practises and also the best crops with highest productivity. If one crop has a very low productivity then it would be better to advice farmers to opt for the better ones.

2.10 Soil Moisture monitoring

In this period of water scarcity, it is crucial to use water as efficient as possible. Also of importance is good crop growth. To maintain a good water balance in the soil for adequate crop growth, soil moisture monitoring is necessary. Many farmers and irrigation managers use different methods to monitor the soil moisture balance and schedule their irrigations. There is a wide range of methods available that range from the simple gravimetric method, use of tensiometer, neutron probes, electrical resistance methods, and TDR and capacitance probes. Of late capacitance probes have been gaining popularity because of their higher accuracy, efficiency and affordability (affordability in comparison to TDR). In the Gamtoos valley, these are the ones that are widely used by farmers to schedule their irrigation. Below I discuss more of the mechanism and functioning of the capacitance probe.

DFM Continuous Logging

These are multilevel soil moisture content and temperature-logging devices. Readings can be taken at 6depths hourly and 4000 readings can be stored locally, this is approximately 5 and half month's readings. There are two different types, that is, short and medium range and the long range.

2. 11. 1Mechanism

The soil moisture probes measure soil moisture content by means of capacitance which is the ability of on object to store an electric charge (Davidson 2003). The probe has a number of sensors mounted on a vertical probe which are inserted in the soil vial a water proof access tube (Adam Pirie 2004). The probe has two metal rings which are the plates and the soil acts as the dielectric of the capacitor which completes the circuit(Adam Pirie 2004). When water is added in the soil, the probe will measure the change in the capacitance as a result of a change in dielectric permittivity. Water has a high permittivity of up to 80 ε_r compared to air which has 1, organic matter 4 and mineral soil 4 (CSGNetwork 2012).

The higher the conductance the higher the soil moisture and the reverse is true (Mahbub Alam 2001). The DFM has designed software which instantly converts the probe readings to soil moisture percentages that will be shown in form of graphs. The probe is also calibrated to know 0 and 100 % soil moisture content. Because of the variations in soil type the output is indicated in percentages and not in mm (Wiese 2012).

2.10.2 Short Range and medium

With this system, readings are downloaded by use of a mobile logger. The user has to physically go to the planted probe in the orchard to download the latest readings; however they are not required to collect readings every day. The probe can be set to default and can then store readings up to 4000. The probe communicates with the logger via radio signal. The maximum radio distance between the probe and the mobile logger is 5 meters. The range is however an estimate and it depends on site limitations. The logger is an interface between the user and the probe and can be used to force readings, show the value of the last reading taken, change the reading interval, put probe into "Sleep" mode, etc.

Figure 2.8 Example of a short and medium range system

2.10.3 Long Range Systems

With this system the user can download information directly to the computer with the use of long range repeaters. There is no need for physically visiting each probe to download information. All readings taken by the probe over a period of time can be downloaded directly to a computer at the users' leisure. Readings are sent from the probe to a repeater which is located on the probe site. The later sends data to the Central Point Server (CPS) where it can be downloaded by the user to the computer. The maximum range from a repeater to the CPS is 1.2km (dependant on site conditions), but data can be collected from probes that are located more than 1.2km* away from the CPS via use of a hop-along repeater system.

The repeater system works as a hop-along system, thus a repeater further than 1.2km can send data to a repeater closest to it, the receiving repeater will also then send the received data to the next close repeater or CPS. Probe information is send at hourly intervals to the CPS. To be able to download data the CPS need to be directly connected to the PC via serial cable, Cell phone modem, Wi-Fi link or GPRS.

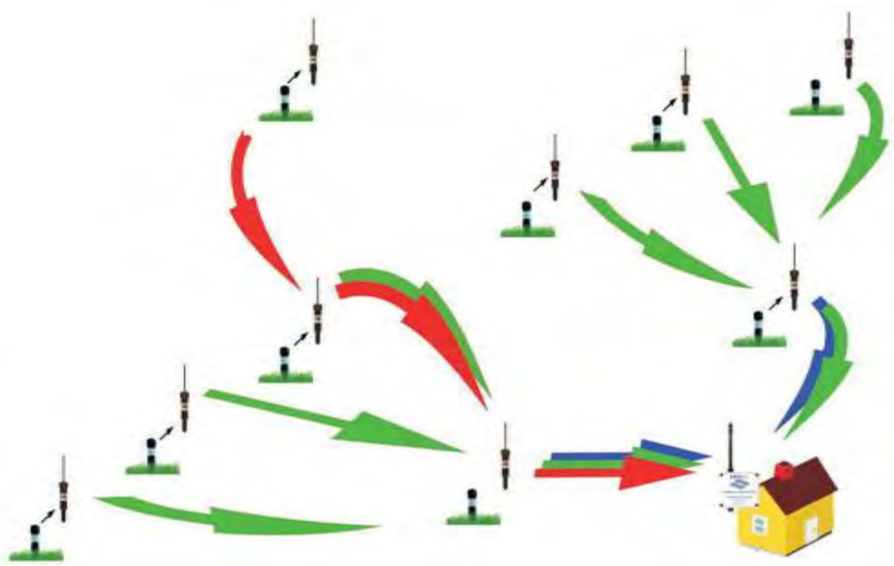


Figure 2.9 Example of a long range system

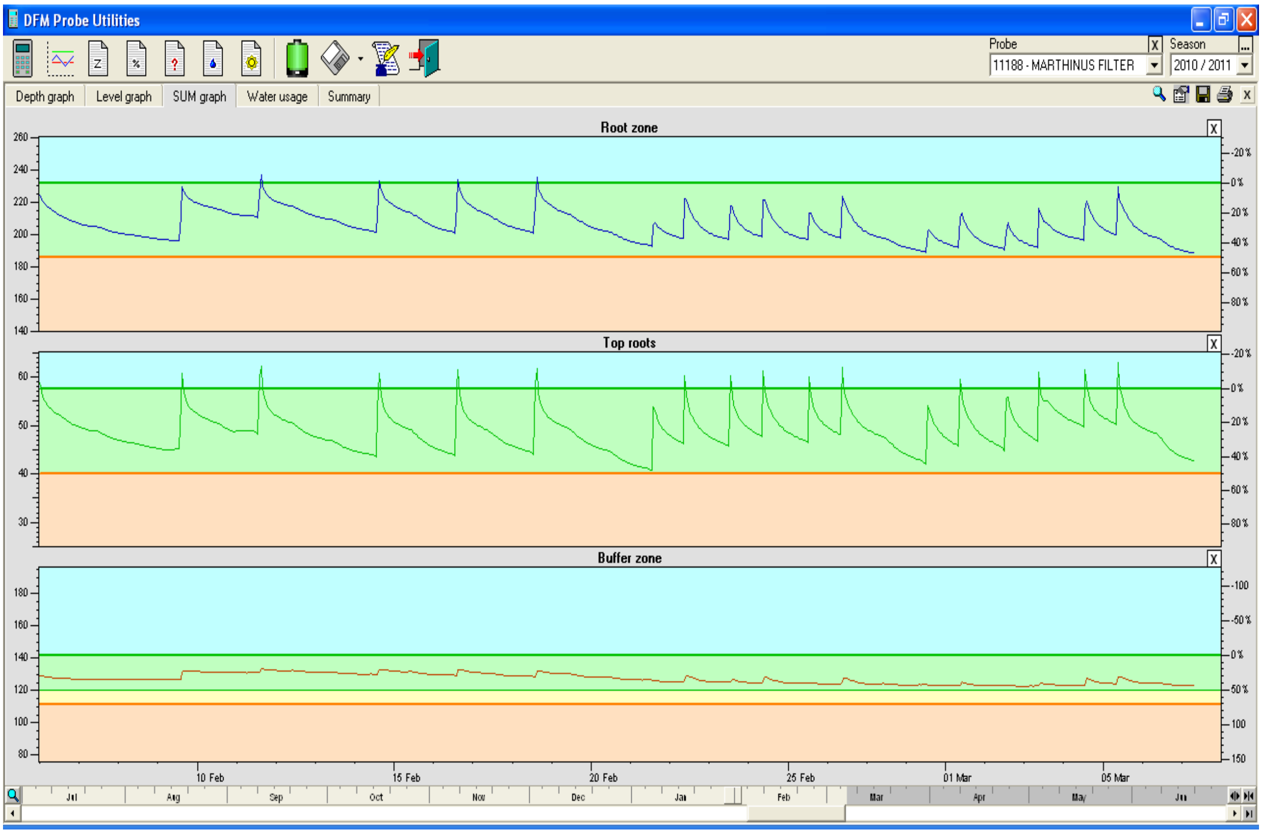


Figure 2.10 Example of sum graph used by farmers to schedule irrigation

The sum graph above is the output the farmers sees on his computer and use it to make decisions on when to irrigate. The left vertical axis is the depth and the right shows the percentage volume of water whilst the x axis shows the time. There are three different graphs for the root zone, top roots and the buffer zone. The upper blue line indicates that the soil still has water and it is above the field capacity (green line). Therefore if the line is in that part no irrigation is needed. The green part is the readily available moisture which is just below the Field capacity. Water is allowed to deplete up to the readily available moisture (RAM) and not go beyond that point. Under that point is the wilting point and it is advisable that farmers avoid crops reaching this point as it result in moisture stress for crops. Most irrigation is done when the line is about to hit the bottom of the RAM or before depending on the farmers 'decision and water availability.

2.11 Water Requirements for Livestock

Livestock production is a major enterprise in the Baviaanskloof. However, assessment of WUE of livestock is complicated and involves many things. One would want to know how much is consumed by each animal and the meat conversion rates which are very cumbersome. This study therefore did not look at the livestock Water use efficiency but only considered the estimates of water used for drinking and dipping. This was important for the estimations of total water use in the Baviaanskloof. The WUE of fodder/ pasture was calculated based on what the price would be if it were sold.

Different livestock also have different water requirements which are influenced by different factors. Even within the same type of livestock, water requirements can be different mainly dependant on the stage of growth. Figure 2.11 shows the main factors that influence water intake of livestock.

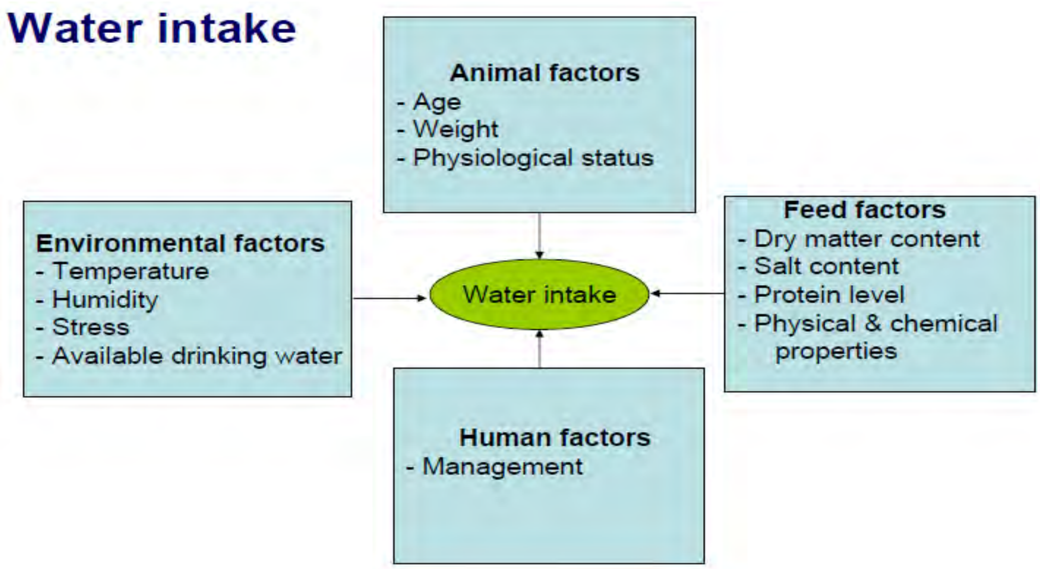


Figure 2.11 Showing factors that affect water intake in livestock

Source: (D. AL-Ramamneh 2009)

Water Requirements for:

Goats

Both goats and sheep used water amounting to about 8% of their body weight per day when water was available *ad libitu*.(Taylora 1971). Goats require 4–5 litres/day, and more for lactating does. Goats also prefer drinking clean water and not contaminated water.

Beef Cattle and sheep

Beef Cattle Type	Weight Range (kg)	Water Requirement Range[a] (L/day)	Average Typical Water Use[b] (L/day)
Feedlot cattle: Backgrounder	181–364 (400–800 lb)	15–40	25
Feedlot cattle: Short keep	364–636 (800–1,400 lb)	27–55	41
Lactating cows with calves	–	43–67	55
Dry cows, bred heifers & bulls	–	22–54	38

[a] A result of the animals' environment and management.
[b] Typical consumption over a year on a daily basis under average agricultural conditions in Ontario.

Animal Type	Weight Range (kg)	Water Requirement Range[a] (L/day)	Average Typical Water Use[b] (L/day)
Feeder lamb	27–50	3.6–5.2	4.4
Gestating meat ewe/ram	80	4.0–6.5	5.25
Lactating meat ewe plus unweaned offspring	80+	9.0–10.5	10
Gestating dairy Ewe/ram	90	4.4–7.1	5.75
Lactating dairy ewe	90	9.4–11.4	10.4

[a] A result of the animals' environment and management.
[b] Typical consumption over a year on a daily basis under average agricultural conditions in Ontario.

Figure 2.12 Showing the typical water requirement for beef cattle and sheep in Ontario, Canada

Source: (McKague 2007)

CHAPTER 3 METHODS AND MATERIALS

A basic survey was conducted in both of the two catchments to get to know and understand the area. This helped to review the different methodology options and come up with the best method of getting needed data considering the area, number of farmers, accessibility and most of all availability of materials. In the Baviaanskloof, information was gathered from all farmers as it was the main area of interest and it was also easy to contact the farmers. In the Gamtoos area, a number of farmers were selected with the help of GIB based on the following criteria:

3.1 Site Selection

- **Zone area of the farm**: the valley is divided into 3 sub zones subdistrict I is the Patensie area (mainly citrus), Subdistrict II (less citrus and more vegetable) is the Hankey area and Subdistrict III is Loerie and Mondplaas (vegetables and dairy farming).
- **Major crops** – the aim was to cover the main crops grown in the valley and consistent ones. The other focus was to try to find those farmers that cultivate the same crops as those in the Baviaanskloof for comparison of physical water productivity.
- **Previous year's data availability**- good record keeping is very important for getting reliable data, so with the help of GIB personnel who knew which farmers had the best records even for the previous years we selected those farmers.
- **Resources**- the study also tried to cover farmers with different resources and of different income levels. For example, those who use soil moisture probes and those who do not.
- **Language**: although quite a number of farmers speak English and Afrikaans, some were also not able to speak English and therefore I also chose farmers who had a better English proficiency to enable easy communication and obtaining better data.
- **Accessibility:** some farms were really hard to access especially without a guide from the GIB

3.2 Data collection Methods

Interviews

Interviews were done first with Personnel: mainly with the Gamtoos Irrigation Board (GIB) which is the organisation that manages the water in the Gamtoos catchment. These interviews helped to understand the distribution of water in the area and how the farmers in the Gamtoos Valley get their water. All the contact information of farmers was also obtained from the GIB CEO.

With Farmers: Interviews were also conducted with farmers to get data on their crop and water use. The questions or main issues discussed were:

- The crops cultivated during the period 2010/2011

- The number of hectares for the different crops
- Dates of planting and harvest
- The yield per crop
- The unit price and cost of production for each crop
- The volume of water applied or irrigation schedule
- The soil type(s)

Electronic mail correspondence

This was done with the operations manager from DFM software to get more information on the functioning of their soil moisture probe and irrigation software system.

Irrigation Schedule

Figure 3.1 a picture showing soil moisture probes in farmers' field

Most citrus farmers used the DFM system which comprised of a soil moisture probe, a radio transmission and final output received from the computer. The farmers made then their decisions based on the sum graphs (Chapter 2.9).

Meter Readings

These were obtained from the GIB which collects all the readings of water use at every farm. The readings were mainly used to see how much they the deviate from the values obtained from the farmers.

Bucket method

In some cases there were no meters and farmers did not use the DFM system or know the discharge of the sprinklers, bucket system was used. Buckets of known volume were placed in the field when the pivot starts irrigating and the set time recorded together with the amount of water collected during that time.

Weather Data

Weather data was obtained from the South African Meteorological department and Agricultural Research Council (ARC) which gave different data for the weather stations in Patensie (Gamtoos) and the Baviaanskloof. Daily data on rainfall, minimum and maximum temperatures, wind, sunshine hours, relative humidity were recorded.

Literature study

Reviews of literature were done in order to understand better the subject and the area. Papers from prior studies in the area were read from the Living Lands data base and some information was also obtained from GIB. Further literature was searched from the internet to understand the different concept of water use efficiency and water productivity, the water use of the different crops and also livestock water use among other things.

Crop Information

The length of growth for the different crops and the kc values were obtained from the SAPWAT programme which gives more detailed information taking into account the South African conditions.

CropWat Simulation

The collected daily weather data was entered into the Eto and rainfall module of the model. The days were most rainfall was received during the year was identified from the rainfall module and the simulation started a day after the heavy rain. This was assumed to be the field capacity. The actual water use was used to calculate water productivity of the different crops. The total gross irrigation from the simulation was also compared to the total volumes of irrigation given by the farmers.

Basic Calculations

From the collected data, different calculations were used to come up with the economic WUE and below are the formulas used.

Formulas		
Total yield(t or kg)	**TY**	Yield(t/ha)*No. of ha
Total Income®	**TI**	Unit price*Yield*No.of ha
Total cost®	**TC**	Cost of production(R/ha)*No. of ha
Water applied(m3)	**WU**	water application(mm)/1000* No. of ha*10000
eWUE		(TI-TC)/WU

3.3 Data Analysis

All the data was recorded in excel files each farmer with his own sheet. The calculations were done using excel program and the data was presented in the best way possible in form of pie charts, tables, bar and line graphs.

CHAPTER 4: RESULTS

The results presented are based on the calculations and analysis of data collected from the farmers' in the respective catchments. It is important to note that although there are 9 farmers in the Baviaanskloof, calculations of the economic and physical water use efficiency is based on 7 farmers only which were involved in crop production. This is because the other were not intensively involved in crop production: one of the farmers did not cultivate crops at all, the second is an emerging farmer who has just started olives production and hadn't harvested yet. Among the considered 7 two of them are mainly focused on tourism and livestock but do have a small portion of pasture and Lucerne. Some data from the Gamtoos was not used for comparisons in order to bridge the gap between the two catchments units (highlighted in red, see appendix).

4.1 Most common crops cultivated in the Baviaanskloof and Gamtoos valley

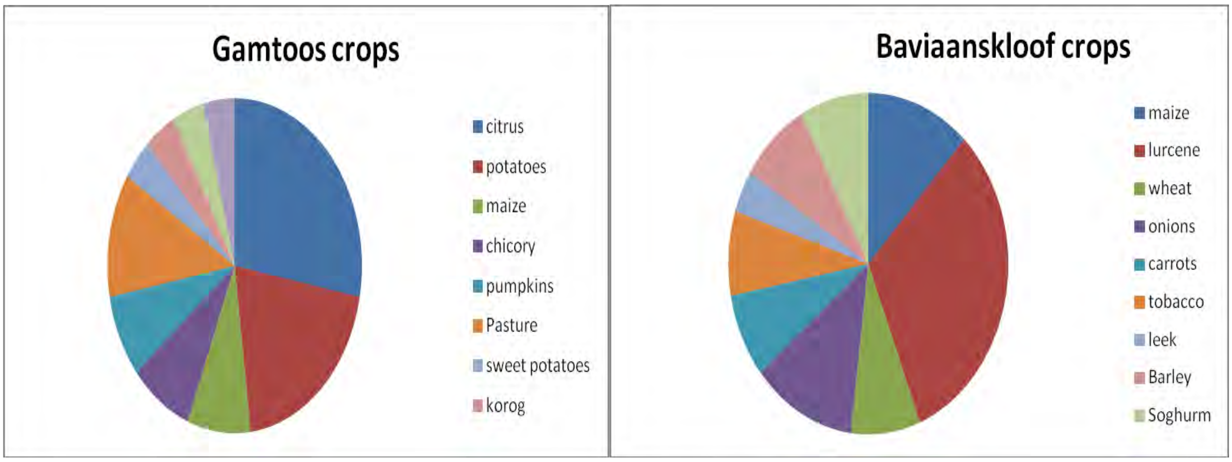


Figure 4.1 Showing the common crops in the areas per number of farmers growing it

As from the pie charts above the crops grown in the two catchments are quite different, although there are also some that are found in both areas. Citrus and potatoes dominate in the Gamtoos whilst lurcerne is the most dominant in the Baviaanskloof followed by maize, onion. At least all but one farmer in the Baviaanskloof cultivate lurcerne. The cropping pattern and varieties differs from farm to farm as in the case also in Gamtoos. Some farmers have only 1 or 2 crops whilst some cultivate 5 or more crops.

4.2 Results for Baviaanskloof

First to give an indication of local conditions, the weather conditions during the year 2010 were analysed to show how they could have affected crop growth or water use. The ETo and rain graph calculated from Cropwat are presented in figure below. It shows high ETo values up to 5 to 6 mm/day with the highest in the summer period from November to February. The months of May, June and July have lower values since it is the winter period and temperatures are low. The rainfall was also erratic with only a few peaks received during the year. The total rain received throughout the year was 266 mm which is lower than the long-term average of 300mm indicating that it was a dry year. Most of the rain was received during the summer period in December, January and March and also in June.

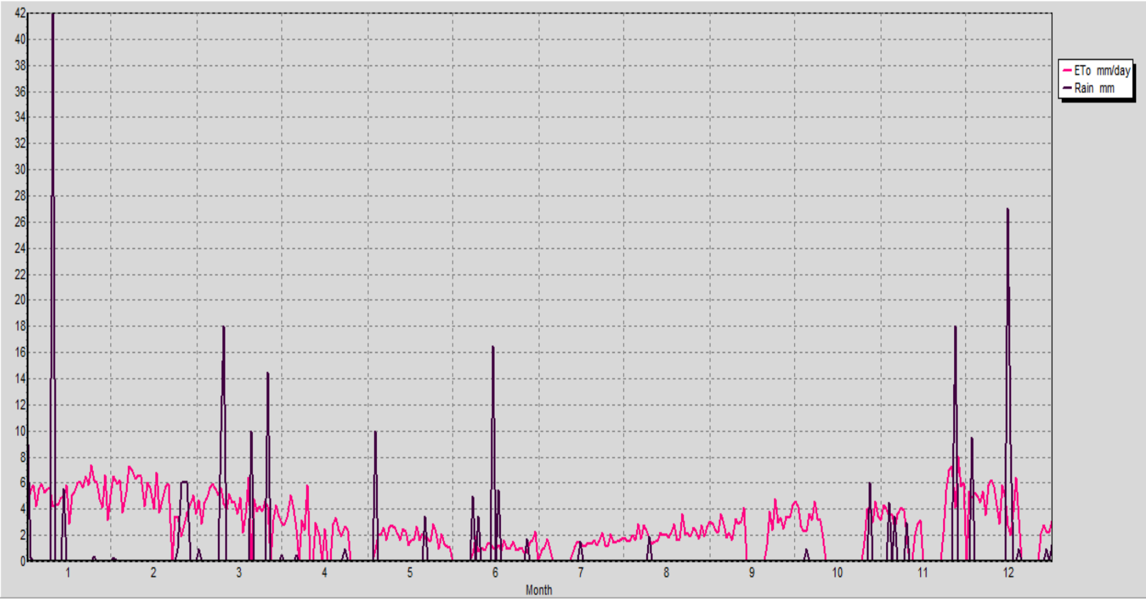


Figure 4.2 ETo and Rain received in the Baviaanskloof during the year 2010

4.2.1 Raw Data

Data was collected from farmers and recorded in tables like the one shown in Table 4.1. Shown in the table is one example from one farmer, the rest can be found in the appendices. The information was all obtained from farmers themselves during interviews and field observations. The different crops cultivated on the farm are given together with other important factors to be used in determing the economic water use effieciency. The unit price and production costs for the different crops were obtained. These were the most recent figures from the farmers' accounts and/or invoices. The volume of water applied per season and the irrigation schedule estimated by farmers were also recorded in tables. For the irrigation schedule, in centre pivots there were different settings which enabled farmers to know what what amount of water is applied. The schedule also differed from crop to crop and season.

Table 4.1 showing an example of raw data collected from farmer II in the Baviaanskloof

crops	Year	area (ha)	date of planting	date of harvest	No. of days	type of irrigation	yield	Unit	Unit price	Unit2	cost	Schedule	Q	soil
											R/ha	mm/day	mm	
Maize	2010	6	14-Jan	03-Sep	224	Centre pivot	8	t/ha	2400	R/t	7000	5.36	1200	LS
	2011	6	november	after 5-6months	180		8					6.67		
Lucerne	2010	5	10years ago	evry six weeks	42	Centre pivot	3	t/ha	1100	R/t	1500	2.86	120	LS
	2010	3			42	sprinklers	3					2.86		
	2011	5	2years ago		42	Centre pivot	3					2.86		
Carrots	2011	3	11-Aug	1st wk Feb	168	drip	650	kg/ha				5	850	SL
Barley	2010/1	5	April	grazed by goats		Centre pivot	GF					0.60	25	/6wks
	2010/1	15				sprinklers	GF					0.60	25	/6wks
Sorghum	2010/1	Rotaion	November				GF					0.60	25	/6wks

*The Q given is farmers' estimation

4.2.2 Determination of physical and Economic WUE

Season 2010 data was used for calculation of the physical and ecoconomic WUE. Different calculations and conversions were done to get to the eWUE. First the total yield was calculated by multiplying Yield(t/ha) by the number of hectares. Total income was the product of Total yield and Unit price whilst the Total cost was Production cost (R/ha) multiplied by the number of hectares. The volume of water applied was converted from mm to m^3 by using the formula: water application(mm)/(1000* No. of ha*10000). These calculations were done for each crop but barley and sorghum which were used for animal grazing so were not included.

4.2.3 Results at Plot Level

The economic and physical water use efficiency was calculated for each crop. The physical WUE was obtained by dividing the total yield by the water applied (m^3). For the economic WUE the following formula was used (Total income- Total costs (R)) / water applied (m^3). Table 2 summarises the results of the calculations for one farmer.

Table 4.2 Showing the calculated results for farmer II

crop	yield	Total Income	Total Cost	Net incom	Water Use	Water Use2	WUE	eWUE
	kg	R	R	R	mm	m3	Kg/m3	R/m3
maize	48000	115200	42000	73200	1200	72000	0.67	1.02
lurcene	60000	66000	12000	93600	480	24000	2.5	2.44
lurcene	36000	39600			480	14400	2.50	
Total	144000	220800	54000	166800	2160	110400	1.30	1.51

The same procedure was done for all the farmers and the results summarised in one table 3.

Table 4.3 showing the economic and physical WUE of the Baviaanskloof farmers at plot level

farmer	crop	Area	irrigation type	Total yield	net value	Water Use	eWUE	WUE
		Ha		kg	R	mm	R/m3	kg/m3
i	Maize	15	centre pivot	120000	234000	1200	1.30	0.7
ii	maize	6	centre pivot	48000	73200	1200	1.02	0.7
v	maize	5	centre pivot	35000	40000	1400	0.57	0.5
i	lurcene	25	centre pivot	250000	262500	480	2.19	2.1
ii	lurcene	5	centre pivot	60000	93600	480	2.50	2.4
iii	lucerne	12	sprinklers	150000	176250	1000	1.47	1.3
iv	lucerne	5	centre pivot	50000	50000	600	1.67	1.7
v	lurcene	8	sprinklers	80000	320000	1176	3.40	0.9
vi	lurcene	30	centre pivot	300000	315000	347	3.03	2.9
ix	lurcene	13	centre pivot	200000	200500	480	3.21	3.2
iii	onion seed	5	drip	11500	34500	600	1.15	0.4
iv	onion seed	3	centre pivot	500	55000	625	2.93	0.0
v	onion seed	2	flood	500	-40000	900	-2.22	0.03
iii	carrots seed	2	drip	1300	135000	450	15.00	0.1
iv	carrot seed	5	centre pivot	4000	220000	625	7.04	0.1
i	potatoes	2	sprinkler	20000	54000	800	3.38	1.3
iii	onion bulb	1.6	micro sprinklers	50000	84000	450	11.67	6.9
iv	leek	3	centre pivot	2400	132000	718.8	6.12	0.1
v	tobacco	2	flood	4000	40000	436	4.58	0.5
v	barley	15	centre pivot	52500	40500	800	0.34	0.4

Quite notable differences were identified in the results amongst different farmers and crops. In maize, there was not much difference between farmer i and farmer ii as they both had a eWUE of 1. 3 and 1.02 R/m3 respectively and they both had a WUE of 0.7 kg/m3. Farmer v's maize crop however had lower eWUE and WUE of 0.57 and 0.5 respectively. This was because more water was used which lowered the WUE and also the net value of the farmer was less than for the other two farmers which resulted also in a lower eWUE. The amount of water applied by the first two farmers was the same hence the equal WUE. Farmer i had the highest net value probably because he had a larger area that is why his eWUE is the highest amongst the three farmers.

Large variations were identified in lurcene also among the farmers whith values ranging from 1. 47 to 3.21 R/m^3. the main reason was because of their net income from the crop, the farmeres who had a high eWUE also had a high net income whilst some had a lower income. The reason for a low income in case of farmer iv was because of high production costs as a result of planting. If it is a planting year, more costs are incurred. In terms of WUE farmer v and iii had the lowest of 0.9 and 1.3 kg/m^3 respectively. The lower values are as a result of high water use of around 1000mm compared to the others who used less water. This can also be because these two farmers used hand move sprinklers which have a lower efficiency than the centre pivots used by the other farmers.

For onion seed, the economic WUE was only high for farmer iv and lower for farmer iii, while for the fifth farmer it was even in the negative. The main issue was because of the germination percentage. Farmers only get paid if germination is more than 96%. Farmer v got a low germination less than the required and this can be linked to the furrow irrigation he used in relation to drip and centre pivot which have a higher efficiency. Also this was the first year of the farmer to try out onion seeds therefore there might have been mismanagement. In terms of WUE however, farmer iii has the highest value of 0.4 kg/m^3 and the other two both have a value of 0.03kg/m^3. This is because farmer iii used less water than the other two and his efficiency was high since he irrigated with drip irrigation.

For carrots, farmer iii had a higher eWUE than famer iv because farmer iii used less water than the other farmer which resulted in a low denominator hence higher value.

Looking at the variation in WUE of these common crops at plot level therefore, the differences in maize efficiency were as a result of water and net value, in lurcene it was because of a combination of net income and water use whilst in carrot seed and onion seed it was because of water. Therefore we can conclude that water is the main factor affecting and causing differences in eWUE and WUE at plot level.

4.2.4 Results at farm level

Shape file of the area was obtained from a fellow student who was doing his study in the area and using GIS a map and demarcation of the different farms was done. The map is important to show the location of the different farms in the basin.

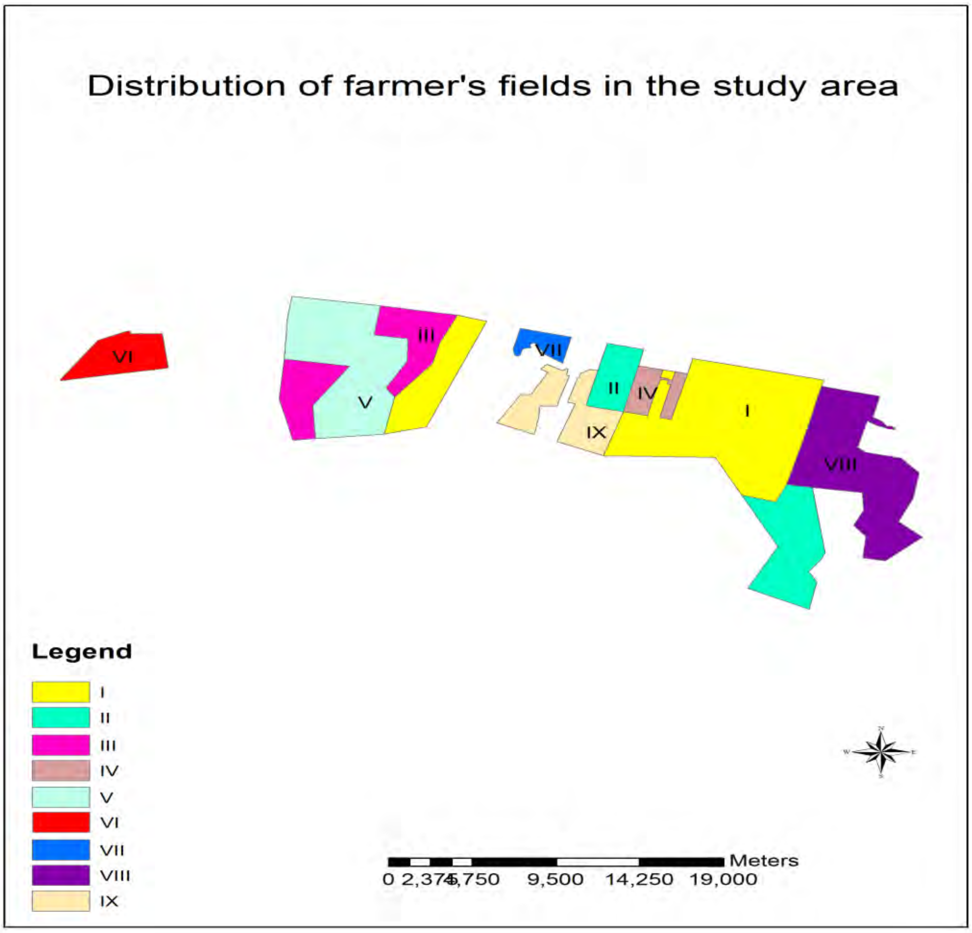


Figure 4.3 A map of the Baviaanskloof indicating farms' locations

In case of farmer I,II and III who have two potions of land on different areas, the potion with a written number is the one used for crop cultivation, the other is for tourism, game , livestock and bee keeping in terms of farmer III.

The total income, costs and water use per crop were summed up to derive the totals for the farm (see table 4. 2). Then the economic and physical WUE were determined using the same equations given above. The results from the different farmers were then combined into one table as shown in table 4.5 below.

Table 4.4 economic and WUE of irrigated crops in the Baviaanskloof at the farm level

Farmer	Area	Yield	Net Income	Water Use	eWUE	WUE
	ha	kg	R	mm	R/m3	kg/m3
i	110.5	402500	325500	2120	1.44	1.78
ii	32	72000	87600	1440	0.88	1.07
iii	27.2	67154	262800	1700	3.74	0.96
iv	52	15228	406180	2118.8	5.14	0.19
v	39	112000	40500	2009.8	0.17	0.47

Quite significant differences were noticed among the different farmers. There was also a very high range between the highest and lowest with the highest having 5.14 and the lowest having 0.17 R/m^3. The main contributing factor is the net income per farm. Farmer iv with the highest eWUE also had the highest net income and the others followed in the same order. The main reason why the last farmer had such a low eWUE may be attributed to the fact that two of his crops did not do so well in 2010 and he had a net loss which resulted in a very low income at the end.

Another contributing factor may be crop diversity. The first two leading farmers both had at least four different crops, of which three were vegetables. The third had three crops, one vegetable and potatoes. The forth only had maize and lucerne. Although the fifth farmer also had a variety of crops 2 of them did not do well as already explained above.

This contrasts to the results at plot level where water was the main factor affecting the eWUE. At farm level it shows that the net income is the main factor contributing to differences. Also the values at farm level are lower as compared to some at plot level. This is because the crops which performed both good and poorly are combined and the water use increases and this reduces the efficiencies.

4.3 Results from Gamtoos Valley

Daily weather data for the area was obtained from the Agricultural Research Council (ARC). The average ETo given by the ARC and total rainfall was combined into one table and line graphs created to show the distribution of rain and the trend of the ETo during the growing season 2010/1. The Cropwat could not be used as before because data on wind speed and sunshine hours was not available.

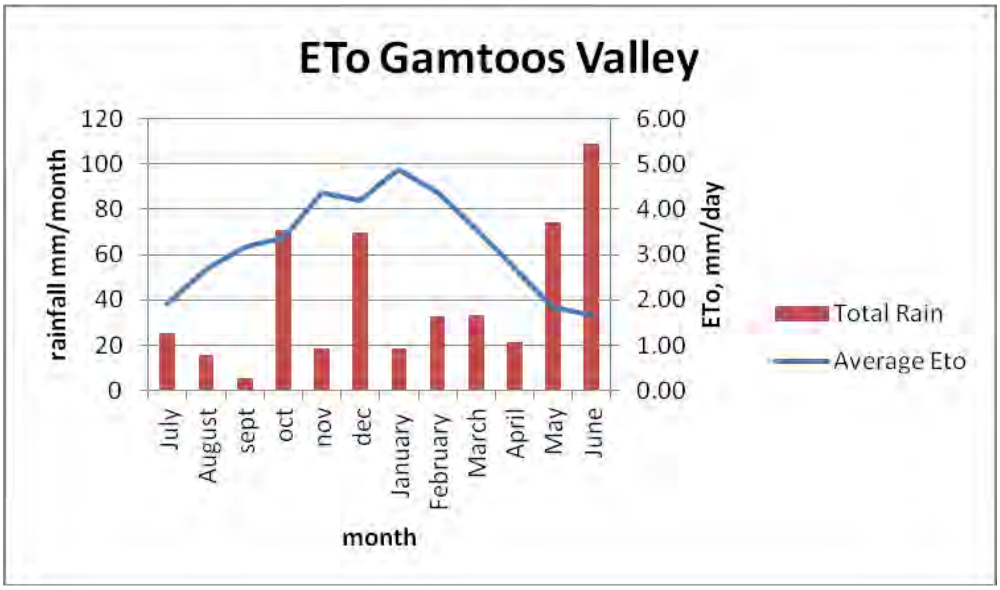


Figure 4.4 Graphs showing the ETo and total Rainfall of the Gamtoos Valley for 2010

The total rain received in the Gamtoos, 553. 3 mm was almost two times higher than in the Baviaanskloof. Most rainfall was received in June which is not normally the case as usually rainfall is received during the summer period. The ETo was also high during the summer period from September to March when the temperatures are high and lower during the winter months.

It is important to note that this was marked as a dry year and it resulted in the GIB cutting farmers' water allocations. Farmers only received 40 % of the normal water allocation. This, according to the GIB, resulted in farmers' to practice water trading selling water at a rate of R4/ m^3 which is quite high compared to the normal rate of R0.25/m^3.

In the downstream area data was collected from both the farmers and GIB. From the farmers I got basic information on the different crops, yield, prices and costs. From the GIB I got the volume of water applied per farm in m3 for the season July 2010 to June 2011. The results were recorded in a similar table to the one for Gamtoos. Table 4.5 shows an example of the data collected downstream. This is data from one farmer located in subdistrict ii near Hankey.

Table 4. 5 example of Raw data collected per farm from Gamtoos (farmer 1)

crops	area (ha)	date of planting	date of harvest	No. of days	Type of irrig	yield	unit price		cost	Water Use	Total WU
potatoes						kg/ha			R/ha	mm/day	mm
early crop	20	15Feb-20March	June	120	centre pivot	38000	2.3	R/kg	65000	2.08	250
late crop	30	20june-30 aug	19/11-20jan	150	centre pivot	45000	2.8	R/kg	68000	1.87	280
chicory											
early crop	6	April	January	270	draglines	35	1200	R/tonne	27000	1.19	320
late crop	10	august	march	240	centre pivot	40	1100		32000	1.46	350
citrus											
novas	0.85	1998		365	drip	62000	4	r/kg	45000		
valencia	5.3	1986		365	drip	60000	1.47	r/kg	40000		
navels	4	1986		365	drip	45000	1.07	r/kg	35000		
butternuts	10	october	dec	90	centre pivot	30000	1.4	r/kg	22000	3.22	290
	10	november	feb	120	centre pivot	30000	1.4	r/kg	22000	2.42	290
	10	January	apr	120	centre pivot	30000	1.4	r/kg	22000	2.42	290

Table 4.6 Example of collected water use (m^3) data per farm level in Gamtoos

2010						2011						
Jul	aug	sep	oct	nov	dec	jan	feb	mar	apr	may	jun	Total
9230	4880	26650	17860	15190	12690	15050	10140	40150	27250	10440	5960	195490

The volume of water was recorded from meter readings by the GIB field assistant after which they entred the data in their computer programme. Most farmers in the Gamtoos did not know the volume of water applied per crop hence not all crops are included in the calculations of eWUE at plot level.

4.3.1 Results at Plot Level Gamtoos

Table 4.7 calculated results at plot level for farmer 1

crop		Total Yield	Total income	Total Cost	Water Use		eWUE	WUE
		kg	ZAR	ZAR	mm	m3	R/m3	kg/m3
potatoes	Early	760000	1748000	1300000	250	50000	8.96	15.2
	late	1350000	3780000	2040000	240	84000	20.71	16.1
chicory	Early	210000	252000	162000	320	19200	4.69	10.9
	late	400000	440000	320000	350	35000	3.43	11.4
butternuts		900000	1260000	660000	290	87000	6.90	10.3

Table 4.7 shows the results of the crops that the economic and physical WUE efficiency was calculated for that one particular farmer. The same calculations were done for the other for

which there was enough water data per crop. The results were summed up and are presented in table 4.8

Table 4.8 economic and Physical efficiency for Gamtoos at plot level

Farmer	crop	season/variety	Area	Net income	water use	yield	eWUE	cWUE
			ha	R	mm	kg	R/m3	kg/m3
1	Potatoes	Early	20	448000	250	760000	8.96	15.2
		late	30	1740000	240	1350000	20.71	16.1
	Chicory	Early	6	90000	320	210000	4.69	10.9
		late	10	120000	350	400000	3.43	11.4
	Butternuts		30	600000	290	900000	6.90	10.3
2	Pasture		280	4480000	315	5600000	5.08	6.3
3	Maize		2	22452.6	422	7839	2.66	0.9
4	Pasture		300	7800000	444	5400000	5.85	4.1

Form the results that could be calculated at plot level only pasture was common among two farmers. Farmer 4 had a slightly higher economic efficiency but lower physical WUE than farmer 2. The reason for a higher eWUE was because of a higher net income but lower yield and higher amount of water use resulted in a lower physical WUE.

The late potatoes had both a higher economic and physical WUE as a result of more net income and also higher yields. The difference is less for physical but much higher for economic WUE which is more than double. This is also explained by a high margin between the net incomes; potatoes might have been in higher demand in a later period.

For chicory the eWUE was higher for the early crop than late one despite the fact that the later one had a higher net income and yield. This can be attributed to water use, as the late crop used more water than the early crop which resulted in the lowering of eWUE. The physical WUE was higher for the late crop than for the first crop. This is because of the high yield for the late crop which in turn increased the WUE.

Looking at all the crops, potatoes had the highest physical and eWUE and this can be best explained by the low quantity of water applied to the crops. Of all the crops it is the one with the lowest water use also, the yields and net income were also relatively high. Maize on the hand had the lowest physical and WUE. All the three factors were lower for the crop mainly because it was cultivated on a smaller scale by a poor resource farmer. The marketing was also done locally and this explains the low net income.

4.3.2 Results at Farm Level: Gamtoos

Below is a map giving an indication of the location of the Gamtoos farmers. It is important to note that this is a rough estimation and not according to scale. Different ward maps for the area can be found in the appendices.

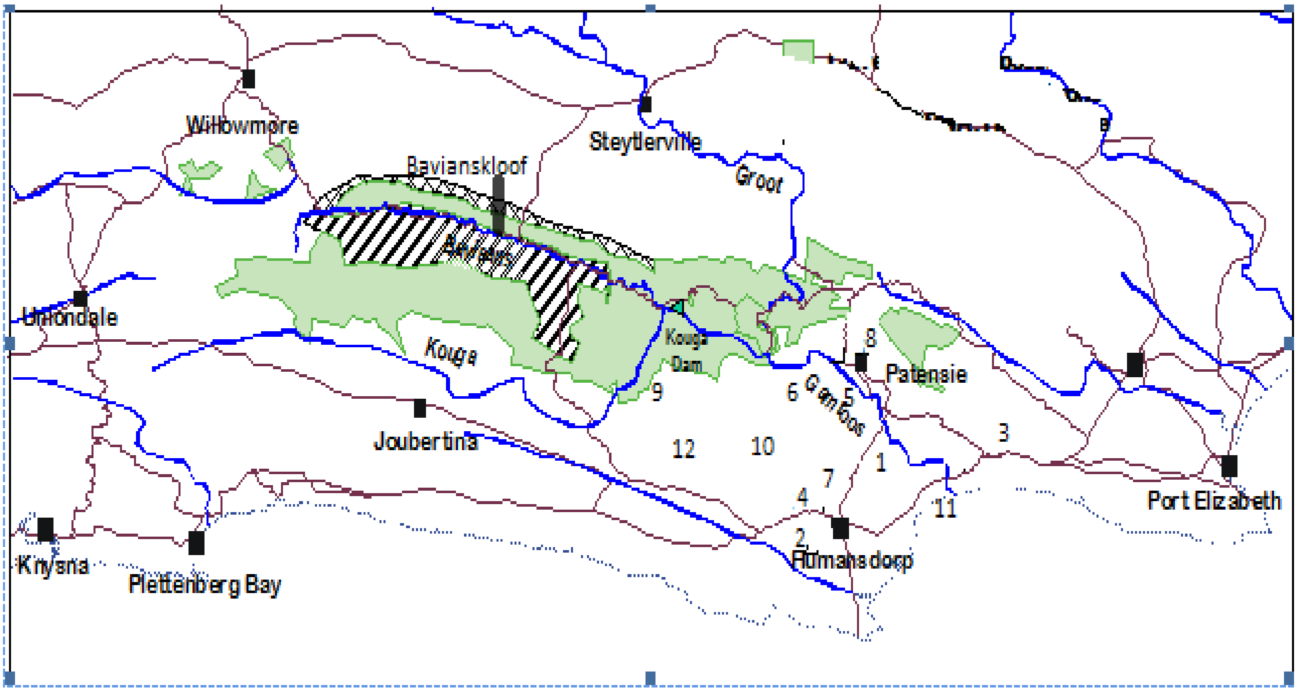


Figure 4.4 A map of the Gamtoos catchment showing location of studied farmers

Source: (Alison Joubert 1999)

On the map areas close to the Kouga Dam to Patensie fall under subdistrict 1, those around Patensie form subdistrict ii and those close to Humansdorp subdistrict iii.

The incomes, costs and yield were summed up for all the crops and the same formulas from above used to calculate economic and physical WUE at farm level. The same procedure as described for the Baviaanskloof. Table 4.10 summarises the results of all the farmers. For the last four farmers who are highlighted the results were much higher than the rest and were therefore not considered in the comparisons with the other catchment. The reason for these high values is because the farmers did not give adequate data on the income, production cost and/ or yield and therefore I had to use the trends from the farmers.

Table 4.9 economic and physical efficiencies at farm level for the Gamtoos Valley

Farmer	subdistrict	DFM	Crops	Area	Net Income	Water use	eWUE
				ha	R	m3	R/m3
1	3	no	Citrus	10.15			
			Chicory	16			
			Potatoes	50			
			Butternuts	30			
			total	**116.3**	**2991750**	**195490**	**15.30**
2	3	yes	Rye/Grass	280	4480000	882650	5.08
3	3	no	Maize	3	22453	8433	2.66
4	3	yes	Rye/Grass	300	7800000	1333270	5.85
5	2	yes	citrus	71.55			
			cucumber	4			
			total	**75.55**	**2368835**	**210760**	**11.24**
6	1	yes	citrus	91.57			
			potatoes	17			
			total	**108.57**	**3037120**	307590	**9.87**
7	3	no	sweet potatoes	8			
			maize	110			
			korog	70			
			pumpkins	4			
			cabbage	2			
			squash	1			
			total	**195**	**1553833**	**267609**	**5.81**
8	2	no	citrus	97.7			
			potatoes	18			
			pumpkins	8			
				123.7	**38379**	**219970**	**0.17**
9	1	yes	citrus	82.7			
			potatoes	22			
			chicory	17			
			total	121.7	3998869	184682	21.65
10	2	yes	citrus	31.21	2432398	61692	39.43
11	3	yes	citrus	67.8	6765656	112250	60.27
12	1	yes	Citrus	41			
			Potatoes	29			
			total	**70**	**8415500**	**138510**	**60.76**

The table above shows the net income, water application, yield, eWUE of the Gamtoos valley farms. The different crops cultivated per farm are also included to give an indication of the farm's cropping intensity.

Note that most highlighted are citrus farmers and it is much likely if accurate data was used, the eWUE of these farms was going to be high compared to other farms. This is because the farmers use more advanced technology for citrus like drip irrigation and DFM system. They also get a lot of income from their exports and citrus is the main enterprise in the area.

For the first farmers not highlighted, there was a very wide range in the physical and eWUE. Farmer 1 had the highest eWUE and this is because his water use was low although he has a lot of hectares. The other three farmers that follow after him are all citrus farmers and their water use is also relatively low especially compared to the dairy farmers. They have a eWUE of 11.24, 9.87 and 6.31 R/m^3. The reason why the third farmer has a lower than the other citrus farmers is because of the low net income he had in relation to the rest of the farmers. This was because he had to incur more production costs since he had to send his fruits to the pack house whilst the other farmers do the packing on the farm.

Overall, farmer 3 has the lowest having a eWUE of 2.7 R/m^3. This was significantly low compared to the highest of 15.30 R/m^3. The reason is farmer 3 is a smallholder farmer who is still struggling to make ends meet whilst the other farmers are more established big farmers. Also the small farmer only has a small area and sells his yields locally while the others are more into exporting. This has resulted in a very low income which in turn lowers the eWUE.

Farmer 2 and 4 also had a low eWUE after farmer 3 and these are dairy farmers. The main reason for the lower eWUE is their high water use and they also have large fields. High water use may also be attributed to the fact that they irrigate those large fields throughout the year. Farmer 8 was also in the same lower range with the dairy farmers with a eWUE of 5. 81. In this case it was mainly because of the low income in comparison to the dairy farmers. The farmer had no citrus crops and cultivated different crops instead.

Generally, the farmers who have citrus had a higher eWUE because of more income from the exports and high irrigation efficiencies since farmers use mostly drip irrigation and centre pivots and have soil moisture probes that guide them.

Both water and net income affected the eWUE at farm level in the Gamtoos whereas at plot level the yield was also another contributing factor. There was no major difference in the Gamtoos between the plot and field level values. The values at farm level were still high and in some case the same where it was a sole crop. This is so because at least all the crops had good values.

4.3.3 Results at Basin Level

The yield, income, costs and water use totals from every farmer were all entered in one table and summed up. The grand total of the four factors was determined and calculation of the economic and physical done from there using the same formulas given in earlier paragraphs. This was done for both catchments. For the Gamtoos catchments, the last four farmers were not considered in order to eliminate bias. The results at basin level are summarised in table 4.11.

Table 4.10 economic and physical efficiency for the Gamtoos valley and Baviaanskloof valley (below)

	Farmer	Total Yield	net income	WU	eWUE
		kg	R	m3	R/m3
	1	590000	550500	316000	
	2	144000	166800	110400	
	3	212800	429750	166200	
	4	56900	457000	101564	
	5	172000	400500	310807	
baviaanskloof	**Total**	**1175700**	**2004550**	**1004971**	**1.99**
	1	4170700	2991750	195490	
	2	5600000	4480000	882650	
	3	7839	22452.6	8433	
	4	5400000	7800000	1333270	
	5	2523291	2368834.949	210760	
	6	5863.35	3037120.016	307590	
	7	8515000	1553833.333	267609	
	8	7452600	1388379.333	267609	
gamtoos	**Total**	**33675293.35**	**23642370.23**	**3473411**	**6.81**

There was a very significant difference between the two catchments with the downstream almost 6 times higher than the upstream catchment both for economic. There was a very large difference in the net income, water use and total yield with the Gamtoos having higher values in all the factors. The high differences in the two catchments can be attributed to a number of reasons such as market possibilities, cropping intensities and irrigation scheduling techniques. The level and/or intensity of agriculture in the two catchments are very much different, with the downstream highly intensified and making use of more advanced technology and precision agriculture. They also have a better market than their upstream farmers whose location makes it challenging to have good markets.

4.4 Comparing EWUE of the Gamtoos and Baviaanskloof catchment

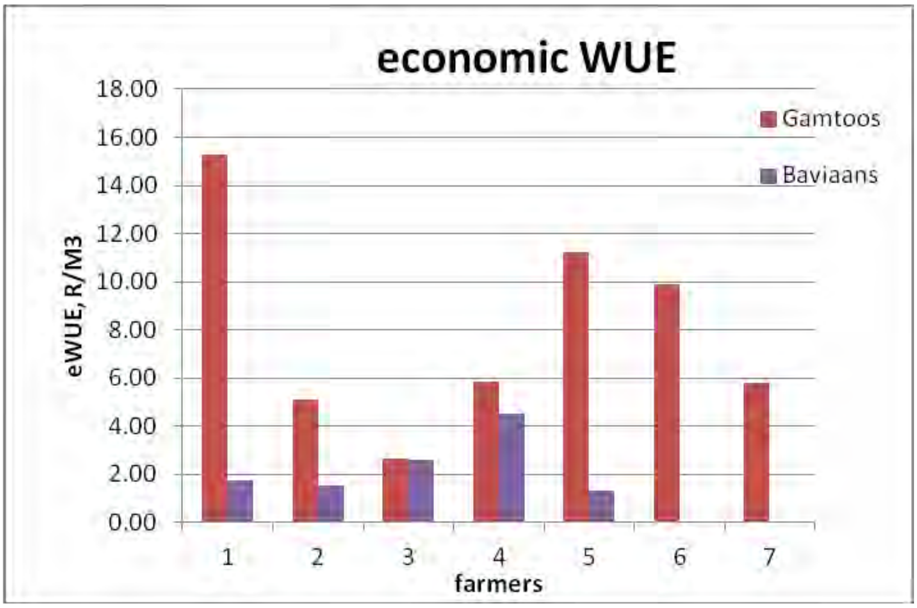
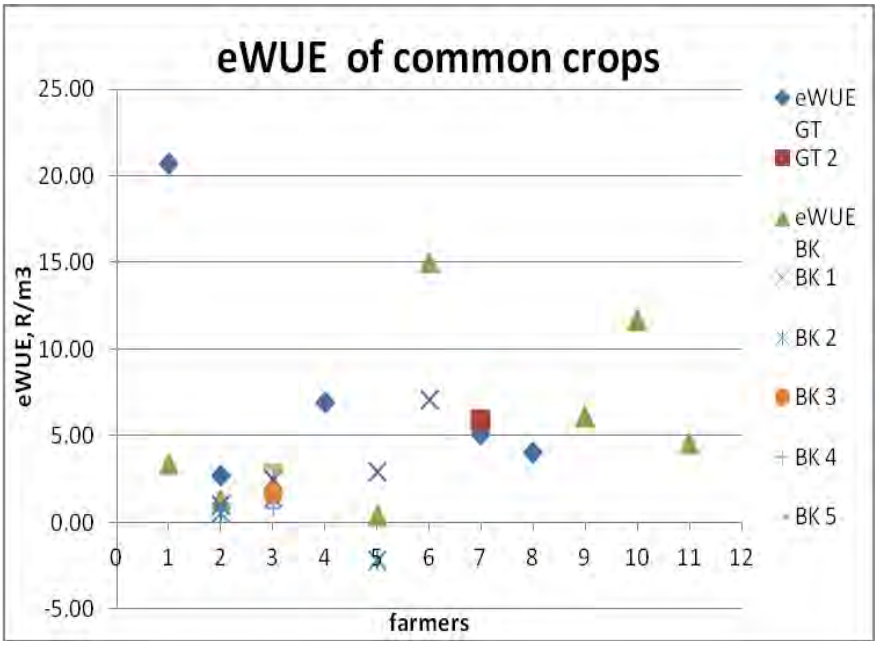


Figure 4.5 Showing the difference in the economic water use efficiency

The difference in the economic WUE is illustrated in figure 4.5. A significant difference was noticed in the economic WUE of the two catchments. The 2 farmers with highest eWUE in the Baviaanskloof were almost equal or in the same range with Gamtoos farmers with low eWUEs. The very lowest eWUE were from the Baviaanskloof. The highest were from Gamtoos especially the three citrus farmers who had high figures. The main reason for the sharp differences is the net income which is quite high among Gamtoos farmers and low for the Baviaanskloof. The figures are highlighted in table 4.11. Many factors contribute to these differences, for example the market is much better for the Gamtoos farmers than the others. They also cultivate different crops with the Gamtoos farmers being more intensive and use precise agriculture which results in a higher efficiency generally.

4.4.1 Comparison of the economic use efficiency of the common crops

The averages of different farmers' values of different crops were calculated and tabulated as in table 4. 11 (Please see appendices for the rest of the crops). These were then illustrated in a bar graph to make the distinction more clear.



1	potatoes
2	maize
3	lurcerne
4	butternuts
5	onion seed
6	carrot seed
7	pasture
8	chicory
9	Leeks
10	onion bulb
11	tobacco

Figure 4.6 economic WUE of the common crops

The economic WUE for the most major crops in the area are shown in the figure 4.6. There are only two crops, potatoes and maize that are found in both areas and in the case of potatoes only one farmer grows them in the Baviaanskloof. Each farmer has a different shape and/or colour. For the first crop, potatoes there is a huge difference between the two farmers with the highest being from Gamtoos. It is also the the highest among all the crops. Carrot seed and onion bulb follow then butternuts and leeks. There is no significant difference between the pasture in the Gamtoos and the other vegetables from the Gamtoos. In case of maize the Gamtoos farmer was slightly higher than the other Gamtoos farmers.

Table 4.11 comparison of economic and physical WUE for common crop in both catchments

		Gamtoos					Baviaanskloof				
crops	Replicates	yield	water	net income	eWUE GT	WUEGT	yield	water	net incom	eWUE BK	WUEBK
		kg/ha	mm	R	R/m3	kg/m3	kg/ha	mm	R	R/m3	kg/m3
potatoes	1	38000	250	448000	8.96	15.2	10000	800	54000	**3.38**	1.3
	2	45000	280	1740000	20.71	16.1					
Average					**14.84**	15.6				**3.38**	**1.3**
maize	1	7839	422	22453	2.66	0.9	8000	1200	234000	1.3	0.7
	2						8000	1200	73200	1.02	0.7
	3						7000	1400	70000	0.57	0.5
Average					**2.66**	**0.9**				**0.96**	**0.61**

There is a large difference in both the physical eWUE of both crops with the value of Baviaanskloof far below of the Gamtoos. The reason is that the farmers in the Gamtoos used less water 250mm whilst more water was used in the Baviaanskloof, 800mm. the use of less water in the Gamtoos is because of the planting period for the early crop which is during the winter season and there is less ETo. Also more rainfall was received in the area than upstream which also results in a better WUE for irrigated agriculture. The yield was also almost 3 times higher in the Gamtoos (30t/ha) than in the Baviaanskloof (10t/ha) and this also ended up in less net income.

In the case of maize the main issue is water which resulted in lower values in the Baviaanskloof. The later used much more water, almost three times more than used by the farmer from Gamtoos valley. One farmer from the Baviaanskloof even used more water than others and had a lower yield which resulted in him having a lower value and hence reducing the average also.

Looking at all crops from the Gamtoos, potatoes had the highest eWUE followed by butternuts and chicory (keep in mind that citrus had the highest although I am not using the data here because of unreliablility but still probably highest). This is also because of the water use by the different crops as is shown in Table 4. 9. In the Baviaanskloof carrots are the highest followed by leeks, potatoes, onion seeds, lurcerne and maize in that order. The lower values in maize were as a result of high water use compared to the other crops. For lurcene , the low values can be explained by the low net income as the figures are shown in Table 4. 3.

4.5 Water Productivity for Baviaanskloof and comparisons of Farmers' estimates to the model output

Water productivity calculation was done for the year 2011 using data from CropWat model as well as that obtained from farmers. The rain and ETo module were entered with daily weather data obtained from the ARC. For the crop module, more crop information was obtained from the SAPWAT programme. The different crops were selected from the SAPWAT program's crop file and period of planting, the program then provided with the number of days for the different development stages and provinces in South Africa. In this research, the Eastern Cape Province results were used. The other crop parameters were from the FAO set as default in the Cropwat model.

During the simulation, where there was a frequent interval of application and more water was used, the Kc value was also increased. And for a crop like maize which stayed in the field until drying period the number of days were also adjusted to suit the time period.

After obtaining the irrigation schedule, settings were changed and adapted to suit the amount applied given by farmers. This was done using by pressing options icon and then changing the irrigation timing (irrigation at fixed interval per stage) and the irrigation application where the fixed application depth was set. The efficiency was also changed to suit the type of irrigation system used. In centre pivots an efficiency of 80% was used whilst 90% was used for drip systems.

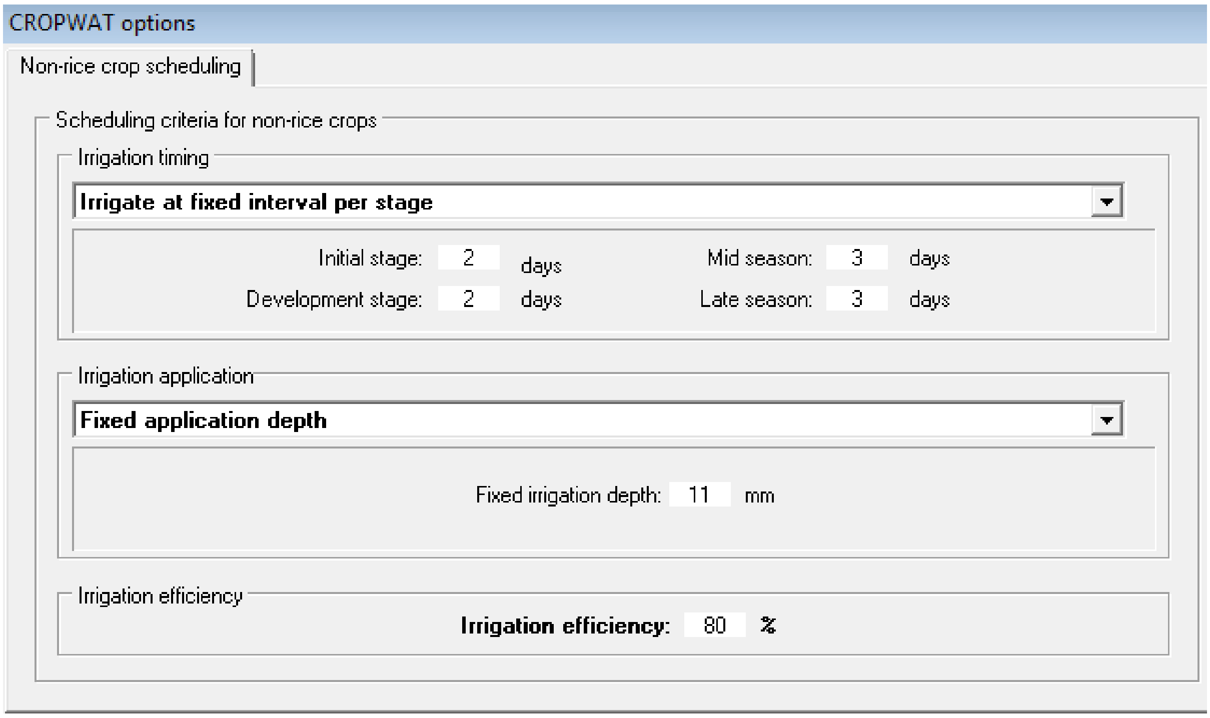


Figure 4.8 showing an example of CropWat options for the maize crop

The above figure shows the options entered for farmer ii's maize crop. The values were chosen to suit to the 1200 mm gross application given by the farmer. The output schedule gave an output of 1223.8 mm which is close to 1200mm. The output was also illustrated in a graph as shown in figure 4.6.

The graph represents crop water requirements and is guided by three important factors; field capacity, total available moisture (TAM) and readily available moisture (RAM). TAM is the available balance in the root zone between in the FC and wilting point whereas RAM is a portion of TAM readily available to the crop. The depletion (red bars) should not go beyond RAM to avoid water stress to the crop. FC is the amount of water that can be held by soil; values above field capacity reflect too much water in the soil.

The graph shows that much more water than required was applied during the growing period for maize. This can be shown by the many depletion bars above the field capacity. The actual water used by the maize crop was only 676.4 mm which means the rest of the water was lost as deep percolation. This accounts for slightly less than half of the gross water applied. The over application of water is probably because there are no soil moisture measurements done between irrigations which leads to farmers not knowing exactly when and how much to apply.

Figure 4.7 also has over application but to a lesser extent than the other. For carrots the gross application was 860mm whilst the actual water used by the crop was 583.1 mm which means almost half was lost as deep percolation. It is still a lot of water but less than for maize probably because for the carrots drip irrigation was used which has a higher efficiency and applies less water per given time.

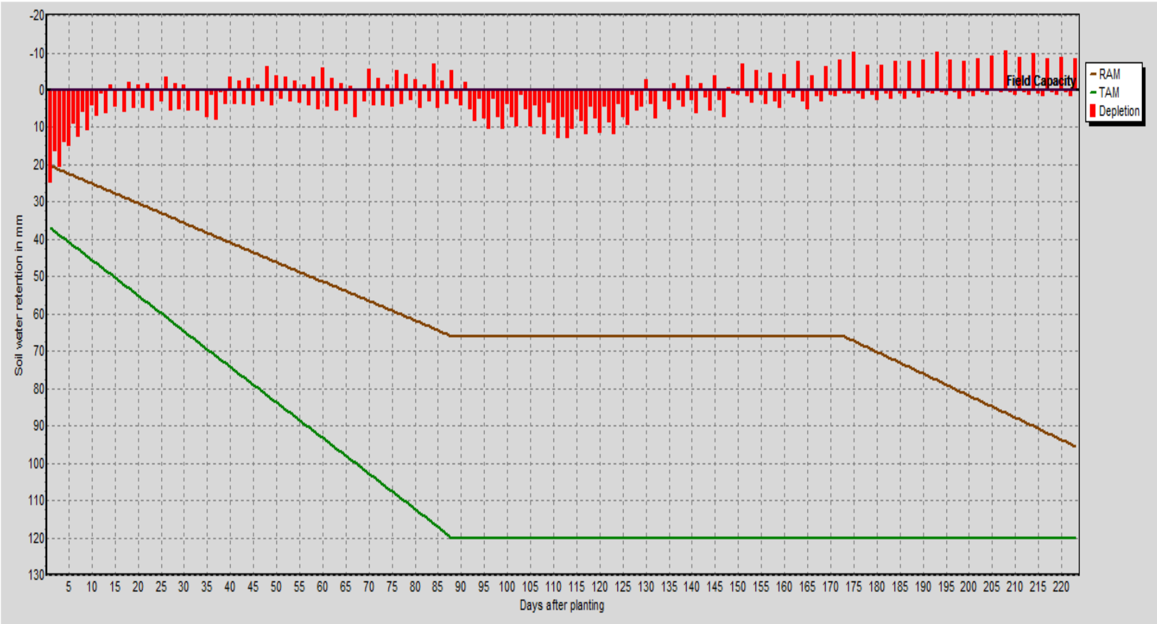
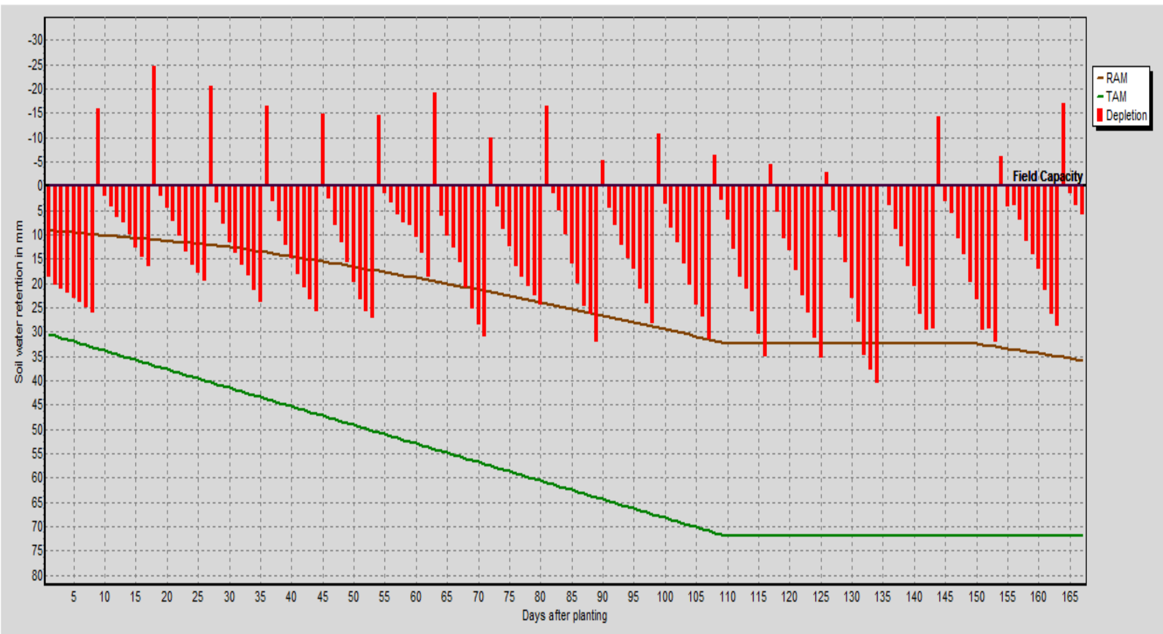


Figure 4.9 Showing irrigation schedule output for maize (above) and carrots (below)



The simulations were done for all the farmers who had crops during the year 2011. For the maize graph the first days starts with the depletion of the antecedent moisture. During the initial and development stage, not much water is depleted as the crop is still young and using less water, resulting in over irrigation as indicated by the bars above the field capacity. Approaching the mid- season, however, the crop is using more water and although the depletion does not go further down, still the field is adequately irrigated. At this point, there are no bars over the field capacity hence no over irrigation.

The distribution of water differs per crop, with schedule, soil and other factors and this affects the graph. Like the carrots seed graph is different from the maize. In carrots more depletion is allowed and only once in a while is there over irrigation. At times also the depletion even goes beyond the RAM.

More graphs for the different crops and conditions are shown in the appendices and it is interesting to see the variation in the pattern of water depletion and refill. The figures for gross irrigations and actual water use from the simulations were combined and are presented in table 4.12 for discussion.

Table 4. 12 Cropwat simulation results for the different crops and farmer schedules

crop	farmers	Tg	Act WU
wheat	i	1245	465
maize	i	1225	742
	ii	1223.8	676
	v	1461.3	757
carrot seed	ii	860	583
	iii	462.2	494
	iv	605.6	445
onion seed	i	613.3	470
	iii	613.3	488
	iv	630	542
	v	888.9	616
tobacco	v	434.3	280
Onion bulb	iii	460	144
leeks	iv	712.5	794
potatoes	i	800	649

Tg is total gross irrigation, Act WU is water use by crop

From the CropWat results, the wheat crop tends to have most losses which amounted to 468 mm almost half of the net irrigation. This is mainly because the actual water used by the crop is low yet a lot of water is applied for irrigation.

For maize, there were minor variations among the three farmers. The losses were higher for farmer since he applied more water than the other farmers. The net irrigation for the first two farmers was almost equal but there was however a slight variation in losses and actual water use by the crop. This minor difference can be because of the differences in planting dates as farmer I planted in October and the other in November.

In carrot seed farmer iii had the lowest losses and net applications. This is because of a high efficiency since he used drip irrigation and he is also located more upstream of the other farmers. Other main reason is the difference in irrigation schedules of the farmers which affects the pattern distribution and the losses.

Variations were also observed in onion seeds, with farmer iii having the least actual crop water use followed by farmer iv, v and i respectively. However in terms of irrigation losses the order was in reverse with farmer i having minimal losses. This can be attributed to difference in soil type. Farmer i reported having clay soils and these tend to store more water and reduce losses. The low water use from farmer iii is most likely because of the use of localised irrigation.

4.5.1 Optimal Cropwat Modelling

The model was also run optimally without any alterations to the options to check what would be the best schedule for efficient irrigation. This helped to see the lowest possible amount that can be applied without causing stress. The difference in the optimal and farmer estimates shows over application. The ETo, rain crop and soil modules were entered with data from farmers as before. An efficiency of 90% was used in the simulation. From the output, the gross and actual irrigation amounts were recorded for the different crops. The gross irrigation was used for comparisons with the gross amounts given by the farmers.

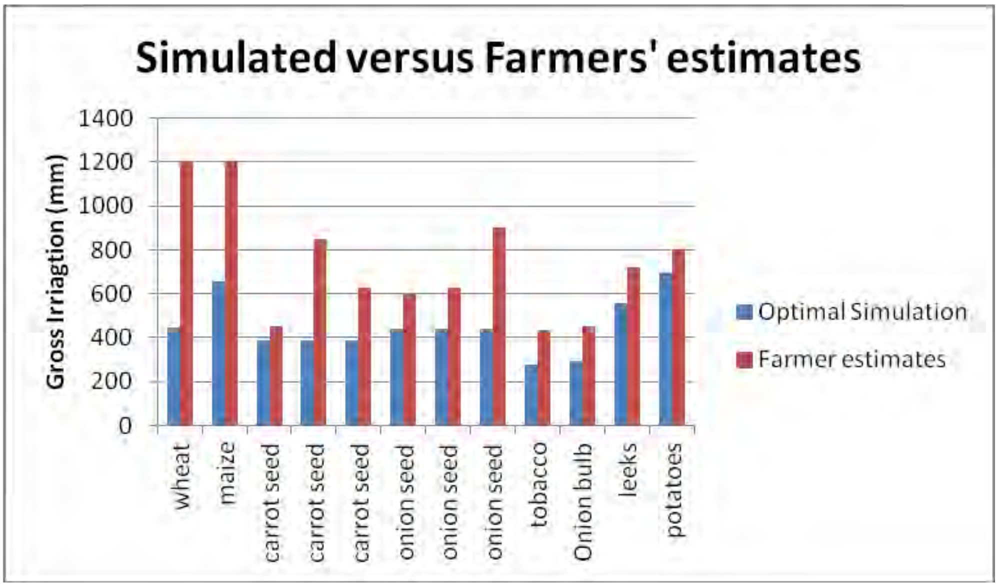


Figure 4.10 Comparison of the Simulated and Farmers recorded gross Irrigation applications

The comparison of the total gross irrigation applications of the data obtained from farmers and that from the simulation are presented in figure 4.6. In all crops the volume of water applied by farmers is more than that from the simulation. The difference is was the largest for wheat, maize and one replicate of carrot and onion seed. For the other crops the difference was smaller.

The high water use in these crops is also reflected by the low WUE as shown in figure 4.7.

For tobacco and onion bulb the figures are slightly different which means the two applications almost tally together. Overall there is not much difference expect for in wheat and maize which means the farmers applications are more in line with the correct crop requirements.

Looking at the balances between the farmers' estimates and the simulated results, approximately 40% (farmer estimates- simulated)/farmers' estimates) will be saved if farmers' cut down the water use. This also results in the cutting of pumping costs for them.

4.5.2 Water Productivity for Baviaanskloof Crops

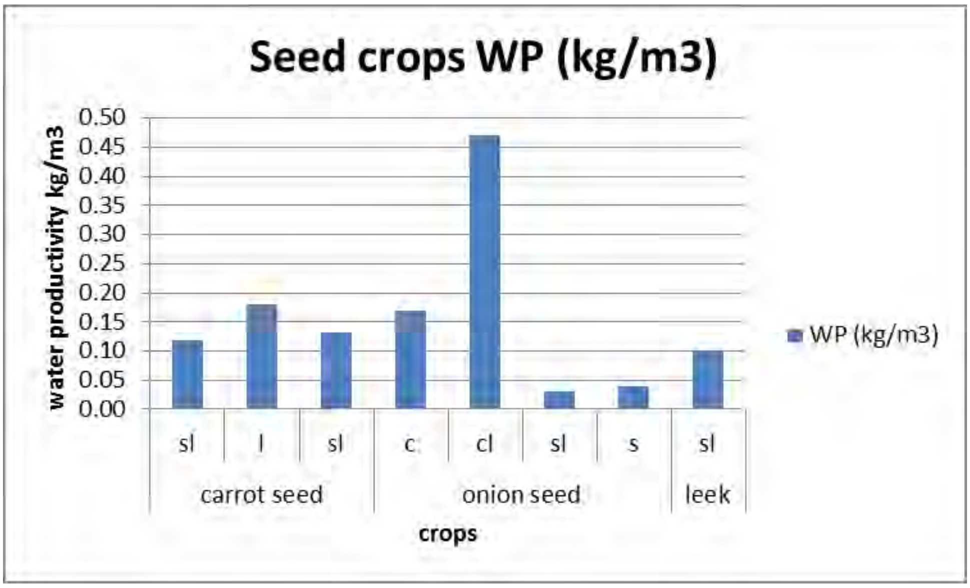
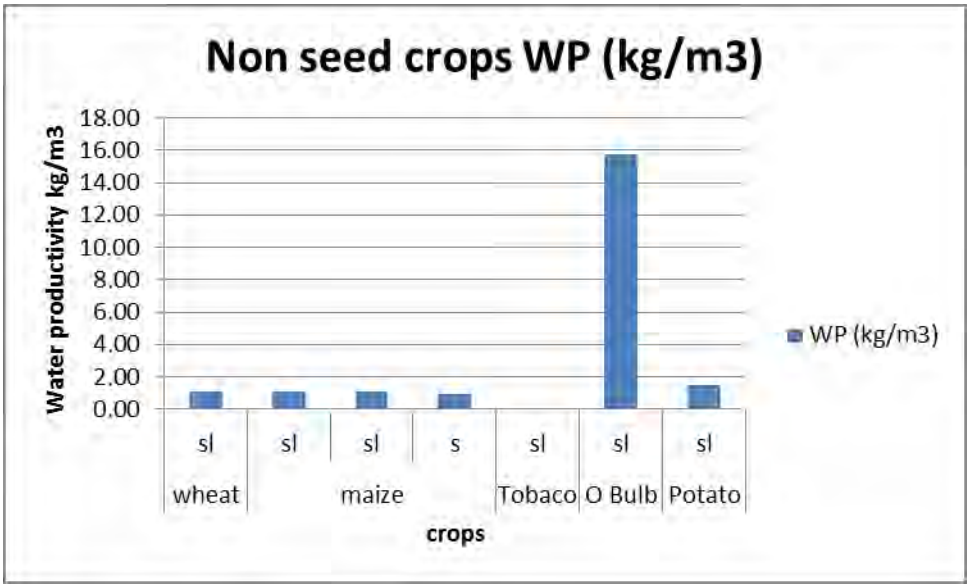


Figure 4.11 Water productivity of different seed (vegetable) above, and non seed (below) crops in the Baviaanskloof

*Sl - sand loam, l - loam, c - clay, cl - clay loam

*Every soil type represents a different farm with different conditions



For the seed crops and leeks shown in the top graph carrots and onion seeds, both had relatively high water productivity on the soils and conditions found in the different farms in the Baviaanskloof. For onion seed however there was a differentiation with the first two farms having a higher productivity than the other two. This is because of yield and water use as reflected earlier in the chapter. The yield for the first two was higher 800kg/ha whilst for the other it was 500kg/ha. Another factor which might be contributing to these differences is the differences in soil type among the farmers. The first have clays whilst the others are sandy loam and sand.

For the non seed crop onion bulb had the highest productivity than the rest of the crops followed by potatoes, wheat, maize and tobacco. The variation is largely based on water but also the weight of the crops. Onion bulbs are harvested fresh and have a heavier mass than the other crops, as do potatoes. Comparing between the two, potatoes use more water that than onion bulbs that's why the productivity is lower. The same applies to maize, the actual water use is higher than for the vegetables (refer to table 4.12) and this also resulted in low WUE. The more water means a higher denominator and a lower WUE value. The differences among the three farmers who had maize are also because of the actual water use by the crop (shown in table 4. 12). For farmer ii it was less hence the higher productivity than for the other two.

4.5.3 Water Productivity versus Water use Efficiency

The difference in water productivity and water use efficiency is highlighted in figure 4.7.

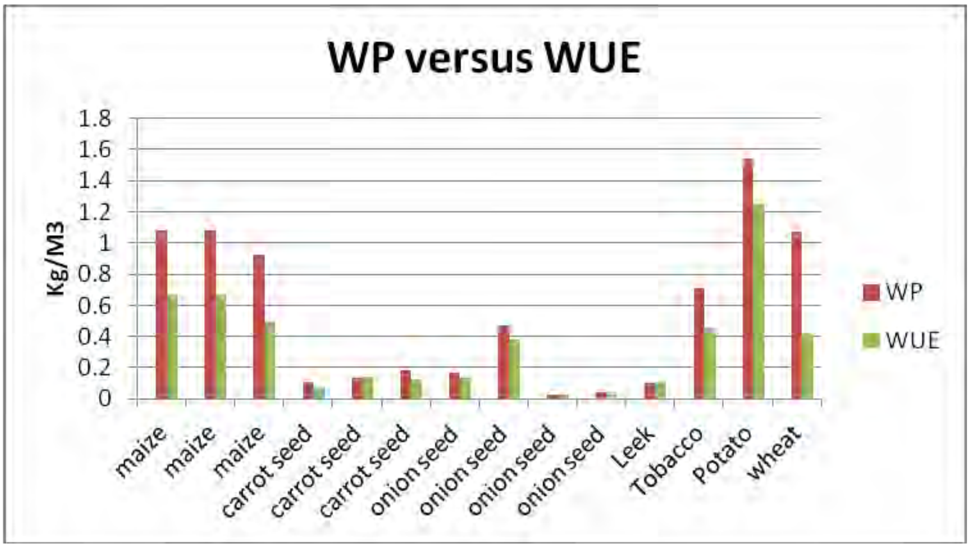


Figure 4.12 comparisons of WP and WUE for the Baviaanskloof crops

The figure shows that for most crops the water productivity is higher than WUE. This is the case in tobacco, potato, wheat and maize. The margin was very high in the case of wheat and maize. This is because of the difference in the actual water used by the crop and the water applied. In these crops the gross application was far much higher than the water used by the crop which resulted in a high WUE.

For the seeds and leeks the WP and WUE were almost the same indicating that most of the water applied by the farmers was used productively by the crops. In the case of leeks the WUE was slightly less than the WP. This is because the estimated actual water used by the crop from Cropwat was higher than the gross application by the farmer.

4.6 Quantity of water used in Baviaanskloof

To quantify the quantity of water used per farm, livestock data was also collected since livestock production is quite common in the area. The different livestock per farm were recorded and their numbers. Through literature review the water consumption of livestock was obtained. Since there was a range and many factors affecting the water consumption, the average figure was used in the calculation. The water use was calculated by multiplying water use per animal by the number of animals and the frequency of use. The main water use by animals was drinking. Dipping did not use so much water and in most cases farmers did not dip their but instead used chemical drops to control ticks. The number and variety of livestock also varied from farm to farm. Below is an example from one farmer, the same was done for each and every farmer (see Appendices)

Table 4. 13 an example of data collected for livestock water use

livestock	number	Uses	Quantity of water	unit	Frequency	unit2	water use (m3)
goats	500	dipping	3000	L	3	times /year	9
		drinking	4	L	365	days	730
cattle	60	dipping	40	L	1	per 3 month	0.16
		drinking	30	L	365	days	657
Total LWU							**1396.16**

The totals from every farmer for both crop and livestock were combined in one table and summed up to give the total amount of water used in the valley. For the crop water use, the figures were based on the crops cultivated during the season 2011. The water use for every crop was calculated in cubic meters based on the area under cultivation for the year 2011.

Table 4.14 quantification of agricultural water use per farm and the whole Baviaanskloof catchment

Farmer	crop WU	l/stock WU	Total WU
	m3	m3	m3
I	1118000	10403	1128403
II	122750	1396	124146
III	216900	840	217740
IV	101564	1711	79064
V	404444	1781	406225
VI	104000	876	104876
VII	168500	219	168719
VIII	0	1270	1270
IX	74400	365	74765
Total	**2236157.6**	**17225**	**2229172**

From the values shown in table 4.1 it shows that more water is used for crop production than for livestock. It accounts for approximately 98% of the total agricultural water use by the Baviaanskloof farmers. There is a large variation also among the farmers between the largest and the smallest user. It is important to note that the smallest value is also because the farmer is not involved in crop production but only beef cattle. The gross volume of water obtained is almost the same with the 2 million m^3 recorded by DWARF, 2004 in the Internal Strategic Perspective, and 1.75 million m^3 reported by Jansen in 2008. It is not clear how DWARF came to the figure but Jansen estimated the water requirements for the different crops grown during that year and he added 5-15% to account for evaporative losses (Jansen 2008).

4.6.1 Future Agricultural activity in the Baviaanskloof

The agricultural production in the Baviaanskloof is currently at stake as reflected by the results. The farmers are struggling and the recurrent drought conditions are making matters worse. In an interview with one farmer he openly said ‘If anyone wants to come and buy this farm, I would sell it straight away’. This statement was drove by the frustrations the farmers are facing in crop production. In a study carried by Jordy Stokhof de Jong in 2011 where he worked with farmers about the future of Baviaanskloof, he made a scenario which the farmers agreed upon (see appendices). This included a transition to citrus production in the future. In order to see if this is sustainable with the available water resources, calculations were made.

The calculations were based on the five farmers who have significant areas devoted to crop production, the ones WUE was determined for. The number of hectares under cultivation was determined per farmer. Then the optimal simulation was run using Cropwat to see the water requirement of citrus. The weather data used was for 2011, and the crop data was the FAO default values. The simulation was started in July when the highest rainfall (2011) was received and the percentage TAM was dependant on that. The irrigation efficiency used was 90 % assuming drip irrigation will be used. The total gross irrigation from the output was 664.8 mm per hectare per year and this was used for the calculations. The efficiency of rain from the CropWat simulation is 34.9 % which means 131 mm of the total 375.6 mm was effective. The gross irrigation was multiplied by the number of hectares to give the total required amount of water. The calculation was repeated for quarterly percentages of total hectares. The total required for each quarter was subtracted from the total current crop water use by the five farmers (balance 1) and all farmers (balance 2) to compare the water needs for cultivating citrus to the water used currently on the current mix of crops.

Table 4.15 calculation of possible hectares for citrus production in the Baviaanskloof

% ha	Area	water use	Required	Balance 1	Balance 2
	ha	mm	m3	m3	m3
100	270.7	665	1799614	164044	436544
75	203.025	665	1349710	613947	886447
50	135.35	665	899807	1063851	1336351
25	67.675	665	449903	1513754	1786254

The results show that the amount of water currently used for crop production can be sustainably used for citrus production.

Chapter 5: Discussion

From the results presented in the last chapter it is evident that there are significant differences between water use, efficiency, and productivity between the Baviaanskloof and the Gamtoos valley. The differences are mainly centred on three main factors which are water application, crop yields and net incomes. This chapter will try to go deeper into each of these factors relating to the results.

5.1 Water application

For the crops that were common in both the catchments there was a huge difference in the volumes of water applied. In the case of maize the Gamtoos farmers applied 422 mm whilst the farmer who applied the lowest amount in the Baviaanskloof applied 1200mm. This very large difference may attribute to a number of factors. Firstly, in the Baviaanskloof the cropping season is much more prolonged than in the Gamtoos. The farmers took a lot of time to harvest their maize. It stayed in the field for about 6months and this has an effect on the crop factor. It is reflected that the harvesting date is one of the factors that affect Kc (Pereira 2005) and hence the amount of water needed by the crop. It could be also be because of different varieties used.

Another contributing factor is the difference in rainfall received. The Gamtoos received more rainfall of 553.3 mm (Agromet 2011) during that year than the 265.9 (Agricultural 2011) received in the Baviaanskloof. This meant that at least more water was added to the soil from the rain and the irrigation requirements were cut whereas for the upstream a lot of irrigation was needed. The differences in the rainfall amounts itself also makes the comparisons a little bit tricky as rainfall affects the WUE. High rainfall amount means also a more favourable WUE and this already sets a difference between the two catchments.

Another factor may also be the lack of irrigation scheduling or measurements in the Baviaanskloof. Lack of proper irrigation measurements leads to random applications which are not accurate and results in over or under application of irrigation water. This is a common occurrence. For example, this was observed by Sharma et al, in their study of seedless grapes in Maharashtra state, they highlighted that 'Due to lack of scientifically standardised irrigation schedules for grafted vines the growers have been irrigating the vineyards arbitrarily' (Jagdev Sharma 2008). It is a possibility that because of the high temperatures and low rainfall the farmers might have overestimated the ETo leading to much more water application than crop usage. For the Gamtoos farmers it is better, since they have an established irrigation scheduling systems which guide them and informs them of the exact field conditions.

It is also crucial to note that the downstream farmers are guided by the water allocations given by GIB from the Kouga Dam. They receive 800 m^3/ ha/ year and for the year 2010/1 their allocation were cut to a quarter of the normal. This alone restricts the farmers in their water use as they know they would not be able to get more water if they use more than their allocation. The system has also led to the practise of water trading among the farmers. Water trading leads to an increase in the overall benefits for water use (Vernon Topp. 1998). Farmers would try to use water more efficiently to avoid incurring extra costs by buying more water from others. In the Baviaanskloof there are no such restrictions as each farmer has their own water sources and no one controls that. The only limitations are electricity or fuel costs for pumping.

On the other hand however, since the farmers did not keep water records, it is also a possibility that in giving the amounts of irrigation they mentioned amounts greater or lower than they actually applied in some cases. Although at one point measurements were done, it is still not correct to make the assumptions that all the irrigation events are the same. It would be more ideal if the farmers could measure and record each irrigation event.

5.2 Yields

The maize yield from the Baviaanskloof was similar to that of the small farmer from the Gamtoos valley, with a value of 8 t/ ha. These yields are above the South African average yields of 4 t/ha (Esterhuizen 2012) that was also recorded by the United States Department Of Agriculture, which reflects that the crop did quite well. This means that yield was not the factor resulting in low economic and physical WUE in maize. As already mentioned above the water application was quite high for the Baviaanskloof therefore it is one factor that resulted in a lowered WUE. The economic part will be discussed later in this chapter.

In the case of Potatoes however, there was a very high difference in the yield. The Gamtoos farmers had a yield ranging from 30 t/ha to 45 t/ha whilst the farmer in the Baviaanskloof only had a yield of 10 t/ha. The notable difference between the two catchments is the planting dates. The Gamtoos farmers plant their potatoes around June / July to be harvested in December/ January. In the Baviaanskloof however, the cropping season was from September to February. Therefore it is likely that this could be a contributing to a low yield since the weather conditions during these periods are different hence this will affect the growing of the crop. Potatoes perform best when the summers are cool ranging between 18 and 21 ^{0}C (CornellUniversity 2006), whereas the temperatures in the Baviaanskloof are over 23^{0}C during the summer. The cropping period in the Gamtoos is during the winter time and the temperatures are low. Therefore an assumption can be made that the high temperatures during the growing season in Baviaanskloof resulted in lower yields.

Another reason for the low yields in the Baviaanskloof can be due to the over application of water. Potatoes do well in well drained soils (AgriLife. 2009). Since there was over application in potatoes in the Baviaanskloof, there might have been a point where the soils were not well drained which led to low yields.

In the Baviaanskloof the yield for onion seeds for many farmers was 250 kg/ha which is lower than the reported average yield in South Africa to range from 400 to 1000kg/ha (JWSeeds). No seeds were produced in the Gamtoos valley. For carrot seed again the farmers had a yield of 650 kg/ha which is also lower than the reported 800 to 1500 kg/ha. The reason for the low performance and low yields can be due to a number of factors.

The farmers in the Baviaanskloof do not have an agricultural extension service that can advise them pertaining cropping activities. This generally means that they work on their own. Even during interviews farmers mentioned the need for a farmer organisation and/ or extension services. Extension services help with information on different aspects affecting agriculture. It is also easier for agricultural organisations to work with a farmer association than individual farmers. For instance, the Gamtoos case, consultants from DFM Solutions work with the GIB to communicate with the farmers. The Gamtoos farmers also receive some advice and information from the GIB which helps them manage their crops better and increase production (Joubert 2011).

5.3 Net Income

The price and costs were different for the two catchments. The potato price for the Baviaanskloof was 30 R /10kg pocket whilst in the Gamtoos the price ranged from 23 to 28 R/10kg. This difference can be explained by the difference in the time of harvest. An additional explanation is the different market places. In the Eastern Cape the Gamtoos Valley is a place of relatively high potato production and therefore the price is lower due to the bumper quantities of the produce. In the Baviaanskloof however, only one farmer produces potatoes and the potatoes are sold in a different area, Willowmore.

In terms of the costs the Baviaanskloof farmer also had a lower cost of 3,000 R/ha which was far less compared to values of around 60,000 R/ha from the Gamtoos. An assumption can be made that the very low costs from the Baviaanskloof are because less inputs were used, which may have contributed to the much lower yields described above. It is also most likely that less is spend on labour in the Baviaanskloof. Despite the fact the price was higher and costs were lower in the Baviaanskloof, the eWUE was still far less (3.38R/m3) than for the Gamtoos which had a eWUE of 8 R/m3. This was because of the high water use and the low yields from the Baviaanskloof.

For maize crop the unit price in the Baviaanskloof was 1400 R/ha and this was difficult to compare with Gamtoos since he sold his maize locally from home, some fresh cobs and some as dried grains in big bags. The costs were 6000 R/ha for Baviaanskloof and the smallholder farmer from Gamtoos had lower costs amounting to 3000R/ha only. This could also be because he did not have transport or packing costs. Because the maize was sold locally and not commercially, it was also sold at a lower price. Many people grow the maize crop even for subsistence hence this lowers the demand and prices. One cob of maize costs R1.70 and a 50kg bag costs R 90. This can be explained by the law of demand, which says that all other being constant the demand curve moves in the opposite direction of price (NetMBA 2010). It can also be illustrated as in the graph:

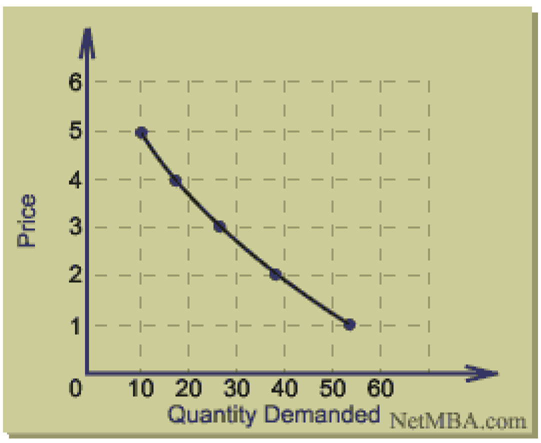


Figure 5. 1 showing the demand curve

(From NetMBA.com)

From the graph you can depict that the higher the quantity demanded, the lower the price and the opposite is true. Therefore, in case of potatoes, butternuts and maize, the later is usually available and can be cultivated by a lot of people even individuals at home hence available in higher quantities, which is not the case for the other crops. Another factor may be that being one of the staple food, it is likely that policymakers are motivated to use their power to manage the price and make it affordable to all classes (COMESA 2010).

In the case of the Baviaanskloof however, the situation is a little bit different with the economic WUE higher than the physical WUE. This can be explained mainly by the high quantity of water used for irrigation in the area which then ends up lowering the physical WUE.

Generally in the Baviaanskloof the vegetables had high eWUE compared to other crops in the valley because they are high value crops hence they have a higher market value than traditional cereals and export crops (Andrew E. 2006). This is also evidenced by the values obtained in the Baviaanskloof; carrot seeds had the highest eWUE of 11 R/kg followed by onion bulb, leeks and onion seed. Maize had the lowest eWUE of about 1R/kg and even 0.57 R/kg for one farmer.

It is also important to note that the data used may be subject be really exact as it was obtained from farmers and not measured directly. In most cases also farmers did not have recordings and gave a rough estimate. There can however be only minor variation as indicated by the bucket method that was done to validate the reported data.

Chapter 6: Recommendations and Conclusions

After analysing the data collected and discussion of the important aspects, certain recommendations were drawn up for the farmers and other authorities. The recommendation is based on two options, that is, to improve the agricultural activities and to stop or reduce agricultural activities with the support of a payment for ecosystem services programme.

6.1 Option 1: Towards agricultural improvement

6.1.1 Baviaanskloof Farmers

From the results in the Baviaanskloof it is evident that some crops are better than others in terms of eWUE and water productivity. These are high value crops like seed crops and vegetables (onion bulb and leeks). The major recommendation is for the Baviaanskloof farmers to stick to these high value crops and improve their production. Also by focusing on these crops they have more or less the same requirements which will make it easier for farmers to manage than dealing with many diverse crops.

The study also seconds the future idea of moving to citrus cultivation in the Baviaanskloof. Citrus is a high value crop and it brings high income from the exports. This is reflected from the Gamtoos valley where more yield and unit price of up to 50-70 t/ha and 1.4 - 4R/kg respectively was recorded. Also from the Gamtoos farmers, one can see that the citrus farmers had a higher eWUE than the rest of the farmers. From the water calculations it also shows that the water currently used for crop production (as per 2011) is enough for citrus production using drip and a high efficiency of 90%. The move to citrus should however be done in steps especially considering that citrus takes about three years before it can be harvested. It is advisable that the farmers start with a certain percentage of the land whilst continuing with vegetables on the other part.

In the hope that if the aforementioned are implemented, the production will improve as well as the income, it would be advisable for farmers to consider converting to drip irrigation that has a higher efficiency and results in less water losses.

6.1.2 Living Lands and GIB

As one of the reasons for the Baviaanskloof problems is the lack of a water user association (WUA)/Farmer organisation and also no external authorities providing extension services and technical assistance to the area. Since Living Lands have worked in the area for some time, they may want to consider facilitating helping the farmers to organise a WUA. They can also help link the farmers with the GIB and personnel from DFM Solutions. GIB may want to consider helping the Gamtoos famers since they are located in the upstream where their activities also affect water availability downstream. When a WUA is created it will be easier for the DFM to approach and help them.

The WUA can also be responsible for organising and helping to establish markets for the farmers. Their duty can also include organising of transport, selling produce at reasonable prices and also buying in bulk covering all farmers.

GIB can also help facilitate linkages between the two farmers’ associations so they can share ideas, trade information and all which might benefit.

6.2 Option 2: Ceasing Agriculture

A second option that was being considered by some farmers and Living Lands is reducing or ceasing agricultural activities and engaging in restoration and land uses (e.g. tourism, low impact game farming) that promote ecosystem services that could be paid for by downstream water users and carbon emissions offset investors. It is too soon to tell if these options are locally viable as some more in depth research and institutional development has to be done. It should be noted that water trading already occurs amongst in the Gamtoos. As an illustration, the water that would have been saved if agricultural use in the Baviaanskloof ceased, amounted to 2,236,158m3/year for 2010. If we consider that on average, in South Africa a household uses 250 Litres of water every day (WaterRhapsody 2010) it means that 24 000 households will receive water in the Nelson Mandela Municipality provided it reaches them. Table 6.1 illustrates the calculation.

Table 6.1 Showing water usage and number of households' that can benefit

1	250*365	91250	l/year
2	91250/1000	91.25	m3/yr
3	226158/91.25	**24506**	householc

The challenge however, is that there is no guarantee that this water will reach all the way downstream if it was not used in the Baviaanskloof since water flows can be diverted and be lost to evaporation, ET, or percolation deep percolation along the way. Also it needs to be clear what the other 'ecosystem services' are and/or land use options so as to see how much water will be used them. This option still needs further research on some aspects as explained below.

6.3 Further Research

Continuous assessment of the WUE and WP should be done to see if the trend. This is also important since this study was carried out during a dry year so it would be good to see the difference in figures during a normal rainfall year.

Further look into optional land uses that can help farmers sustain their livelihoods. It is crucial to do a cost benefit analyses of the different options also considering other factors not only water to see what is best. This can better be done as a long term thing for best results.

6.4 Conclusion

To try to find a sustainable future in the Baviaanskloof, a study was carried out to assess the WUE and WP of the area. These were compared to the downstream catchment to see the difference. The eWUE for the Gamtoos was almost 6 times higher than that for the Baviaanskloof with values of 6.83 and 1.99 R/m^3 respectively. At plot level only potatoes and maize were common in both catchments, Gamtoos valley being the highest. The difference was much sharper in potatoes than maize with values of 14.84 R/m^3 and 3.38 R/m^3; 2.66 and 0.96 R/m3 respectively. The main factors that contributed to the difference at all scale levels are water applied, yield and the net income. Farmers in the Baviaanskloof tend to have a lower income than the downstream farmers especially the citrus farmers. The use of more advanced and better technologies for irrigation scheduling also resulted in less water use and better WUE in the downstream area. It is however important that the crops and rainfall regime between the two areas are different and this makes comparison difficult. More rainfall results in favourable WUE of irrigation water and this therefore affects the comparisons.

From the Cropwat simulation the water productivity was calculated for the Baviaanskloof crops and the WP was higher in all crops than WUE due to much more water use than required. The differences were much higher for the grain crops with values of 1.07 and 0.67 kg/m^3 for maize; and 1.08 and 0.42 kg/m^3

in wheat. Less differences of 0.04 kg/m^3 or less were obtained for high value crops such as seed crops and leeks. This means there is room for improvement for the Baviaanskloof farmers.

The results confirmed that water use efficiency is far much less in the Baviaanskloof in comparison to the Gamtoos. One major step that the farmers can take is improvement of irrigation scheduling which could help cut the water use and save approximately 40% of the water which can then be used downstream.

The Baviaanskloof might need to consider using their water to produce high value crops such as seed vegetables and citrus. Apart from this it is also important to have a WUA which will make it easier for external organisation to help farmers and also for farmers to arrange things together and help each other. The proposal of reducing or ceasing agriculture still need to be reviewed more and more alternative land use options researched before implementation.

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APPENDICES

Appendix A: Raw data collected from Baviaanskloof farmers

Farmer 1

crops	area (ha)	date of planting	date of harvest	No. of days	type of irrigation	yield (t/ha)		Unit price		Costs	Q	Q	soil type
										R/ha	mm/d	mm	
maize 2011	40	Oct /Nov	July	270	centre pivot	8	t/ha	2500	R/tonne	4400	4.44	1200	sandloam
2010	15	Oct /Nov 2010	July	270	centre pivot	8	t/ha	2500	R/tonne	4400	4.44	1200	sandloam
wheat (2011)	40	July	December	180	centre pivot	5	t/ha	2485	R/tonne	4000	6.67	1200	sandloam
onion seed 2011	3	April	December	270	drip	800	t/ha	200	R/kg		2.22	600	clay
lurcene	25	may j/une	summer	42	centre pivot	2.5	t/ha	1200	R/tonne	1500	2.86	120	sandloam
potatoes 2011	2.5	sept	February	180	sprinkler	1000	pkt/ha	30	R/pocket	3000	4.44	800	sand
2010	2	sept	February	180	sprinkler	1000	pkt/ha	30	R/pocket	3000	4.44	800	sand

First step of calculations of WUE, eWUE and WP

2010 season										
crop	yield/season	Unit price	Cost	Net value	Water Used		eWUE	WUE	Actual WU	WP
	kg	R	R	R	mm	m3	R/m3	Kg/m3	mm	Kg/m3
Maize	120000	300000	66000	234000	1200	180000	1.30	0.7	741.5	1.1
lurcene	62500	75000	37500	37500	120	30000	1.25	2.1		
potatoes	20000	60000	6000	54000	800	16000	3.375	1.3	584.3	1.4
wheat	200000	497000	160000	337000	1200	480000	0.70	0.4	465	1.1
Total	**402500**	**435000**	**109500**	**325500**	**2120**	**226000**	**1.44**	**1.8**		
2011										
onion seed	2400				600	18000		0.13	512.8	0.16

Livestock water use

livestock	number	water uses	Quantity		Frequency	water use(m3)
sheep	300	dipping	3300	l	2times/year	6.6
		drinking	6	l	365	657
goats	1000	dipping	3300	l	2times/year	6600
		drinking	4	l	365	1460
cattle	90cows	no dipping	40	l	365	1314
ostrich	200	drinking	5	l	365	365
Total water use livestock						10402.6

Water use (m3) = number *quantity/1000*frequency

Farmer iii

crops	area	date of planting	date of harvest	no. of days	type of irrigation	yield		price		cost		Q	Total, mm
	ha											mm/day	mm
onions seed2011	8			250	drip							2.4	600
	5			250								2.4	600
2010	5	2 wk Apr	27-Dec	250	drip	2.3	t/ha	23	R/kg	230000	R/5ha	2.4	600
carrots seed	2	June	28-Jan	240	drip							1.88	450
2010	2			240		650	kg/ha	150	R/kg	30000	r/ha	1.88	450
onion bulb	1	28-Aug	5-6Dec	100	micro Sprinklers							4.50	450
	1.2			100	sprinklers							4.50	450
2010	1.6			100	sprinklers	50	t/1.6ha	144000	R/1.6ha	60000	R	4.50	450
lucerne	10		6wk interval	42	sprinklers							4.76	200
2010	12		oct- April	42	sprinklers	20	bails/ha	40	r/bail	15	R/bail	4.76	200

livestock	number	water uses	Quantity of water		Frequency
sheep	150	dipping	pour on		
		drinking	6	l/day	328.5
boer goats	50	drinking	4	l/day	73
cattle	30	drinking	40	l/day	438
Total (m3)					**839.5**

2010 season											
crop	yield	unit price	cost	Net value	Water use		Ewue	WUE	actual WU		WP
	kg	R	R	R	mm	m3	R/m3	kg/m3	mm	m3	kg/m3
onion seed	11500	264500	230000	34500	600	30000	1.15	0.4	394.3	51259	0.22
carrots seed	1300	195000	60000	135000	450	9000	15	0.1	535.3	10706	0.12
onion bulb	50000	144000	60000	84000	450	7200	11.67	6.9	144.4	3176.8	15.74
lucerne	4354.49	9600	300	9300	200	24000	0.39	0.2			
Total	67154.49	613100	350300	262800	1700	70200	3.74359	1.0			
2011											
onion seed	29900				600	78000		0.4	394.3	51259	0.58

Farmer IV.

crops	area (ha)	date of planting	date of harvest	no. of days	type of irrigation	yield		price	cost	Q	Total
								R/kg	R/ha	mm/day	mm
lucerne 2011	5		every six wks	42	pivot	7.65	bales/ha	40	2000	3.57	150
onion seed	3	may/june	dec/ January	220	pivot	500	kg/3ha	200	15000	2.5	625.00
carrots	5	may/june	dec/ January	220	pivot	500	kg/ha	70	12000	2.5	625.00
leek	3	june	February	270	pivot	800	kg/ha	70	12000	2.5	718.8
sorghum	36							used as animal feed			
wheat-malt 2011	10	june	dec	180	centre pivot	3.5	t/ha	used as animal feed	5000	5	

livestock	number		water use	Quantity		Frequency	water use
sheep	50		diping	2500	l	2*/yr	5
			drinking	6	l/day		109.5
cattle	100		dipping				
			drinking	40			1460
boer goats	90		dipping	2500		2*/yr	5
			drinking	4	l/day	365	131.4
LWU, m3							**1710.9**

crop	yield	Income	Cost	Net value	Water use	Water Use	eWUE	cWUE	actual WU		WP
	kg	R	R	R	mm	m3	R/m3	kg/m3	mm	m3	kg/m3
lucerne	8328	9180	10000	-820	150	7500	-0.11	1.11			
onion seed	500	100000	45000	55000	625	18750	2.93	0.03	406.1	12183	0.04
carrots	4000	280000	60000	220000	625	31250	7.04	0.13	437.5	21875	0.18
leek	2400	168000	36000	132000	718.8	21564	6.12	0.11	793.9	23817	0.10
Total	15228	557180	151000	406180	2118.8	79064	5.14	0.19			

Farmer V

crops	area (ha)	date of planting	date of harvest	no. of days	type of irrigation	yield (t/ha)		price		cost		mm/day	Q, mm
2010				210								4.29	
onion seeds	2	Jun-10	Dec-10	210	furrows	500	kg/2ha	200	R/kg	70000	R/ha	4.29	900.00
2011	2			210				200	R/kg			4.29	
tobacco 2010	2	Jan-10	Apr-10	90	sprinkler	2000	kg/ha	20	R/kg	20000	r/ha	4.85	436.36
	1	Dec-11	march	90	flood							4.85	436.36
barley	15	Jun-11	Dec-11	180	centre pivot	3.5	tonne/ha	1200	r/tonne	1500	r/ha	4.44	800
lurcene	8	september	march	42 (210)	sprinklers	2500	kg/ha/sea	1.2	r/kg	8000	R/ha/seas	2.33	294
maize 2010	5	october	march	180	centre pivot	7	t/ha	14000	r/ha	6000	r/ha	7.78	1400
2011	12	october	march	180		7	t/ha					7.78	1400

livestock	number	water use	Quantity		Days	water use
cows	50	drinking	40	l/day	365	730
bulls	2		40	l/day	365	29.2
angora goats	200		4	l/day	365	292
pigs	100	drinking	2000	l/day	365	730
TLWU, m3						**1781.2**

2010 season											
crop	yield/season	Unit price	Cost	net value	WU	Water Used	eWUE	cWUE	actual WU		WP
	kg	R	R	R	mm	m3	R/m3	kg/m3	mm	m3	kg/m3
onion seed	500	100000	140000	-40000	900.00	18000.00	-2.22	0.03	501.60	10032.00	0.05
tobacco	4000	80000	40000	40000	436.36	8727.27	4.58	0.46	280.20	5604.00	0.71
maize	35000	70000	30000	40000	1400	70000.00	0.57	0.50	757.20	90864.00	0.39
barley	52500	63000	22500	40500	800	120000.00	0.34	0.44			
lurcene	20000	24000	64000	-40000	294	23520.00	-1.70	0.85			
Total	112000	337000	296500	40500	2024.455	240247.273	0.17	0.47			
2011											
maize					1400	168000		0.21			

Farmer VI

crops	area (ha)	date of planting	date of harvest	type of irrigation	Q		Frequency	Hours
lurcene	30	rotation	grazing	centre pivot	104000	m3	5 days/wk	10hrs /day

livestock	number	water uses	Quantity		Frequency		water use	
cattle	60	drinking	40	L/day	365	days	876	m3

Farmer VII

Crop (variety)	Plant date	No. of ha	Type of irrigation	Hours per irrigation	Day of harvest	frequency of irrigation	dripper spacing
Olives	1997-2000	10	Microjets	30-60 mins (seasonal)	March-April	2-3 days	3-4m
Olives	2011	5	Dripper	3- 6 hrs (seasonal)	March-April	2-3 days	3-4m
Sheep Pastures	2010-2011	14	Draglines	6 hrs a week	no harvest	once a week	no spacing

Livestock	no.	wtr QNT	days	WU
sheep	100	6	365	219

Farmer VIII

livestock	number	water use	Quantity	
cattle	87	drinking	1270.2	m3

Farmer IX

crops	area (ha)	yield (t/ha)		price(R/kg)		cost (R/ha)	
lurcene	13	200	t/ha	1100	R/tonne	1500	R/ha
grass	12	grazing					

livestock	number	water uses	Quantity		Frequency	water use(m3)	
sheep	250	drinking	4	L	365	365	

crop	yield	Unit Price	Cost	Water Use	
	t	R	R	mm	m3
lurcene	2600	2860000	19500	120	340860
grass				100	12000
Total					352860

Appendix B: Raw data collected from Gamtoos farmers

Farmer 1

crops	area (ha)	date of planting	date of harvest	No. of days	Type of irrig	yield	unit price		cost	Water Use	Total WU
potatoes						kg/ha			R/ha	mm/day	mm
early crop	20	15Feb-20March	June	120	centre pivot	38000	2.3	R/kg	65000	2.08	250
late crop	30	20june-30 aug	19/11-20jan	150	centre pivot	45000	2.8	R/kg	68000	1.87	280
chicory											
early crop	6	April	January	270	draglines	35	1200	R/tonne	27000	1.19	320
late crop	10	august	march	240	centre pivot	40	1100		32000	1.46	350
citrus											
novas	0.85	1998		365	drip	62000	4	r/kg	45000		
valencia	5.3	1986		365	drip	60000	1.47	r/kg	40000		
navels	4	1986		365	drip	45000	1.07	r/kg	35000		
	10.15										
butternuts	10	october	dec	90	centre pivot	30000	1.4	r/kg	22000	3.22	290
	10	november	feb	120	centre pivot	30000	1.4	r/kg	22000	2.42	290
	10	January	apr	120	centre pivot	30000	1.4	r/kg	22000	2.42	290

crop		Total Yield	Total income	Total Cost	Net value	Water Use		eWUE	WUE
		kg	ZAR	ZAR	ZAR	mm	m3	R/m3	kg/m3
potatoes	Early	760000	1748000	1300000	448000	250	50000	8.96	15.2
	late	1350000	3780000	2040000	1740000	240	84000	20.71	16.1
chicory	Early	210000	252000	162000	90000	320	19200	4.69	10.9
	late	400000	440000	320000	120000	350	35000	3.43	11.4
butternuts		900000	1260000	660000	600000	290	87000	6.90	10.3
citrus	novas	52700	248000	38250	209750				
	valencia	318000	88000	212000	-124000				
	navels	180000	48000	140000	-92000				
TOTAL		4170700	7864000	4872250	2991750	168	195490	15.30	21.33

Farmer 2

crops	area (ha)	date of planting	date of harvest	Type of irrigation	yield (t/ha)	unit price		cost		Q		soil type	Frequency
rhye grass	280	April/ may	grazing	centrepivots	20	1500	R/ton	700	R/tone	1920000	m3	sand loam	50mm/wk

crop	yield/season		Unit price		Cost		Water Used		eWUE	cWUE
grass	5600	tonnes	8400000	R	3920000	R	882650	m3	5.075625	6.344531

Farmer 3

crops	area (ha)	date of planting	date of harvest	Type of irrigation	yield (t/ha)		unit price		cost	frequency	soil type
2010	1	August	dec	draglines						1*/wk	sand
2011	1	sept	mid jan		14178	cobs	1.7	per cob	3000		
					15	50kg bags	90	R/bag			
superdan	1	nov/ dec	grazing	draglines	grazing					1*/wk	

crop	yield/season		Unit price		Cost		Water Used		eWUE		kg/m3
maize	14178	cobs	24102.6	R	3000	R	8433	m3	2.662469	R/m3	0.929562
	15	bags	1350	R							
			25452.6	R							

Farmer 4

crops	area (ha)	date of planting	date of harvest	Type of irrigation	yield (t/ha)	unit	price		cost		soil type	Q
pastures	300	march	grazing	centre pivot&drag	18	t/yr/ha	1500	t/ha	1000	r/ha	sand; clay	30mm/wk

crop		yield		Unit Price		cost		Water Use		eWUE		cWUE	
Pastures		5400	tonnes	8100000	R/t	300000	Rands	1333270	m3	5.850278	R/m3	4.050192	kg/m3

Farmer 5

field	No. of Trees	spacing		AREA	RAM	RAM	flow	variety	yield		Price		Cost	
NO		RY	BOOM	(Ha)	Q	Lyne	m3/u	11/08/2011	2011	t/ha				
103A	1634	5	2	1.63	3.5	1	11.4	clementines	60.0	36.7	24170	R/ha	45000	R/ha
10	1000	6	4	2.40	1.6	2	12.8	clementines	88.1	**40.0**				
				4.03										
10	1000	6	4	2.40	1.6	2	12.8	midknight	320.0	72.1	66458.82	R/ha	30000	R/ha
11	600	6	2	0.72	3.5	1	4.2	midknight	180.0	65.2	66458.82	R/ha	30000	R/ha
11	1700	6	2	2.04	3.5	1	11.9	midknight			66458.82	R/ha	30000	R/ha
13	300	4	2	0.24	3.5	1	2.1	midknight	13.0	54.2	66458.82	R/ha	30000	R/ha
	2600.0	16.0	6.0	5.4	10.5					70				
12	1700	6	2	2.04	3.5	1	11.9	turkey valencia	120.0	58.8	63618.36	R/ha	30000	R/ha
14	94	4	2	0.08	3.5	1	0.7	turkey valencia		60.0	63618.36	R/ha	30000	R/ha
	1794.0	10.0	4.0	2.1	7.0									
7B	340	6	2	0.41	1.6	2	2.2	cambrias	30.0	73.5	86690.05	R/ha	35000	R/ha
101	280	5	2	0.28	3.5	1	2.0	cambrias			86690.05	R/ha	35000	R/ha
102	1311	6	2	1.57	3.5	1	9.2	cambrias	110.0	69.9	86690.05	R/ha	35000	R/ha
104	1438	5	2	1.44	3.5	1	10.1	cambrias			86690.05	R/ha	35000	R/ha
9	1800	5	2	1.80	3.5	0.5	6.3	cambrias		65.0	86690.05	R/ha	35000	R/ha
	5169.0	27.0	10.0	5.5	15.6									
5	650	6	3.5	1.37	3.5	2	15.9	navels	70.0	51.3	39505.48	R/ha	35000	R/ha
7	832	6	3	1.50	1.6	2	8.0	navels	120.0	80.1	39505.48	R/ha	35000	R/ha
8	840	6	3	1.51	3.5	1	8.8	navels	130.0	86.0	39505.48	R/ha	35000	R/ha
8B	484	6	2	0.58	3.5	1	3.4	navels			39505.48	R/ha	35000	R/ha
OV 1	340	5	4	0.53	50.0	0.25	17.0	navels	25.0	47.3	39505.48	R/ha	35000	R/ha
109A	440	6	4	1.06	2.3	2	8.1	navels	75.0	71.0	39505.48	R/ha	35000	R/ha
109B	822	6	4	1.97	2.3	2	15.1	navels	130.0	65.9	39505.48	R/ha	35000	R/ha
	4408.0	41.0	23.5	8.5	66.7					60.0				
3B	520	5.5	2	0.57	3.5	2	7.3	satsuma	60.0	104.9	70130	R/ha	45000	R/ha
3A	1064	5.5	2	1.17	3.5	1	7.4	satsuma	40.0	34.2	70130	R/ha	45000	R/ha
108	1884	6	2	2.26	3.5	1	13.2	satsuma	80.0	35.4	70130	R/ha	45000	R/ha
105	1336	5.5	2	1.47	2.3	2	12.3	satsuma	130.0	88.5	70130	R/ha	45000	R/ha
	4804.0	22.5	8.0	5.5	12.8					55.0				
1	1091	6	3	1.96	3.5	1	11.5	lemons			187937.25	R/ha	40000	R/ha
OV 2	107	3	3	0.10	50.0	0.25	4.0	lemons	5.0	51.9	187937.25	R/ha	40000	R/ha
4	960	7	2.5	1.68	3.5	2	16.8	lemons	170.0	101.2	187937.25	R/ha	40000	R/ha
	2158.0	16.0	8.5	3.7	57.0					70.0				
106	1667	6	2	2.00	2.3	2	15.3	novas	150.0	75.0	201688.13	R/ha	45000	R/ha
										70				
crops	area (ha)	date of planting	date of ha	Type of iri	yield (t/ha	unit	price		cost		Volume of water applie		soil type	discharge
cucumber	4	27/06/2011	11/08/201	drip	143000	cucumber	3.5	R/cucumber	2	R/cucumber				4l/plant/h

crop			yield/seas	Total inco	Total Cost	Water Use	eWUE	WUE
			kg	R	R	m3	R/m3	kg/m3
cucumber			286000	2002000	1144000			
clementines			161360	97501.78	181530			
midknights			378000	358877.6	162000			
T. valencia			126912	134565.5	63456			
cambrias			357448	476725.9	192472			
navels			510732	336278.6	297927			
satsuma			301004	383807.5	246276			
lemons			261807	702904.1	149604			
novas			140028	403456.9	90018			
Total			**2523291**	**4896118**	**2527283**	**210760**	**11.23949**	**11.97234**

Farmer 6

Crop	No. of ha	Soil Type	Irrigation System	Plant date(s)	Day of harvest	Yield/ha	Price	unit	cost	Irrigation
						t/ha	Rands	kg		
POTATOES	17	Sand Loam	Centre Pivot	July	November	32	25	10	60000	R/ha
midknights	30.6		drip			70	66458.82	R/ha	30000	R/ha
navel	28.4		drip			60	16	r/15kg	35000	R/ha
nova	4		drip			70	40	r/10kg	45000	R/ha
satsuma	8.17		drip			55	70130.34	R/ha	45000	R/ha
clementine	18.6		drip			40	24170.18	R/ha	45000	R/ha
star ruby	1.8		drip			65				

crop		yield/seas	Total price		Total Cost		Water Used		eWUE		WUE
potatoes		544	1360000	R	1020000	R					
midknights		2142	2033640	R	918000	R					
navel		1704	1817600	R	994000	R					
nova		280	1120000	R	180000	R					
satsuma		449.35	572964.9	R	367650	R					
clementine		744	449565.3	R	837000	R					
star ruby		117									
Total		5980.35	7353770	R	4316650	R	307590	m3	9.873923	R/m3	19.4426

Farmer 7

crops	area (ha)	date of planting	date of harvest	Type of irrigatio	yield (t/ha)		unit	price	cost		soil type
sweet potatoes	8	Nov-10	june-Nov 2011	dragline	40	t/ha	40	r/20kg	10000	r/ha	sand loam
maize	110	Oct-11	Mar-12	centre pivots	60	t/ha	18000	r/ha	12000	r/ha	sand loam
korog	70	April	july	centre pivots	20	t/ha	7000	r/ha	4000	r/ha	sand loam
pumpkins	4	Aug-11	dec-feb	dragline	20	t/ha	50	r/30kg	12000	r/ha	sand loam
squash	1	aug	dec-feb	dragline	15	t/ha	15	r/10kg	8000	r/ha	sand loam
cabbage	2	june	october	centre pivots	50	t/ha	10	r/20kg	13000	r/ha	sand loam

crop	yield/season				Unit price		Cost		Net		Water Used	eWUE		WUE
sweet potatoes	320000	kg	16000	20kgpockets	640000	Rands	80000	Rands	560000	Rands				
maize	6600000	kg			1980000	Rands	1320000	Rands	660000	Rands		5.480633	54806.33	
korog	1400000	kg			490000	Rands	280000	Rands	210000	Rands				
pumpkins	80000	kg	2666.667	30kg pckt	133333.3	Rands	48000	Rands	85333.33	Rands				
squash	15000	kg	1500	10kgpckt	22500	Rands	8000	Rands	14500	Rands				
cabbage	100000	kg	5000	20kgpockets	50000	Rands	26000	Rands	24000	Rands		5.806357		
TOTAL	8515000	kg			3315833	Rands	1762000	Rands	1553833	Rands	267609	5.806357	R/m3	31.81881

Farmer 8

Crop	Field	No. of ha	Plant date(s)	Area per plant date	Day of harvest	Yield/ha		Price	unit	cost	frequency	amount /irrigation	Volume/s
								R	kg	R/ha	per season	mm	mm/ha
potatoes		18	may/july		nov/dec	30000	kg/ha	2.8	10	95000	8	30	240
Pumpkins		8	Feb ru		june/july	24000	t/ha	1.33	bag	16000	6	25	150

CITRUS										
Variety	**field**	**No. of ha**	**no. of trees**	**plant date**	**harvest**	**yield**	**gross income**		**packing costs**	**production costs**
units		ha				t/ha	Rands		Rands	R/ha
satsuma		2.2	1900	2004		50	70130	R/HA		45000
navel	1	2.6	1100	1990	june	33	16	r/15kg		
	2	2.4	1000	1993	may	40				
	8	4	1800	1997	june	45				
	13	3.8	3400	2000	july	42	170666.6667	4096000		
Total	**24**	**12.8**	**7300**			**160**				
						160000	kg/ha			
						10666.67	15kg pockets			
cambria navel	9	4.4	2000	1998	aug	13	218000		68000	32000
	10	4.4	2000	1999	aug	11				
total	**19**	**8.8**	**4000**			**24**				
valencia	6	7.5	3100	1996	sept	58	1500000		753000	35000
	7	5.5	3200	1997	sept	61				
	3	2.1	900	1993	sept	65				
	4	1.6	700	1993	sept	68				
total	**20**	**16.7**	**7900**			**252**				
nova	11	2.2	1000	1999	june	65	513000		237700	38000

crop		yield		Unit Price		cost		Water Use				eWUE		WUE	
potatoes		540000	kg	1512000	R	1710000	R	240	mm/ha	43200	m3	-4.58333	R/M3	12.5	kg/m3
Pumpkins		192000	kg	255360	R	128000	R	150	mm/ha	12000	m3	10.61333	R/M3	16	kg/m3
citrus	satsuma	110000	kg	154286	R	138400	R			55200					
	navel	2048000	kg	2184533.3	R	477600	R			164770	M3				
	cambria navel	211200	kg	218000	R	836000	R								
	valencia	4208400	kg	1500000	R	1337500	R								
	nova	143000	kg	513000	R	321300	R								
Total		7452600	kg	6337179.3	R	4948800	R	219970				6.311676		33.88007	kg/m3

Farmer 9

crops	area (ha)	date of planting	date of harvest	Type of irrigation	yield			unit price		cost	
potatoes	22	June	December	centre pivot	2600	10kg pockets		25	R/pocket	58000	R/ha
chicory	17	September	April	centre pivot	33.4	T/ha		1225	R/ton	24500	R/ha
navels	37.2			drip	60	T/ha	4000	16	r/15kg	35000	R/ha
midknights	19			drip	70	T/ha		66458.82	r/ha	30000	R/ha
satsumas	5.3			drip	55	T/ha		70130.34	r/ha	45000	R/ha
clementines	8.5			drip	40	T/ha		24170.18		45000	R/ha
novas	4.9			drip	70	T/ha	7000	40	r/10kg	45000	R/ha
star ruby	3.5			drip	65	T/ha				42000	R/ha
limes	4.3			drip	60	T/ha		201688.1	r/ha	42000	R/ha

crop		yield/season		Unit price		Cost		Water Used				eWUE		WUE
potatoes		572000	kg	1430000	R	1276000	R	200	mm	44000	m3	3.5	R/m3	
chicory		567800	kg	695555	R	416500	R	320	mm	54400	m3	5.13	R/m3	
citrus	navels	2232000	kg	2380800	R	1302000	R							
	midknights	1330000	kg	1262718	R	570000	R							
	satsumas	291500	kg	371690.8	R	238500	R							
	clementines	340000	kg	205446.5	R	382500	R							
	novas	343000	kg	1372000	R	220500	R							
	star ruby	227500	kg											
	limes	258000	kg	867259	R	180600	R							
TOTAL		6161800	Kg	8585469	R	4586600	R	184682		184682	m3	21.65273	R/m3	33.36438

Farmer 10

Variety		field	No. of Trees	Plant year	Plant spacing	area	Plant Direction	Irrigation Type	Discharge	Soil Type	Yield	pockets	unit price		Cost	
WN/GS	navels	3	177	1954	6*4	0.42	WO	DRIP	3.5	red soil	60	4000	16	r/15kg	35000	R/ha
WN/GS	navels	6	111	1955	7*4.5	0.35	WO	DRIP	3.5	redsoil	60	4000				
NE/SC	navels	13B	385	1998	5.5*3	0.64	WO	DRIP	3.5	red soil	60	4000				
						1.41										
MM/SV	midknights	4	72	1998	6*3	0.13	WO	DRIP	3.5	redsoil	65	4333.333	66458.82	r/ha	30000	
MM/CV	midknights	8	1058	1990	6*3.5	2.22	WO	DRIP	3.5	skalie	65					
MM/SV	midknights	9	800	1998	6*3	1.44	NS	DRIP	3.5	red clay	65					
MM/CV	midknights	14	386	1996	5*3	0.58	WO	Micro sprinkler		sand	65					
						4.37										
PN/GS	navels	10	1203	1981	6*3.5	2.53	NS	DRIP	3.5	red/klippe	60	4000	22	r/15kg	40000	
PN/GS	navels	11	2442	1988	5*3.5	3.85	NS	DRIP	3.5	kalk/redsoil	60					
VAL/GS	valencia	5	323	1955	7*4	0.9	WO	DRIP	3.5	redsoil	60					
						7.28										
CN/CV	cambria	12B	513	2001	6*3.5	1.08	WO	DRIP	3.5	red soil	60	4000	86690.05		35000	
CN/SC	cambria	7	700	2004	6*3	1.61	WO	DRIP	3.5	red clay	60					
						2.69										
LN/GV	lemons	12A	513	1989	6*3.5	1.08	OW	DRIP	3.5	red soil	65	4333.333	187937.3		40000	
SEM/CC	satsuma	15	753	2001	5.5*3	1.7	WO	DRIP	3.5	sand	55	3666.667	70130.34		45000	
ES/X639	satsuma	13A	300	1998	6*2	0.36	NS	DRIP	3.5	kalk	55	3666.667				
ES/X639	satsuma	16A	150	1990	3*2	1.2		Micro sprinkler		red soil	55	3666.667				
						3.26										
N/GS	nova	16B	950	1990	3*5	2.2		DRIP	3.5	red soil	65	6500			45000	
N/GS	novas	17	2203		6*4	7	OW	DRIP	3.5	sand	65	6500	40	r/10kg		

crop	yield/season		Total income		Total Cost		Water Use		eWUE	WUE
Citrus									R/m3	kg/m3
navels	84.6	tonnes	90240	R	117350	R			39.4281	29.40981
midknights	284.05	tonnes	290425	R	199100	R				
valencia	436.8	tonnes	640640	R	359200	R				
cambria	161.4	tonnes	233196.2	R	162150	R				
lemons	70.2	tonnes	202972.2	R	111200	R				
satsuma	179.3	tonnes	228624.9	R	214700	R				
nova	598	tonnes	2392000	R	482000	R				
	1814.35		4078098	R	1645700	R	61692	m3		

Farmer 11

orchard no.	variety	rootstock	plant year	ha	no. of trees	type of irrigaton	spacing	Q	Direction	Soil Type	YIELD (T/HA)		Unit price		cost
WL1	Naartjes	cariso	<1970	2.8	1555	micro	6*3	40	SO/NW	sand loam	65	6500	16	R/10kg	40000
WL6	NAARTJIES	SWINGEL	<1990	1.6	888	MICRO	6*3	40	NO/SW	sand loam	65				
WL10	NAARTJIES	cariso	<1990	1.5	833	DRIP	6*3	3.5	SO/NW	SAND LOAM	65				
WL8	NAARTJIES	SWINGEL	<1990	1.3	722	DRIP	6*7	3.5	SO/NW	sand loam	65				
				7.2											
WL9	NAVEL	GSS	2002	3.9	2166	DRIP	6*8	3.5	SO/NW	sand loam/KLEI	65	4333.333	16	r/15kg	35000
AL8	navel	GROWWE SKIL	2000	6.8	3777	DRIP	6*3	3.5	OW	SAND/LM/CL	65	4333.333	16	r/15kg	
WL3,4,5	navel	GSS	2002	2.7	1500	DRIP	6*3	3.5	NO/SW	sand loam	65	4333.333	16	r/15kg	
				13.4											
WL11	SATSUMA	cariso	2002	1.3	722	DRIP	6*3	3.5	SO/NW	SAND/CLAY	50		70130.34		45000
KL1	SATSUMA	cariso	2001	5	2750	DRIP	2.5*5.5	3.5	NS	SAND	50				
WL7	SATSUMA	CARISO	<1990	1.6	1055	DRIP	6*6	3.5	NO/SW	sand loam	50				
				7.9											
WL12	midknight	SWINGEL	<1990	1.1	611	DRIP	6*3	3.5	0W	SAND/CLAY	70		66458.82		30000
AL1	midknight	GROWWE SKIL	1998	4	2221	micro	6*3	40	OW	SAND/LOAM	70				
AL2	midknight	GROWWE SKIL	1999	1.4	777	DRIP	6*3	35	NS	SAND/LOAM	70				
AL3	midknight	GROWWE SKIL	1998	2.4	1333	micro	6*3	40	OW	SAND/LM/CL	70				
AL4	midknight	GROWWE SKIL	1998	2.3	1277	micro	6*3	40	OW	SAND/LOAM	70				
WL2	midknight	cariso	<1970	1.8	1000	micro	6*3	40	OW	sand loam	70				
				13											
VB1	NOVA	GROWWE SKIL	1998	7.6	4125						70	7000	40	r/10kg	45000
GI 11,12,13,	NOVA	cariso		6.8	5666						70	7000	40	r/10kg	
AL5	NOVA	GROWWE SKIL	1998	1.1	733	micro	2.5*6	40	OW	SAND/LOAM	70	7000	40	r/10kg	
AL6	NOVA	GROWWE SKIL	1998	2.4	1333	micro	6*3	40	OW	SAND/LM/CL	70	7000	40	r/10kg	
AL7	NOVA	GROWWE SKIL	1999	2.9	1611	micro	2.5*6	40	OW	SAND/LOAM	70	7000	40	r/10kg	
				20.8											
GI9	CAMBRIA	cariso		**5.5**	3052						65		86690.05	r/ha	35000

crop		yield/season		Total income		Total Cost		Water Use		eWUE	
navels		**871**	Tonnes	**929066.67**	R	**469000**	R				
satsuma		395	Tonnes	554029.70	R	355500	R				
midknight		910	Tonnes	863964.63	R	390000	R				
nova		1456	Tonnes	5824000.00	R	936000	R				
cambria		357.5	Tonnes	476795.28	R	192500	R				
nartjies		468	tonnes	748800.00		288000					
Total		4457.50	Tonnes	9396656.28	R	2631000	R	112250	m3	60.27	39.71047

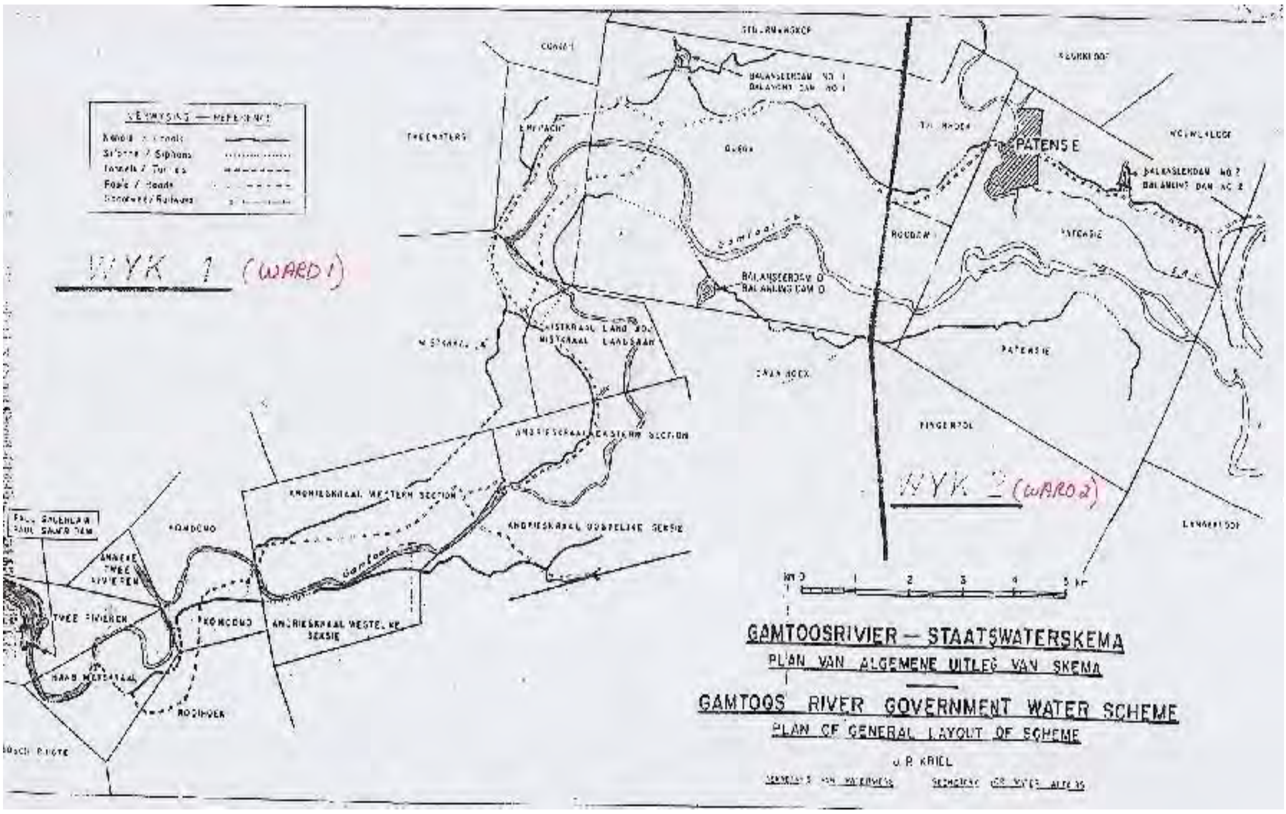
Farmer 12

Crop	Plant season	No. of ha	Day of harvest	Yield/ha		Price		cost		Q
Potatoes	Apr/may	29	October	42000	Pockets/ha	3.5	R/pocket	30000	R/ha	16mm
Citrus		41		65000	kg	2.5	R/kg	40000	R/ha	

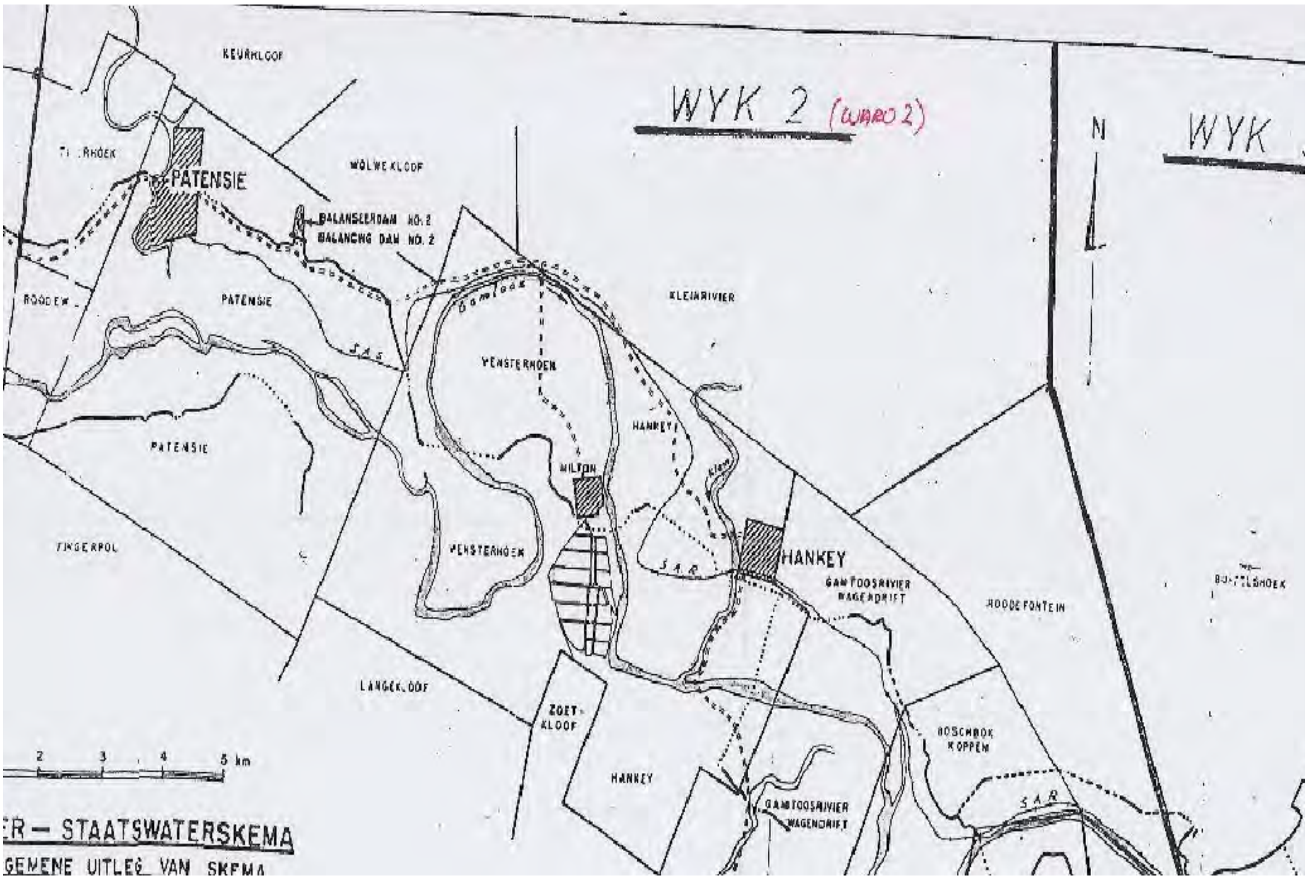
crop	yield		Unit Price		Cost		Water Us(	eWUE	WUE
Potatoes	1218000	kg	4263000	R	870000	R			
citrus	2665000	kg	6662500	R	1640000	R			
TOTAL	3883000	kg	10925500	R	2510000	R	138510	60.75735	28.03408

Appendix C: Map of the Gamtos Valley

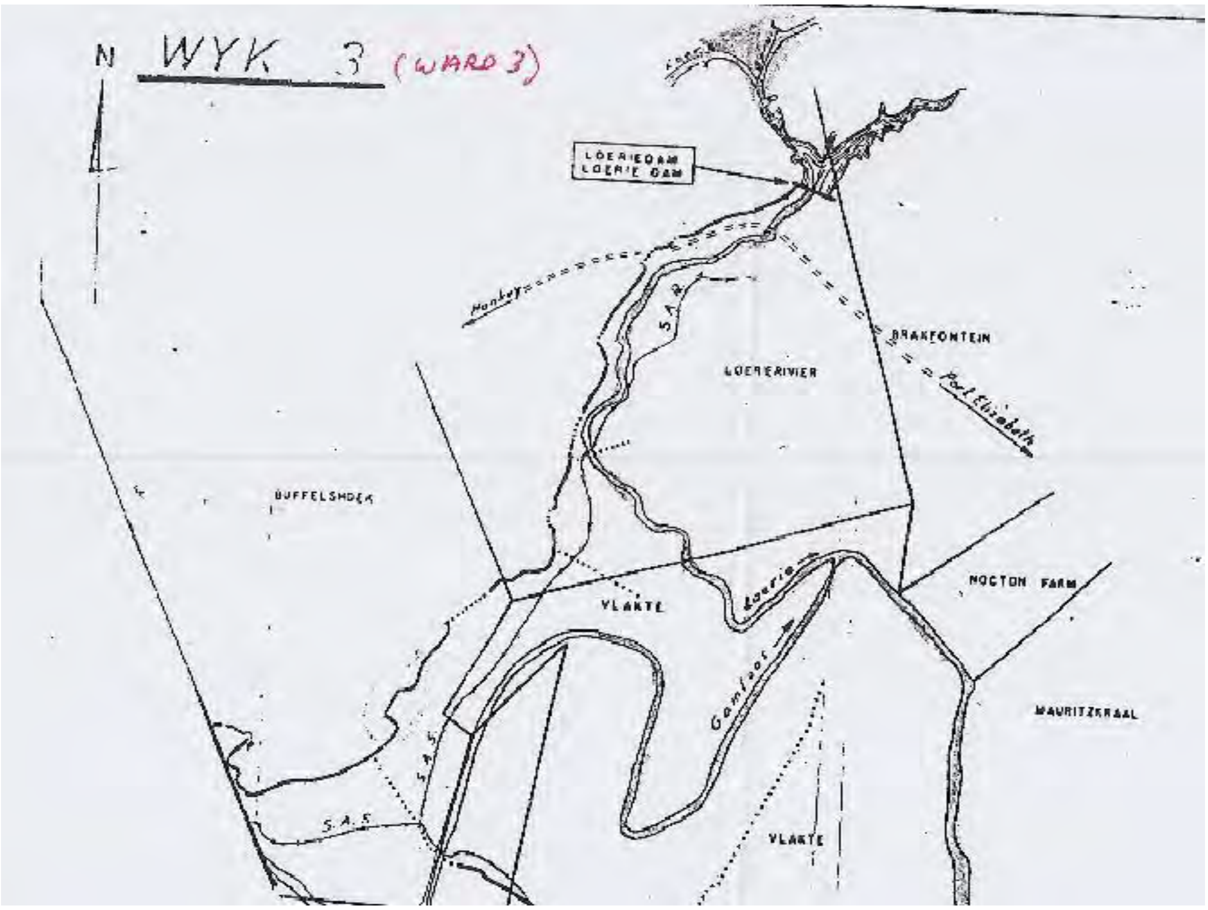
Ward 1 and part of 2



Ward 2 and part 3 Gamtoos Valley



Ward 3



N
WYK 3 (WARD 3)
LOERIEDAM
LOERIE DAM
Hankey
S.A.R.
BRAKFONTEIN
LOERERIVIER
Port Elizabeth
BUFFELSHOEK
VLAKTE
Loerie
NOCTON FARM
Gamtoos
MAURITZKRAAL
S.A.S.
S.A.S.
VLAKTE

Appendix D: Percentage of water saved

crop	Optimal Simulation	Farmer estimates	Water saved %
wheat	446	1200	63
maize	658.6	1200	45
carrot seed	388.5	450	14
carrot seed	388.5	850	54
carrot seed	388.5	625	38
onion seed	442.1	600	26
onion seed	442.1	625	29
onion seed	442.1	900	51
tobacco	275.9	436	37
Onion bulb	295.7	450	34
leeks	558.4	719	22
potatoes	696.4	800	13
Average	5422.8	8855.2	39

Water saved, %= (farmer estimates - optimal simulation/ optima simulation) *100

Appendix E: Different Cropwat input modules

ETo /climate module in Cropwat

Daily ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\Baviaanskloo...

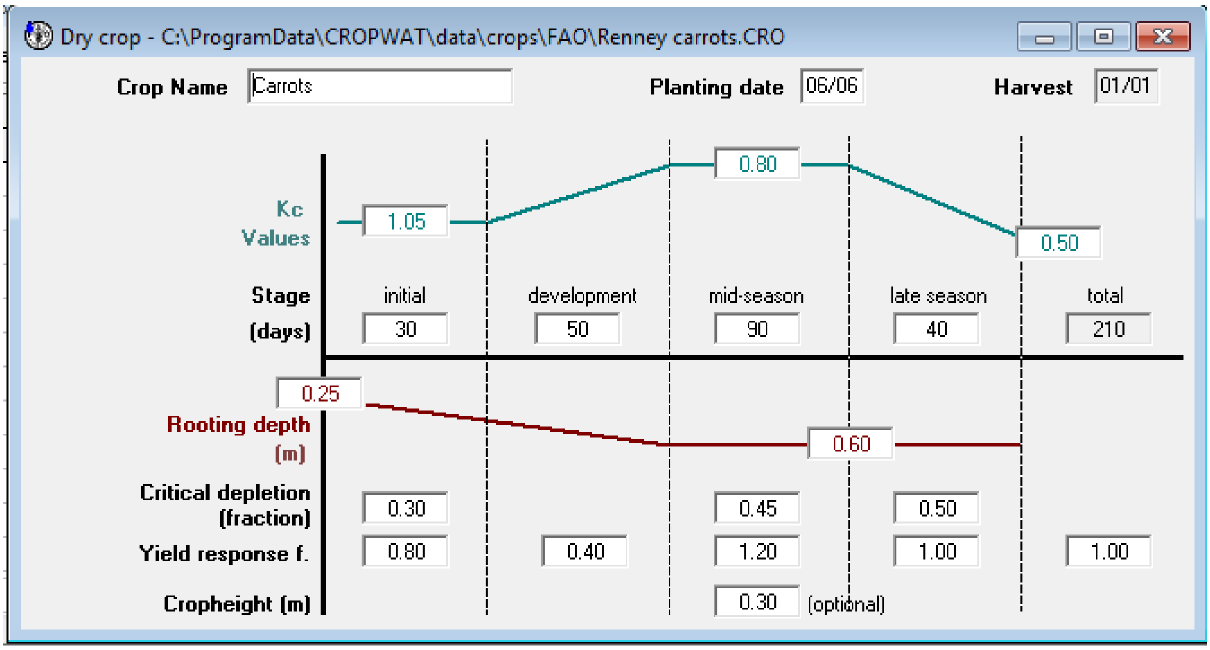
Country South Africa **Station** Baviaanskloof **Year** 2011

Altitude 411 **m.** **Latitude** 33.58 °S **Longitude** 24.11 °E

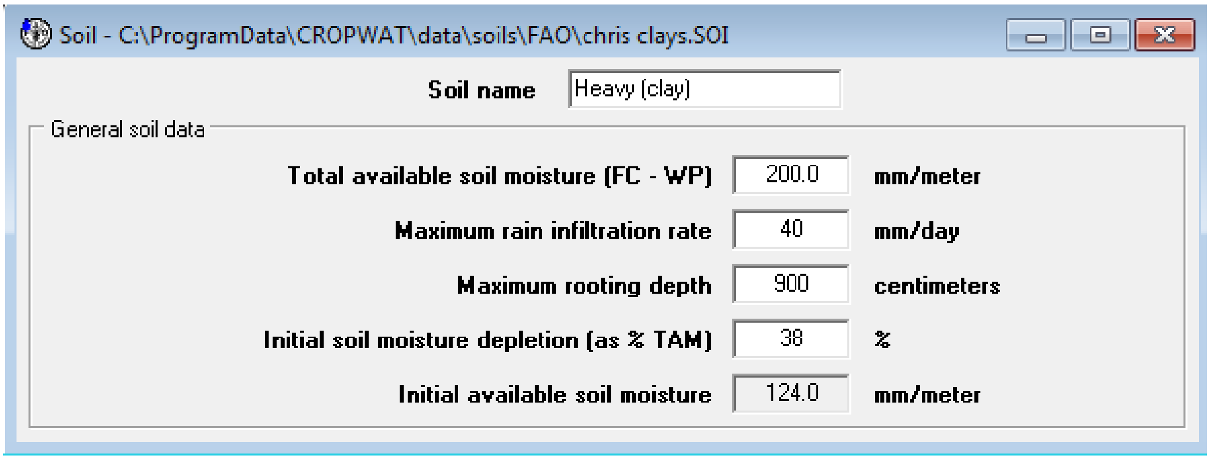
Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	16.9	29.1	66	167	5.0	18.5	4.58
February	18.9	30.3	68	134	4.6	16.6	4.09
March	13.3	29.7	61	122	5.9	16.2	3.73
April	11.2	23.9	63	85	5.1	12.2	2.29
May	9.6	19.8	67	42	3.7	8.3	1.21
June	5.8	16.4	72	62	4.7	8.1	0.97
July	3.6	15.2	63	54	4.5	8.5	1.05
August	5.7	19.1	67	69	5.8	11.8	1.73
September	8.1	23.1	64	115	7.2	16.6	3.01
October	10.7	23.3	64	106	4.6	15.8	3.11
November	11.8	25.0	64	148	6.8	20.8	4.33
December	14.2	27.8	64	153	6.8	21.5	4.77
Average	**10.8**	**23.6**	**65**	**105**	**5.4**	**14.6**	**2.91**

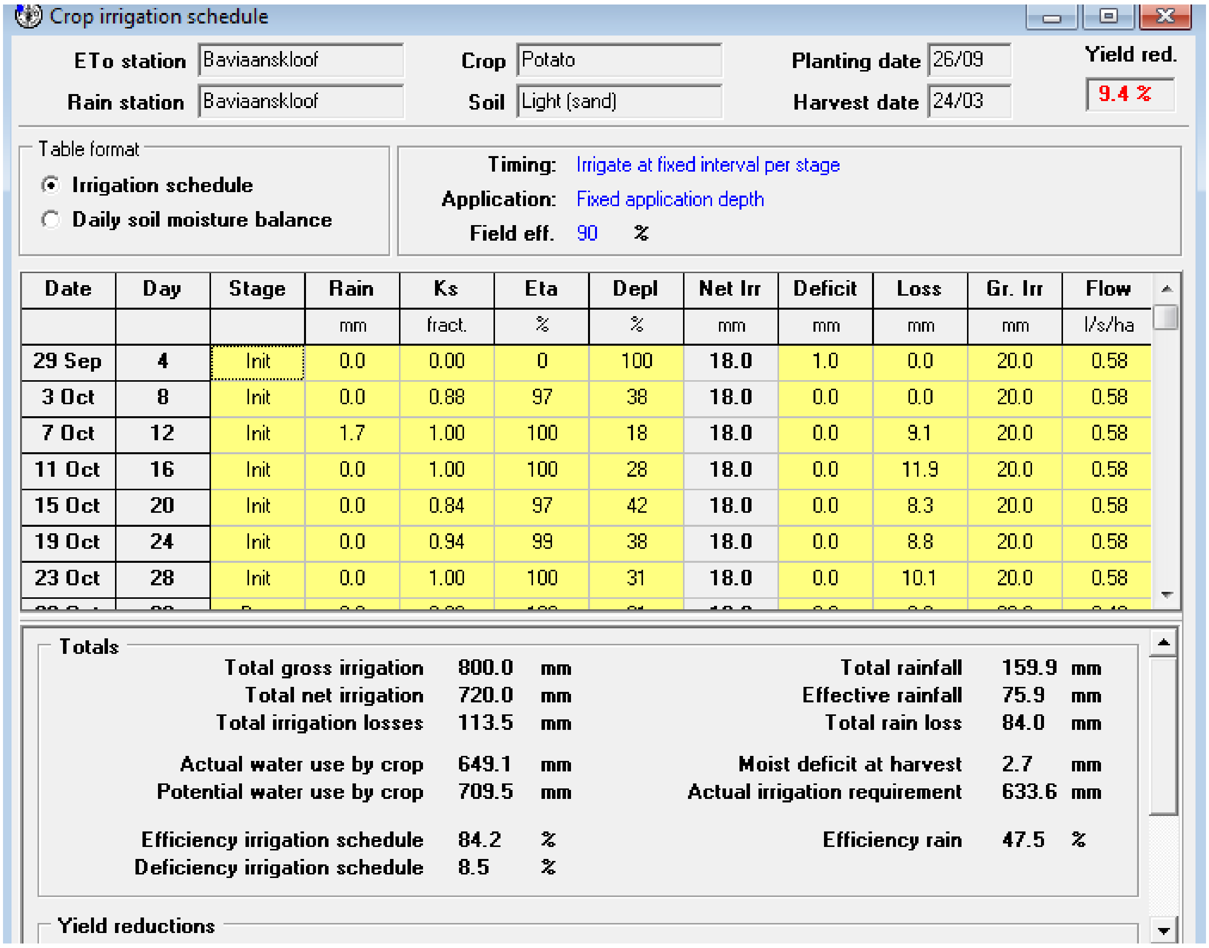
Crop input module



Soil module



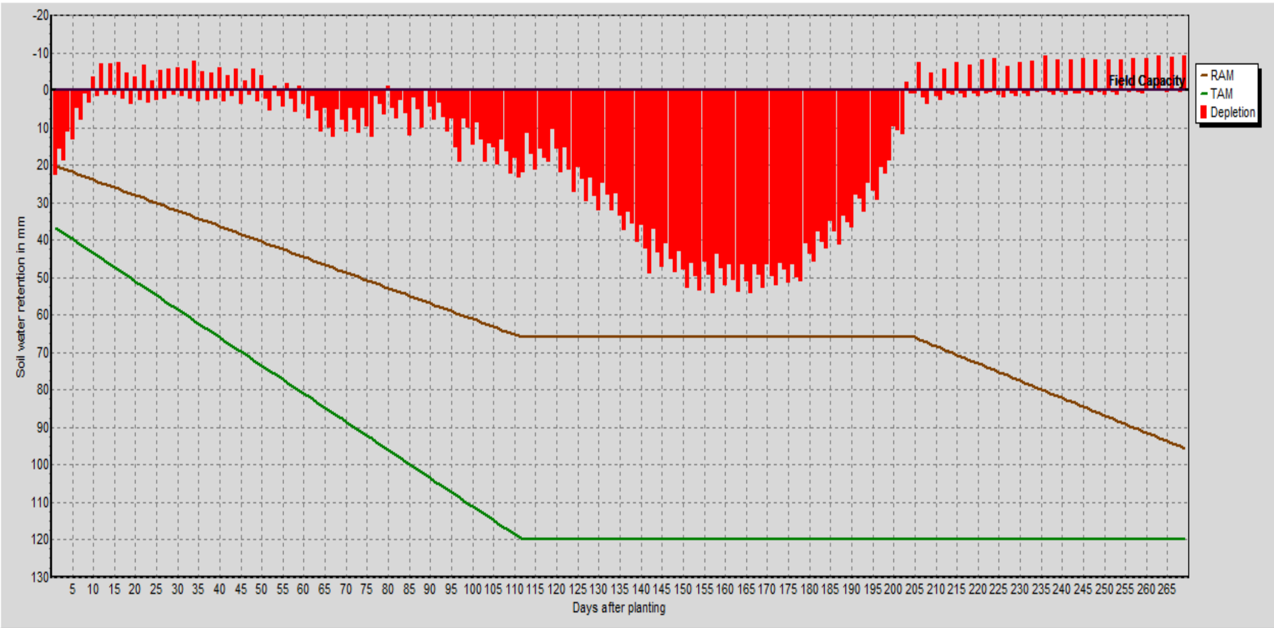
Irrigation Schedule



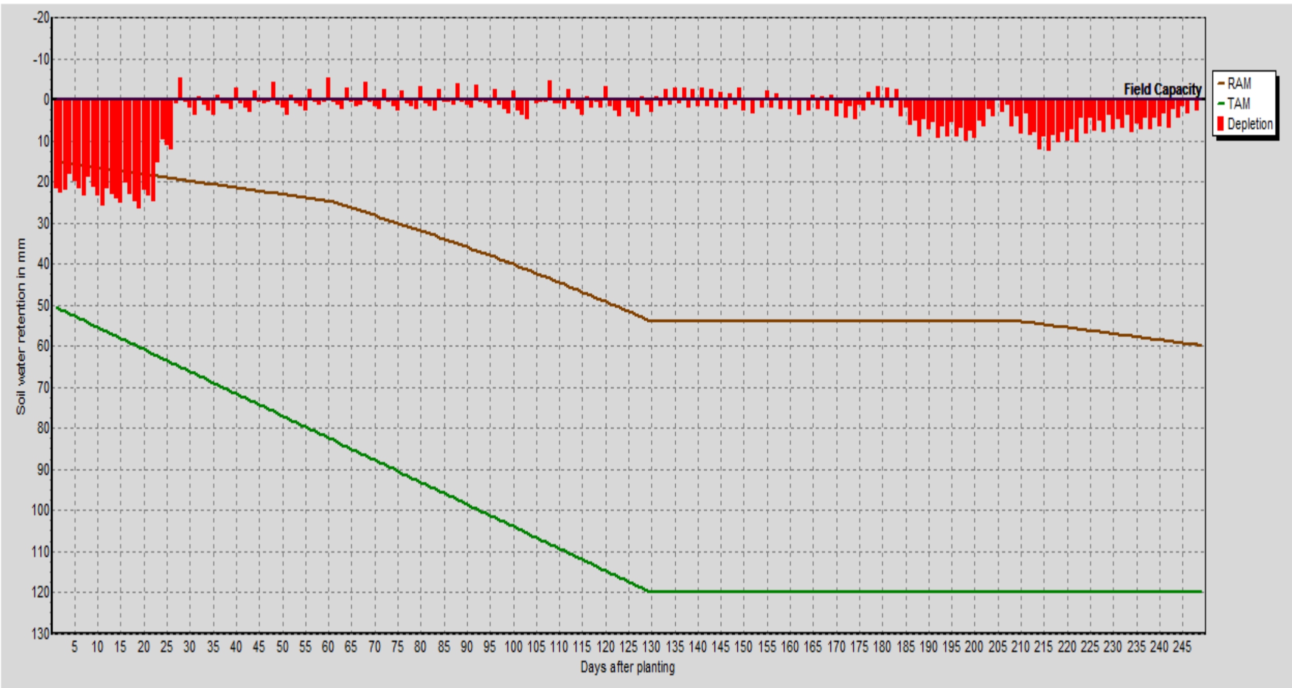
Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
29 Sep	4	Init	0.0	0.00	0	100	18.0	1.0	0.0	20.0	0.58
3 Oct	8	Init	0.0	0.88	97	38	18.0	0.0	0.0	20.0	0.58
7 Oct	12	Init	1.7	1.00	100	18	18.0	0.0	9.1	20.0	0.58
11 Oct	16	Init	0.0	1.00	100	28	18.0	0.0	11.9	20.0	0.58
15 Oct	20	Init	0.0	0.84	97	42	18.0	0.0	8.3	20.0	0.58
19 Oct	24	Init	0.0	0.94	99	38	18.0	0.0	8.8	20.0	0.58
23 Oct	28	Init	0.0	1.00	100	31	18.0	0.0	10.1	20.0	0.58

Appendix F: scheduling graphs from CropWat simulations

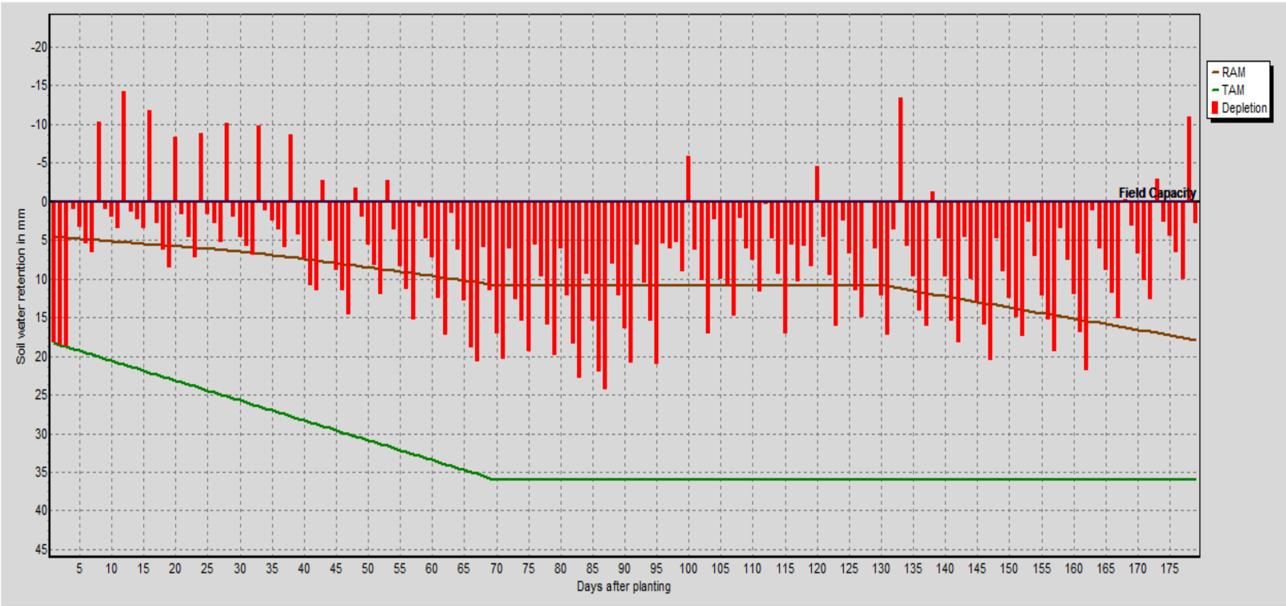
Cropwat schedule graph maize farmer 1



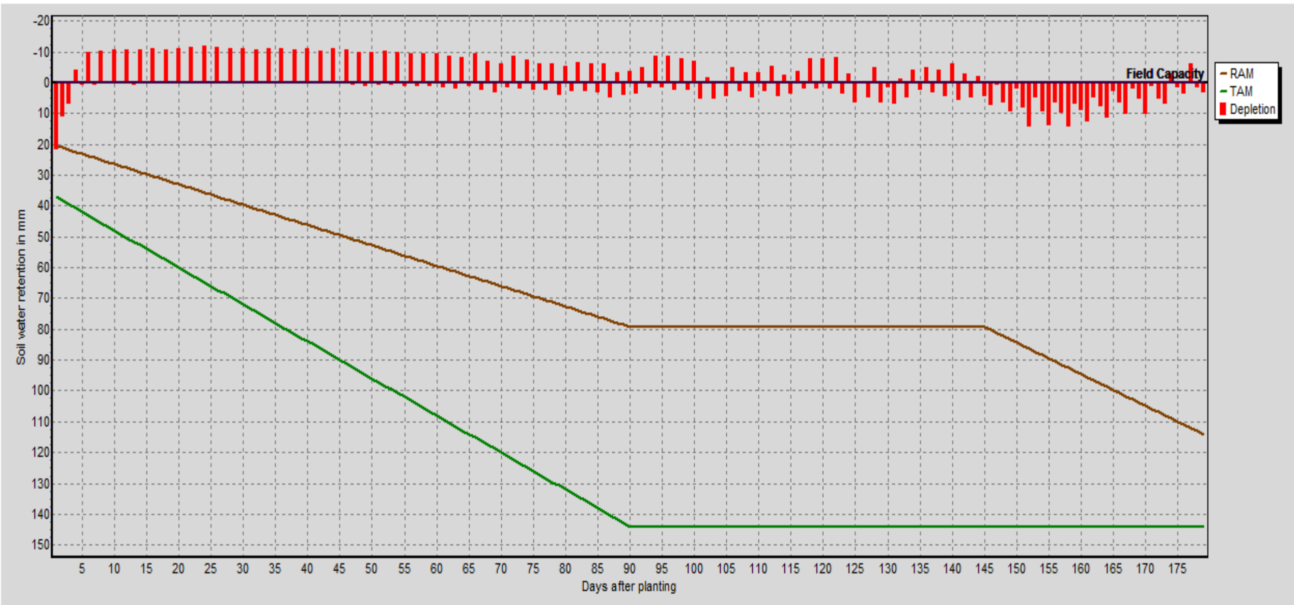
Farmer 1 onion seed



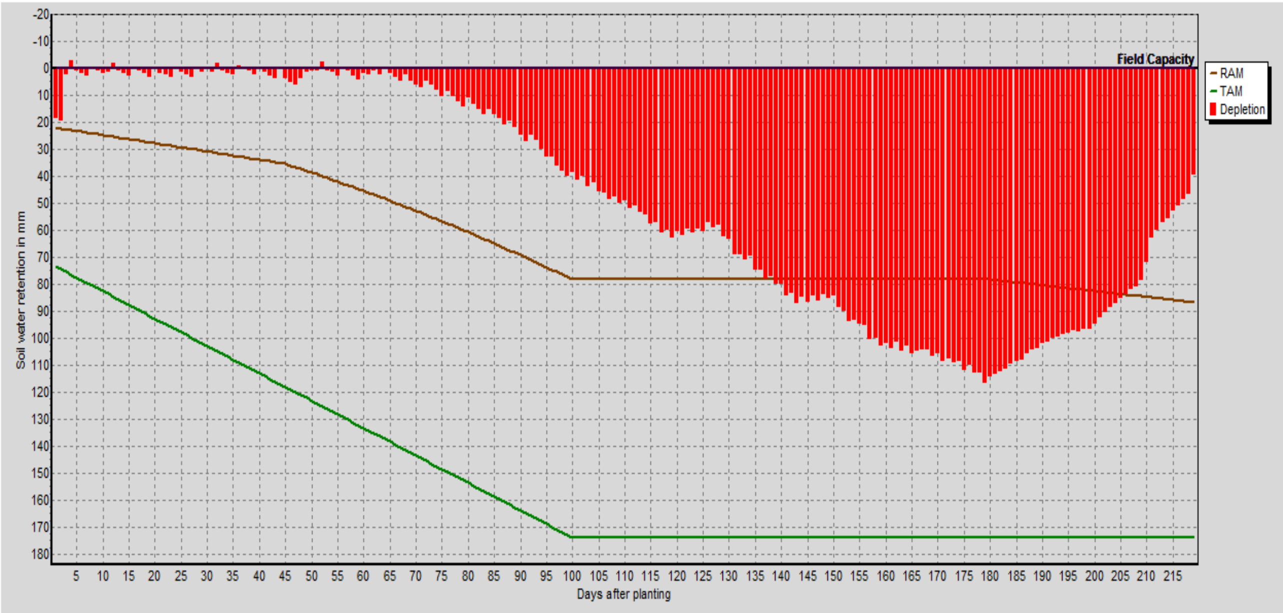
Farmer 1 Potato



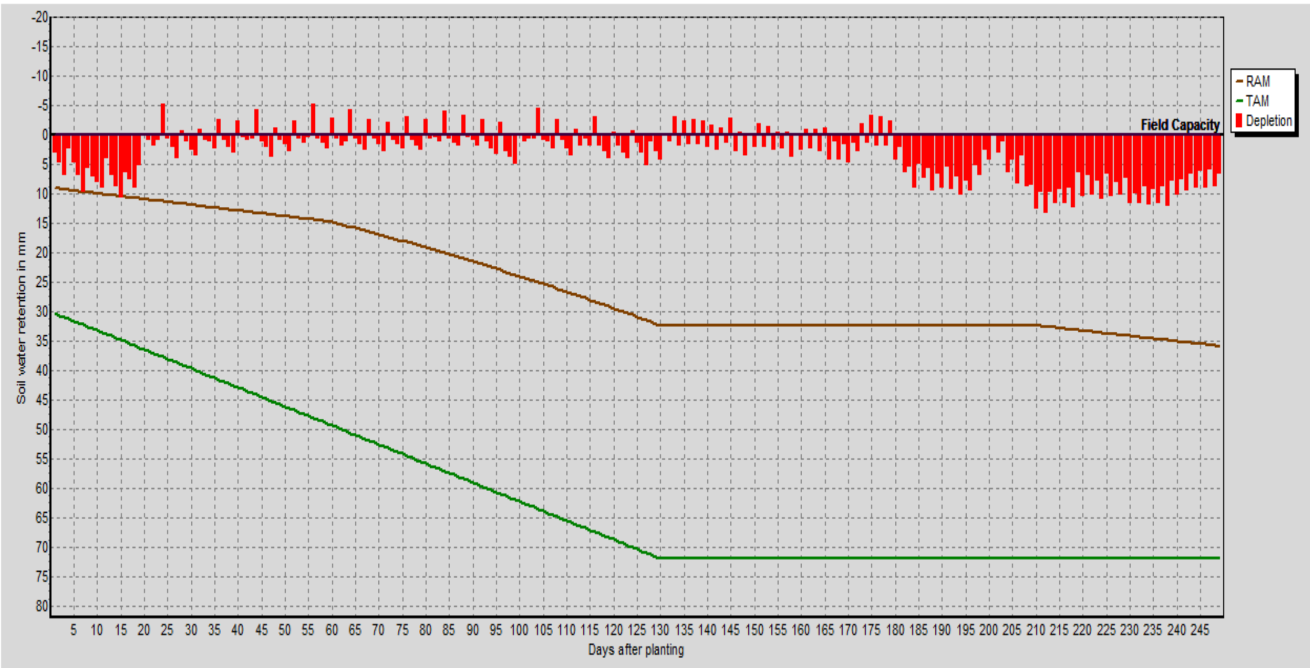
Cropwat Scheduling graph for wheat: Farmer 1



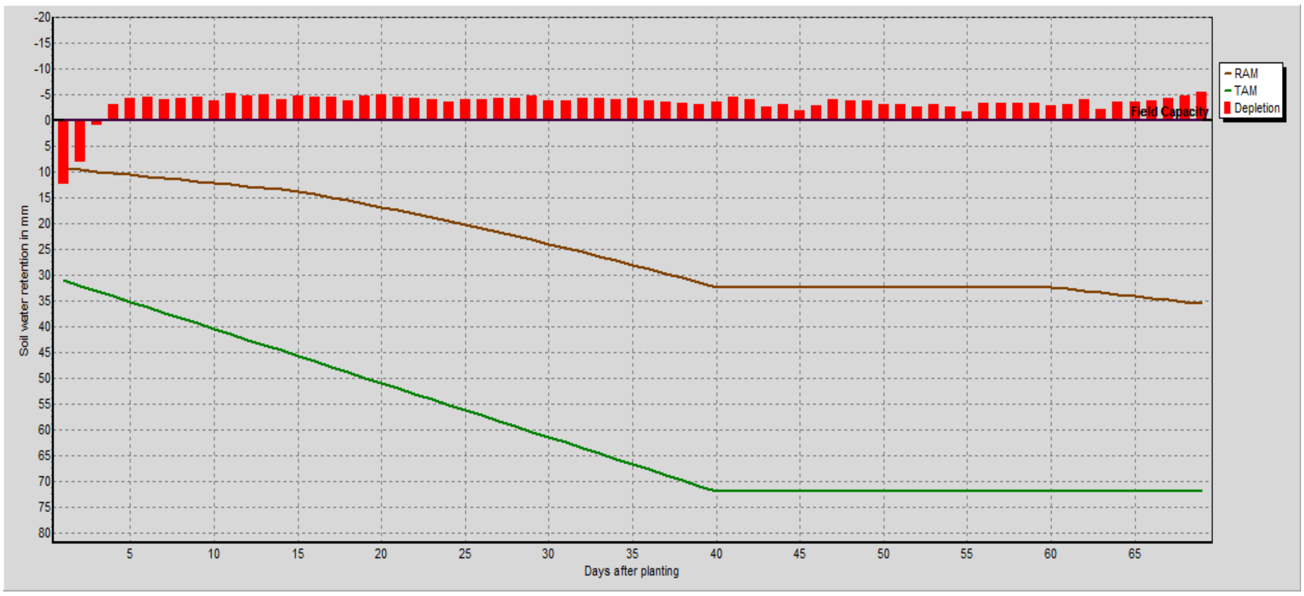
Farmer iii carrot seed



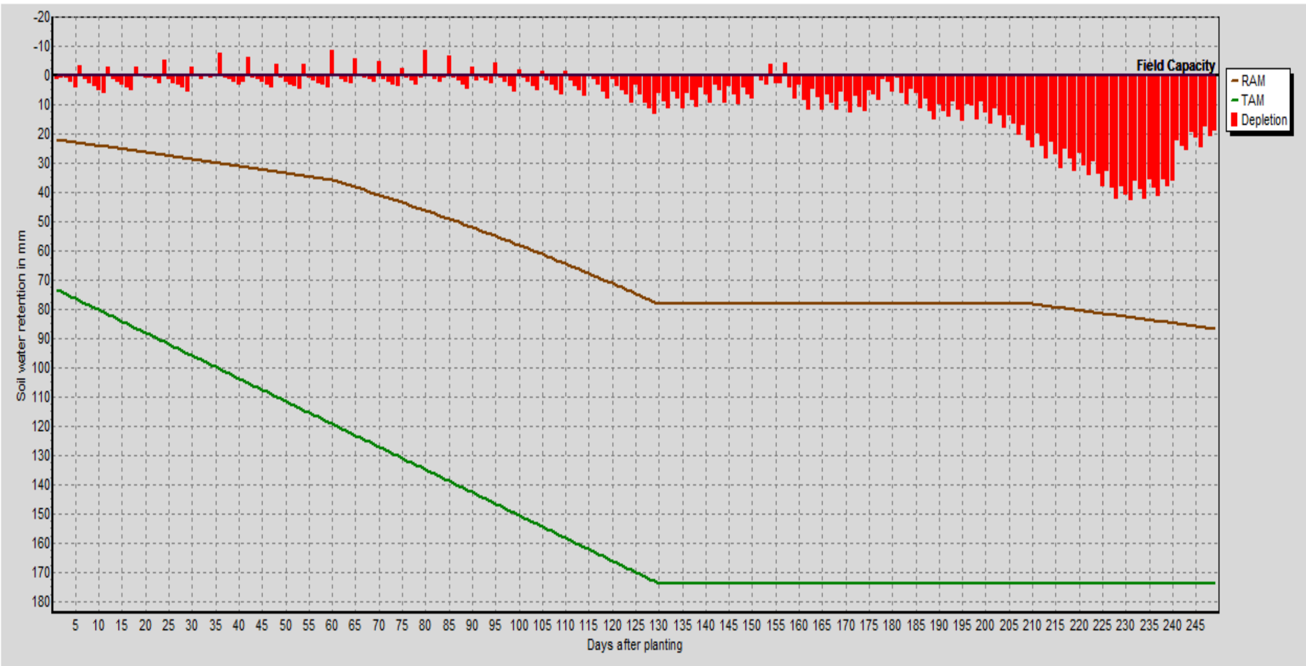
Farmer 3 onion seed



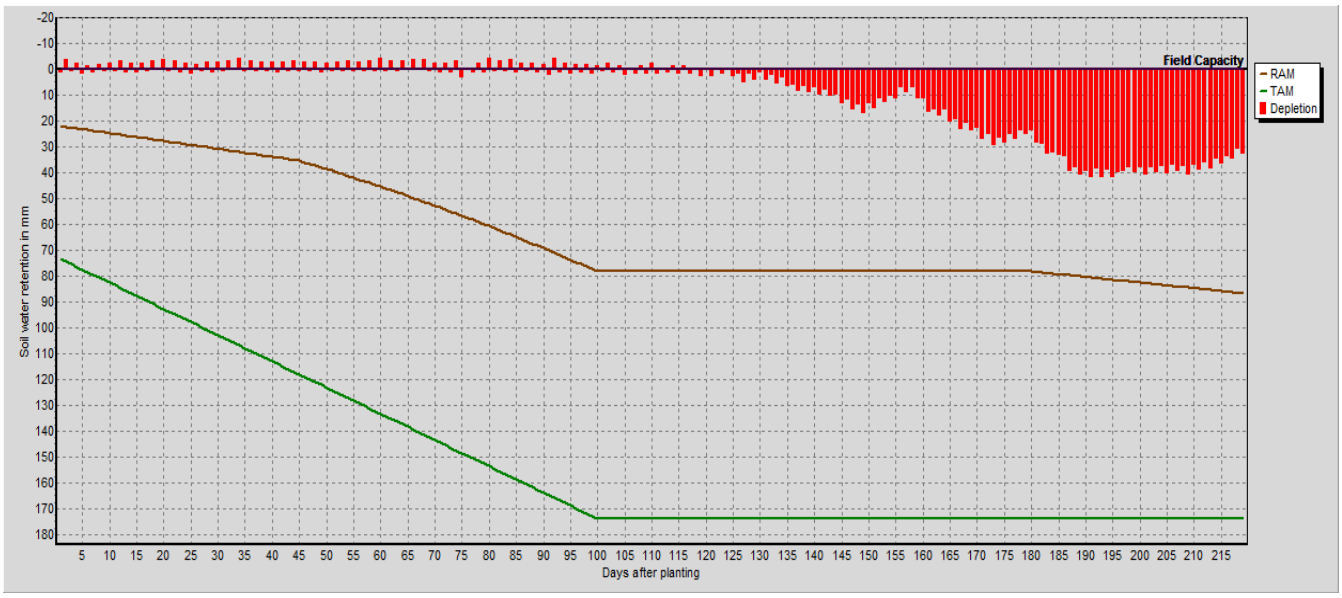
Farmer iii onion bulb



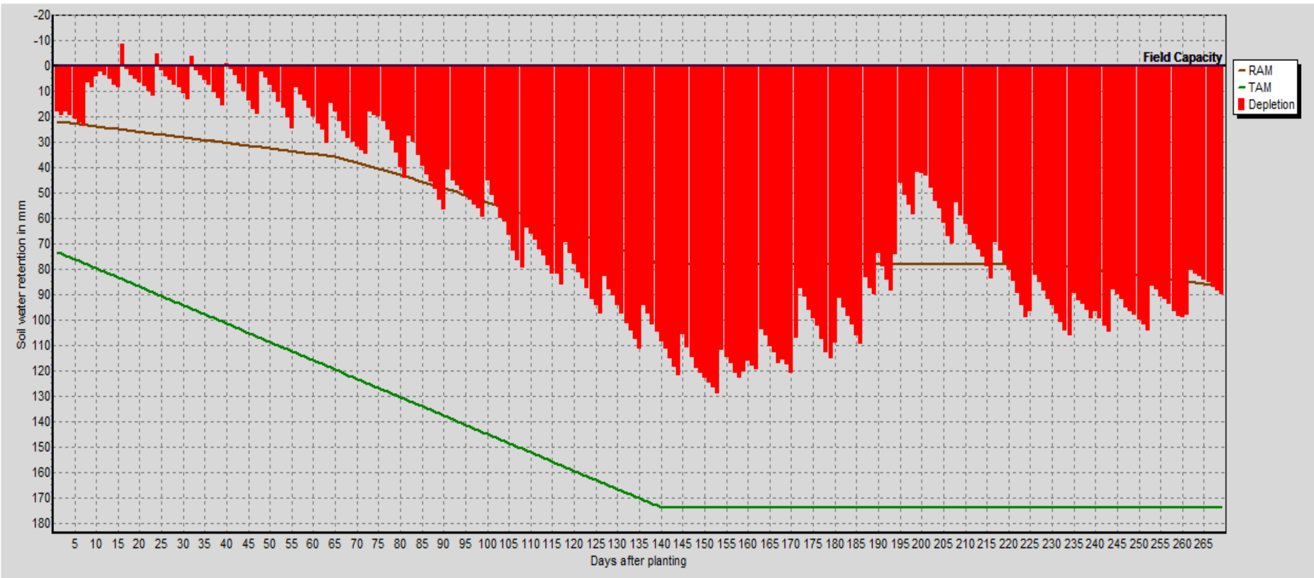
Farmer iv onion seed



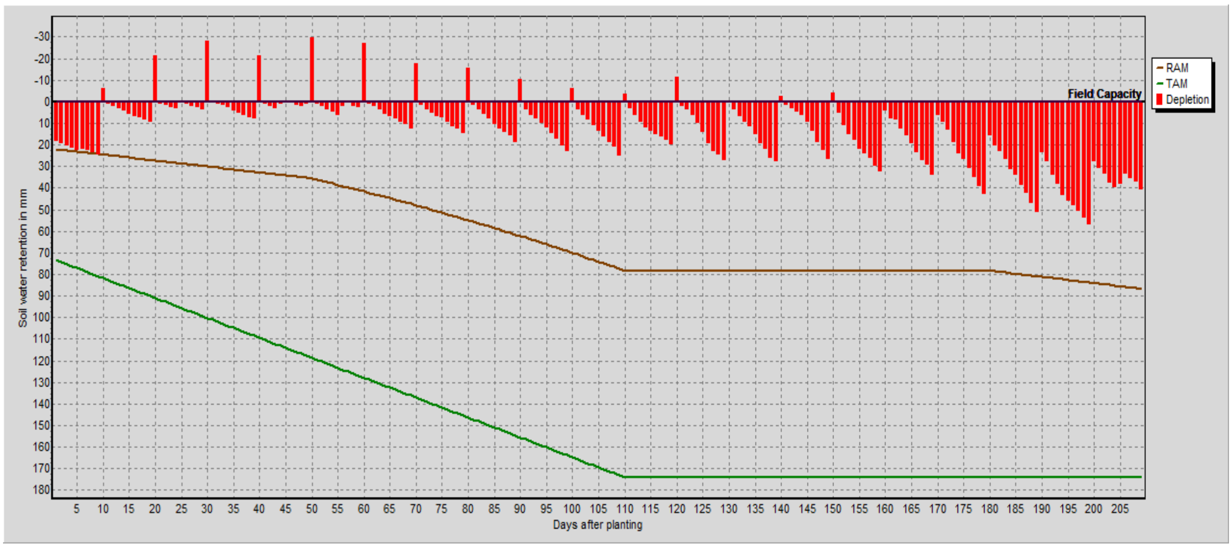
Farmer iv carrot seed



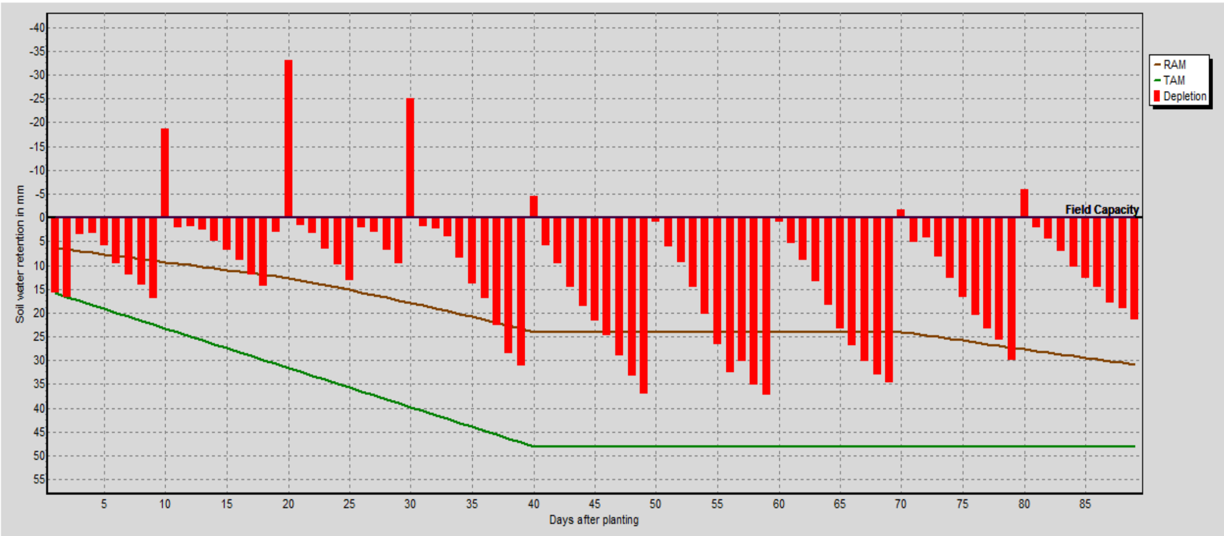
Cropwat schedule graph for Leeks: farmer iv



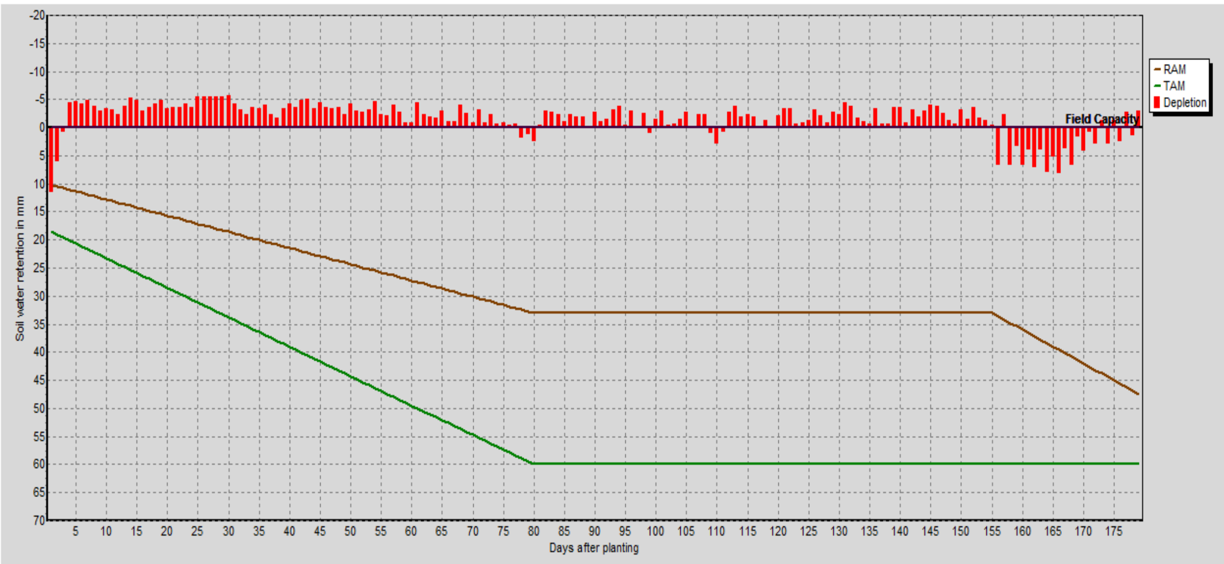
Farmer 5 Onion seed



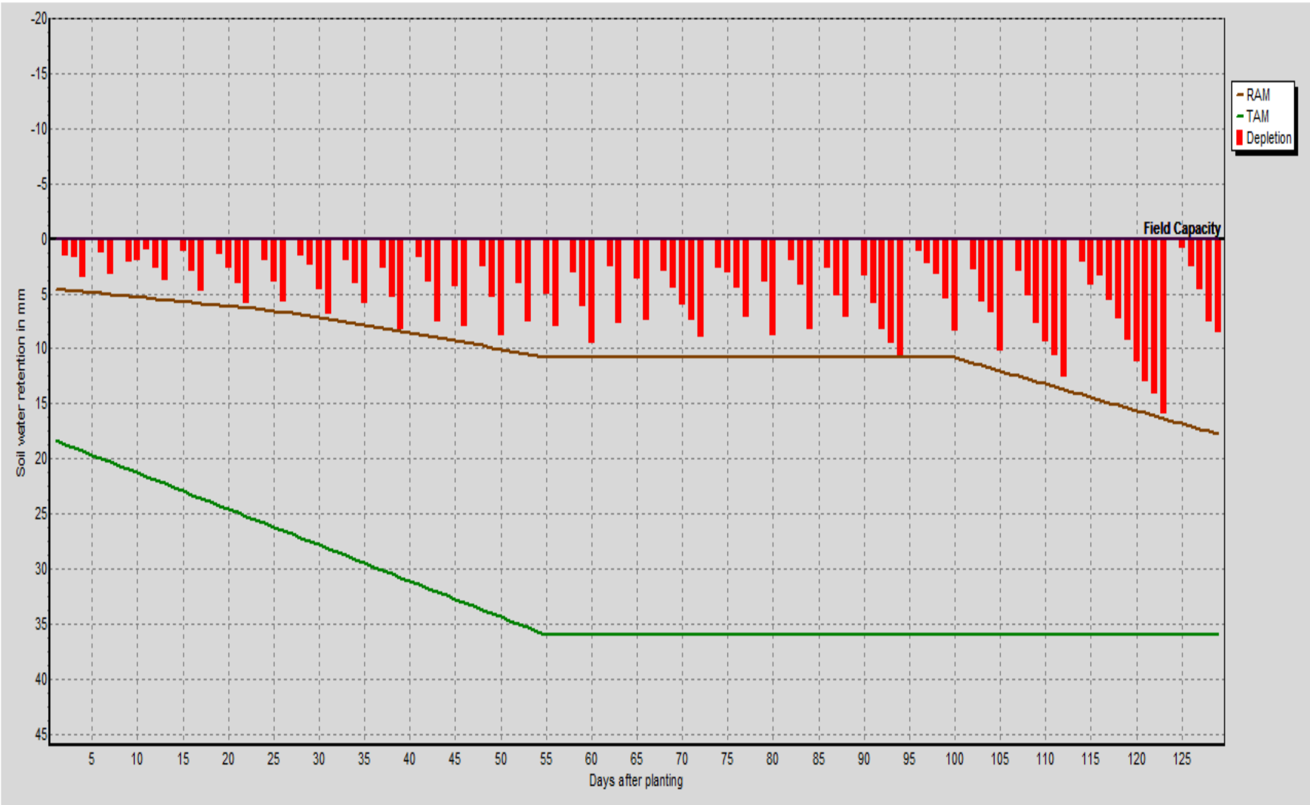
Farmer v Tobacco



CropWat Schedule Graph for maize farmer V



Optimal CropWat simulation output scheduling graph



Annex G. Future scenario of the Baviaanskloof