USING SAPWAT TO ESTIMATE WATER REQUIREMENTS OF CROPS IN SELECTED IRRIGATION AREAS MANAGED BY THE ORANGE-VAAL AND ORANGE-RIET WATER USERS ASSOCIATIONS

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WATER REQUIREMENT OF CROPS IN THE ORANGE-VAAL EN ORANGE-RIET WUA AREAS

1. Introduction

Planners for the use of and managers of irrigation water are sometimes confronted with the question of whether the irrigation requirements estimated for areas are correct and can be applied unconditionally. A computer-planning model, SAPWAT, has been developed (WRC Report no 624/1/99) for this purpose.

The aim of this project is to apply the model in a specific target area with the following objectives:

- to test the applicability of the SAPWAT computer procedure for planning purposes
- to estimate crop water requirements for a selected irrigation scheme
- to make inputs for the development of a water management plan by Water User Associations (WUAs).

This report serves as a user manual for the application of SAPWAT. Furthermore, it demonstrates that the estimation of irrigation requirements can be credible and that the requirements that the National Water Act (Act 36 of 1998) sets for future water management can be met.

The Orange-Vaal and Orange-Riet WUA areas have been identified as a testing area. These areas are situated along the Vaal and Riet Rivers, upstream from the confluence of the Orange and Vaal Rivers. The reasons for the choice of these areas are:

- that research data against which SAPWAT results can be evaluated is available
- a scheduling service against which SAPWAT can be evaluated is in place
- water management and planning for the area is based on volumetric irrigation requirements
- the WUAs indicated a willingness to participate in the project.

Portions of the evaluation area have been irrigated for more than a 100 years and historical farming patterns and water management approaches have been developed that provide a basis for sound water management. The two areas are subdivided into eight sub areas, each of which acts as a separate water management unit, with overall management by the two WUAs. Two hundred and forty four (244) irrigation farmers farm on 12 030 hectares, with an average of 49 hectares scheduled area, ranging from less than 5 hectares to bigger than 500 hectares.

The farmers themselves, through the WUAs, are responsible for building and for maintenance of the water distribution infrastructure. Support from the state was given in the form of grants as well as direct involvement of the Department of Water Affairs and Forestry (DWAF) in the construction and upgrading of canals and weirs.

Initially lucerne, wheat and cotton were produced in the area. During the late fifties potato production increased substantially. The big distances to the larger fresh produce markets limit the production of fruit and vegetables. Since the erection of the first centre pivots in the late seventies, this method of irrigation has become the most important and maize production has increased drastically.

2. Natural resources

The climate is semi-arid, with warm, dry summers and cold winters. Average temperatures vary from 26.3ºC in summer to 9.5ºC in winter, with extremes of 42.2ºC and -8.0ºC. First and last dates of frost are 18 May and 1 September respectively, with 41 nights of frost expected during this period.

Average annual rainfall is 340 mm and average Class A pan evaporation is 2 500 mm, with an average of 10.8 mm.day^{-1} in summer and 3 mm.day^{-1} in winter.

Sources of irrigation water are the Orange, Vaal and Riet Rivers. Water is also transferred from the Orange River through the Orange-Riet and Louis Bosman canals to the Riet River Scheme and to the Douglas weir. On-farm water is applied through flood and furrow systems (30%), sprinkler irrigation systems (68%) and micro and drip systems (2%). The scheduled 8 113 hectares of the Orange-Vaal WUA has a quota of 9 140 m^3.ha^{-1}, while the 3 938 hectares scheduled under the Orange-Riet WUA has a quota of 11 000 m^3.ha^{-1}. Both WUAs make provision for the selling of extra water to farmers if surplus water is available.

Canals have flow measuring structures at their inlets and at the lower ends and there are measuring structures in the Riet River. Water extracted by the farmers is estimated indirectly by the monitoring of areas planted and agreed irrigation water requirements. In cases where water is supplied through gravity out of canals, use is made of sluices with predetermined orifice sizes. Water management is based on mutual trust between the farmers and WUAs.

In order to save on operating expenses, water in the Douglas weir and in the Lower Riet River is managed in such a way that outflow out of the system is kept to a minimum. The salt content of the water of the Lower Riet River and in the Vaal River is high because of upstream irrigation return flow and also because of inflow out of the industrialised PWV area. The consequence of the policy of minimum outflow out of this irrigation area is that the irrigation water becomes progressively more saline. This has the inherent danger that the irrigated soil can become so saline that future crop choice could be limited to more salt-resistant crops and that production potential might be reduced if the excess salts are not leached.

Most of the irrigation is found on alluviums along the Vaal and Riet Rivers, while the balance is found on the adjacent reddish aeolian sandy soils. The lower lying alluviums tend to have a higher clay content, with a relatively high fine sand content, while the aeolian soils also have a high fine sand content. This high fine sand content results in the forming of compacted layers in the profile which limit root development and reduce the infiltration rate of the soils, both of which influence irrigation management strategies. These include:

- centre pivots of 35 hectares or smaller so that the application rate on the outer edge is reduced
- short cycle irrigations
- the management of soil water in such a way that the water content stays close to field capacity.

This management approach can result in the formation of a saline layer at wetting depth. Signs of this have been found at depths that vary from 400 to 1 000 mm. It has also been found that about 25% of the soils should be treated with gypsum because of high SAR values. A leaching requirement of 10% to 20% has also been recommended.

3. Crops

Wheat, maize, lucerne, potatoes and sunflower are the most important crops grown in the area and make up 84% of the total cropping pattern. A high level of double cropping, mainly wheat alternated with maize, potatoes and sunflower, results in an average land use of 136%. Land use and cropping patterns are not the same for all the sub-areas, i.e. lucerne is the most important crop in two sub-areas and wine grapes make up 25% of the pattern in one area, compared to an average total area cover of only 2.5%.

Crop production patterns in the area seem to be fairly stable. A survey done during 1990 as part of the development of a food strategy found that wheat, maize, lucerne, potatoes and cotton were then the most important crops. Since then the importance of cotton has decreased drastically because of a reduction in its profitability.

No drastic change in the crop production patterns are expected on the short term, mainly because:

- licences for the production of wine grapes are too expensive at R533 per ton and are also scarce
- great distances to fresh produce markets limit vegetable production to volumes that can be absorbed locally
- the markets for existing crops are relatively stable
- present cropping patterns have a low labour requirement
- present cropping patterns are in harmony with the total crop production environment.

The intensive crop production system of the area can only be maintained if farmers burn crop residues as part of their land preparation for the next crop. This practice cannot be recommended because of the destruction of organic material that could have been worked into the soil. However, for practical reasons, it seems to be the best solution. Plant diseases and weeds do increase, but these are controlled chemically and also by changing the production cycle from time to time.

4. SAPWAT

The computer program, SAPWAT, was developed to satisfy a need for a user-friendly and credible aid to planning of irrigation schemes and for water management by WUAs. Within the South African context, it is a further development of and improvement on the Green Book of 1985 which has been the basis of irrigation requirement planning for many years, but which has been overtaken by developments in irrigation practice and management. On the international front, SAPWAT links to and is also a further development on an FAO planning model, CROPWAT, which, in turn, leans strongly on several FAO irrigation and drainage reports on irrigation management that have been published since 1977.

SAPWAT is not a crop growth model. It is a planning and management aid that is supported by an extensive South African climate and crop database. Some of the biggest improvements that have been incorporated into SAPWAT are:

- the replacement of the American Class A evaporation pan with reference evaporation from a short grass surface

- the Penman-Monteith calculation methodology for reference evaporation which is acknowledged internationally

- the use of a simple methodology whereby crop factors can be determined and adapted to provide for virtually any growing situation.

The inclusion of an extensive climate and crop database enhances the user friendliness because the user does not have to look elsewhere for data.

SAPWAT takes the user through a process from the selection of up to six weather stations out of 350 which are shown on a map; comparative reference evaporation graphs; crop factors for a selected crop; and a screen which shows the water requirement for that crop, effective rainfall and irrigation requirement. Several options are provided, enabling the user to replicate a specific situation. These include choice of growing periods, planting dates, geographic regions, basic irrigation management options, favourable, normal or severe climatic conditions, inclusion or exclusion of rain as a factor and changeable irrigation efficiency levels.

A management module is also provided that enables the user to evaluate different irrigation strategies in order to identify a "best" strategy for a specific situation.

5. Application of SAPWAT as a planning and management aid

SAPWAT was evaluated in the study area against results obtained with a neutron water meter-based scheduling service and it was found that it gave reliable results within the framework of the complex irrigation management environment. Furthermore, it was found that the farmers of the area have generally accepted the application of SAPWAT as a planning aid and that the results are seen as being credible.

The potential role that SAPWAT can play in water use and water management planning has been tested and a methodology for the application of SAPWAT in such a role has been demonstrated. The conclusion is that SAPWAT can be used with confidence to do the following:

- estimation of the irrigation requirement of individual crops
- estimation of the irrigation requirement of crop rotation systems
- estimation of the irrigation requirements of areas and sub areas
- evaluation of existing management strategies
- estimation of irrigation requirements with inclusion or exclusion of rain
- estimation of irrigation requirements with inclusion or exclusion of leaching requirements
- estimation of the irrigation requirement of alternative crop combinations.

In all these cases the irrigation requirement has been estimated on a monthly basis, which planners and managers can then use with confidence to plan and manage the irrigation requirement of an area or sub area.

Tables 1 and 2 show the estimated irrigation requirements in for crops in mm per hectare for the two areas investigated, as well as the weighted total water requirements for each of the two areas.

Table 1 Estimated irrigation requirements for crops grown in the Orange-Riet WUA area as well as the total irrigation requirement for the area, rainfall excluded from the calculations

Crop	**Planting or starting date**	**%**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
Pastures, annual	01 Mar	1.1			63	78	85	67	75	81					449
Pastures, perennial	01 Aug	1.9	170	129	116	81	60	45	51	76	102	127	147	161	1 265
Potatoes	10 Jan	10.7	73	197	209	137									616
Potatoes	22 Sep	3.0	280	134							15	85	211	266	991
Dry beans	02 Jan	2.4	73	198	192	8									471
Ground nuts	22 Oct	5.8	316	238	101							16	68	191	930
Ground nuts	10 Dec	1.0	126	233	215	49								44	667
Cotton	15 Oct	3.3	296	243	182	13						29	76	179	1 018
Cabbage	15 Mar	0.5			37	75	88	74	25						299
Cabbage	01 Jul	0.4							44	99	167	181			491
Wheat	10 Jul	66.1							23	60	170	239	173		665
Lucerne	01 Aug	9.0	211	160	134	29				51	118	159	184	200	1 246
Maize	01 Nov	1.7	307	243	195	60							60	150	1 015
Maize	13 Dec	21.4	216	243	171									40	670
Cucurbits	30 Aug	1.3									87	175	206	63	531
Sunflower	07 Jan	11.0	61	158	225	75									519
Sweet corn	20 Dec	1.3	161	204	57									29	451
Onions	10 Apr	3.1				32	43	60	84	126	164	113			622
Vineyards	01 Aug	0.7	154	108	46					47	67	105	134	147	808
Carrots	15 Sep	1.9									31	142	217	90	480
Total			**131**	**148**	**122**	**31**	**4**	**4**	**20**	**51**	**133**	**189**	**155**	**62**	**1 051**

Table 2 Estimated irrigation requirements for crops grown in the Orange-Vaal WUA area as well as the total irrigation requirement for the area, rainfall excluded from the calculations

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	15 Mar	1.6			65	80	91	73	84	86					479
Pastures, perennial	01 Aug	2.3	189	133	120	83	64	49	57	80	107	141	162	178	1 363
Potatoes	10 Jan	9.6	80	202	216	140									638
Beetroot	01 Sep	1.1									75	232	184		491
Dry beans	10 Jan	0.4	73	198	192	8									471
Ground nuts	15 Oct	1.5	355	232	63							33	91	253	1 027
Ground nuts	15 Dec	0.3	112	227	226	75								38	678
Cotton	15 Oct	3.7	296	243	182	13						29	76	179	1 018
Wheat	15 Jul	51.4							20	57	164	268	239		748
Lucerne	01 Aug	16.8	233	164	138	30				55	124	176	202	222	1 344
Maize	15 Dec	32.1	197	248	85									39	569
Pecan nuts	01-May	0.7	237	167	151	104	81	62	74	105	136	179	205	225	1 726
Cucurbits	15 Oct	0.8	188									51	182	262	683
Sunflower	12 Jan	4.5	48	125	249	101									523
Onions	15 Apr	2.0				26	44	61	95	134	174	162			696
Vineyards	01 Aug	3.3	171	111	48					50	71	117	148	162	878
Carrots	05 Sep	2.6									63	190	231	29	513
Total			**173**	**145**	**57**	**12**	**2**	**1**	**17**	**38**	**113**	**167**	**160**	**146**	**1 030**

1 INTRODUCTION

The purpose of the project is:

- to evaluate the applicability of the SAPWAT computer procedure for planning purposes
- to estimate crop water requirements for a selected irrigation scheme
- to make inputs for the development of a water management plan by Water User Associations (WUAs).

The implementation of the National Water Act (Act No 36 of 1998) emphasises the urgent need for specific information on irrigation. The establishment of Catchment Management Agencies (CMAs) and WUAs, the quantification of crop water use for registration and licensing purposes, and the development of best management practices and demand management strategies are dependent on realistic and reliable data that are currently not readily available. **It is appreciated that in the long term, the development of a national irrigation database is essential, but there is an interim need for affordable guidelines that can be developed with a minimum of delay.**

Determinations of river basin water balances are currently difficult. There is a lack of information on crop water requirements, irrigation practices and management, particularly with respect to the efficient use of irrigation water. It is appreciated that acquiring this information on a national scale will require a major research project, but in the interim decisions that can have major consequences are based on sketchy information. This is particularly true of decisions by WUAs that are the first link in the development process triggered by the National Water Act (1998).

The primary function of SAPWAT is to estimate crop evapotranspiration for planning purposes so that irrigation requirements for application in planning, design and management can be deduced (Crosby & Crosby, 1999). It is anticipated that the SAPWAT procedure could make a significant contribution.

To test this hypothesis, and to develop a reliable methodology, this pilot study was done in the area of the Orange-Vaal WUA and in Sub district: Lower Riet River[1] of the Orange-Riet WUA. These areas are situated at the confluence of the Orange and Vaal Rivers and in the adjoining lower reaches of the Riet River. The choice of research area is based on the following:

- Both WUAs keep reliable records that could facilitate an initial survey
- At introductory SAPWAT workshops, both WUAs have indicated a willingness to cooperate in further studies

[1] For the sake of consistency, this selected area of the Orange-Riet WUA will be referred to by the name of the WUA in this report.

- Crop water requirements received specific attention in the study area and in the adjoining Riet River Irrigation Scheme. Both GWK and South West Co-operatives introduced a neutron probe scheduling service in the area, a service that is still being provided by GWK. Furthermore, an atmospheric demand scheduling service, based on the PUTU growth model (De Jager, Mottram & Kennedy, 2001) was rendered in the area, while BEWAB (Bennie, Coetzee & Van Antwerpen, 1988) is also applicable. The Riet River Irrigation Scheme has also been the target of a series of research projects and the farmers were, amongst others, supplied with weekly estimates of crop water use, based on real-time automatic weather station data.

- Both the WUAs base their planning and allocation of cost on an agreed estimate of crop water requirement. As can be expected, there is enough data and experience upon which these water requirement estimates can be based. In practice the variability in climate is considered with the use of the S-pan evaporation figures and applicable crop factors, which are adapted empirically to estimate realistic and applicable water requirements.

- The farmers and their organisations and people who provide services to them, know irrigation and production and the efficiency of water use has improved significantly over the past ten years.

- If SAPWAT can be applied in this area, it is a strong indication that it can be applied as a planning aid over the whole country.

- Long-term weather data are available for the area.

- The Orange-Vaal WUA has applied for conversion to a WUA as determined by the National Water Act (1998).

- The areas are adjacent and are within relatively easy reach of the research team.

2 GENERAL BACKGROUND

Unless otherwise indicated, this report is based upon the results of surveys[2] and studies of unpublished material[3].

2.1 ORANGE VAAL WUA

The area of this WUA is situated along the Vaal River, upstream from the confluence of the Orange and Vaal Rivers, over a direct distance of about 40 km and over a river distance of about 70 km. The town of Douglas is situated in the area. Refer to fig. 2.1.1.

In 1845 the founder of the Backhouse mission station, Reverend Isaac Hughes, had already referred to the advantages that could arise for the Griquas who lived in the area if an irrigation scheme were to be developed. In 1866 a white irrigation settlement was marketed as the Albany Settlement, aimed mainly at settlers from the Grahamstown area. By 1868, 88 farms had been surveyed and allocated. Surveying of the planned town of Douglas started before 1871, but was temporarily interrupted because of the annexation of Griqualand West. Surveying resumed in 1880 (Van der Merwe, 1997). Town maps of 1882 indicated the position of a proposed irrigation canal.

After submissions to Parliament by, amongst others, Cecil John Rhodes, MP for the area, an amount of £6 000 was allocated in 1890 for the building of a weir and canal. Construction commenced during 1891 and was completed during 1896. This construction is the top end of the Bucklands canal. The present weir is the sixth that has been constructed at the same site.

Water was originally pumped out of the weir basin with "anthracite motion pumps", the first installed by Llwelyn Roberts as far as could be ascertained. Vaal River Cotton seemed to have been one of the first irrigators in the area. Records indicate that they started in 1895. Irrigation farming was practised on the farms Avoca, Draaihoek, Milford and Zandbult in 1906.

The 1896 weir had apparently not been the first. There are stories of a Griqua weir that had been built in about 1870. Exactly when and where this irrigation took place, and which crops were produced, could not be determined.

The present Bucklands canal services an area that had apparently been irrigated by the Griqua Waterboer at the end of the 19th century. The canal, on the left bank of the river, origi-

[2] Surveying techniques were by way of semi-structured small group discussions with farmers and personnel of the local WUA, agricultural extension office and cooperatives, people knowledgeable of the area on which research was being done. This technique has already proved itself as reliable enough for purposes of surveys of this nature where patterns and tendencies are looked for (Ulschak, Nathanson & Gillian, 1981). Where specific information was required, it was collected directly from published and unpublished source documents and through personal interviews.

[3] Sources of unpublished material and information not specifically referred to, are: (i) The Orange Vaal WUA, Douglas; (ii) The Orange-Riet WUA, Kimberley; (iii) The Agricultural Extension Office, Douglas; (iv) GWK, Douglas; (v) The Northern Cape and Free State Regional Offices of the Department of Water Affairs and Forestry; (vi) The irrigation farmers of the area.

nally serviced only the town of Douglas and the smallholdings, known as “The Plots” downstream from Douglas. In 1937 this canal was extended to form the present Bucklands canal. It was lined for the first time from 1960 to 1965. However, the lining deteriorated to such an extent that the canal had to be relined in 1991 – 1992. The canal is 23,7 km long, and has a capacity that varies from1,8 $m^3.s^{-1}$ at its top to 1,1 $m^3.s^{-1}$ at the end.

Atherton is the oldest irrigation area. It is serviced by an unlined canal out of the weir on the right bank of the river. As far as is known, one Geldenhuys was the first person who constructed a canal in this area. All irrigation development was originally below the level of the canal, but since the 1950’s development also took place above the canal. The canal is 8 km long and has a capacity of 0,8 $m^3.s^{-1}$.

Irrigation was originally by means of flood systems. The first centre pivot systems were installed during 1978 and since then this method of irrigation has become the most important. The biggest centre pivot in the area irrigates 100 ha, although the tendency is to install small systems because of the low infiltration rates of the local soils.

Originally the water allocation was based on a unit area of 25 morgen (21 ha). Irrigation was also limited to within one mile (1.6 km) from the riverbanks. The area cultivated at allocation, as well as irrigation potential, also played a role in these allocations. At a later stage, farmers could buy additional water rights to a maximum of 100 ha.

Initially, very few water shortages were experienced, but since 1953 shortages became more serious as the water requirements of the PWV area increased. In the early 1980’s the water shortages became so serious that it threatened the continued existence of the 180 irrigation farmers. To counter this problem, a scheme, presently known as the Louis Bosman canal, was initiated by the co-operative at an estimated cost of R3 000 000. This scheme consists of pumps and a 24-km canal with a capacity of 6.6 $m^3.s^{-1}$ and diverts Orange River water across the divide and into the Douglas weir basin. A loan was raised and eight months after the commencement of construction the first water flowed into the weir basin. However, final costs escalated to more than R6 000 000.

The soils through which the canal flows are sandy and very soon problems were encountered with unstable canal walls and water logging problems in low-lying areas. In places even the stability of the railway line was threatened. To counter this problem, portions of the canal would have had to be lined at an additional cost of R4 000 000, but this would have increased the total cost to a level above the repayment ability of the farmers. The state was asked to take over the canal. This was implemented and the state initially cemented the canal from its beginning up to a point near the co-operative at a cost of R18 000 000. The rest of the canal was temporarily sealed with plastic and a mixture of soil and lime. The biggest portion of the unlined part of the canal was cemented during 1995.

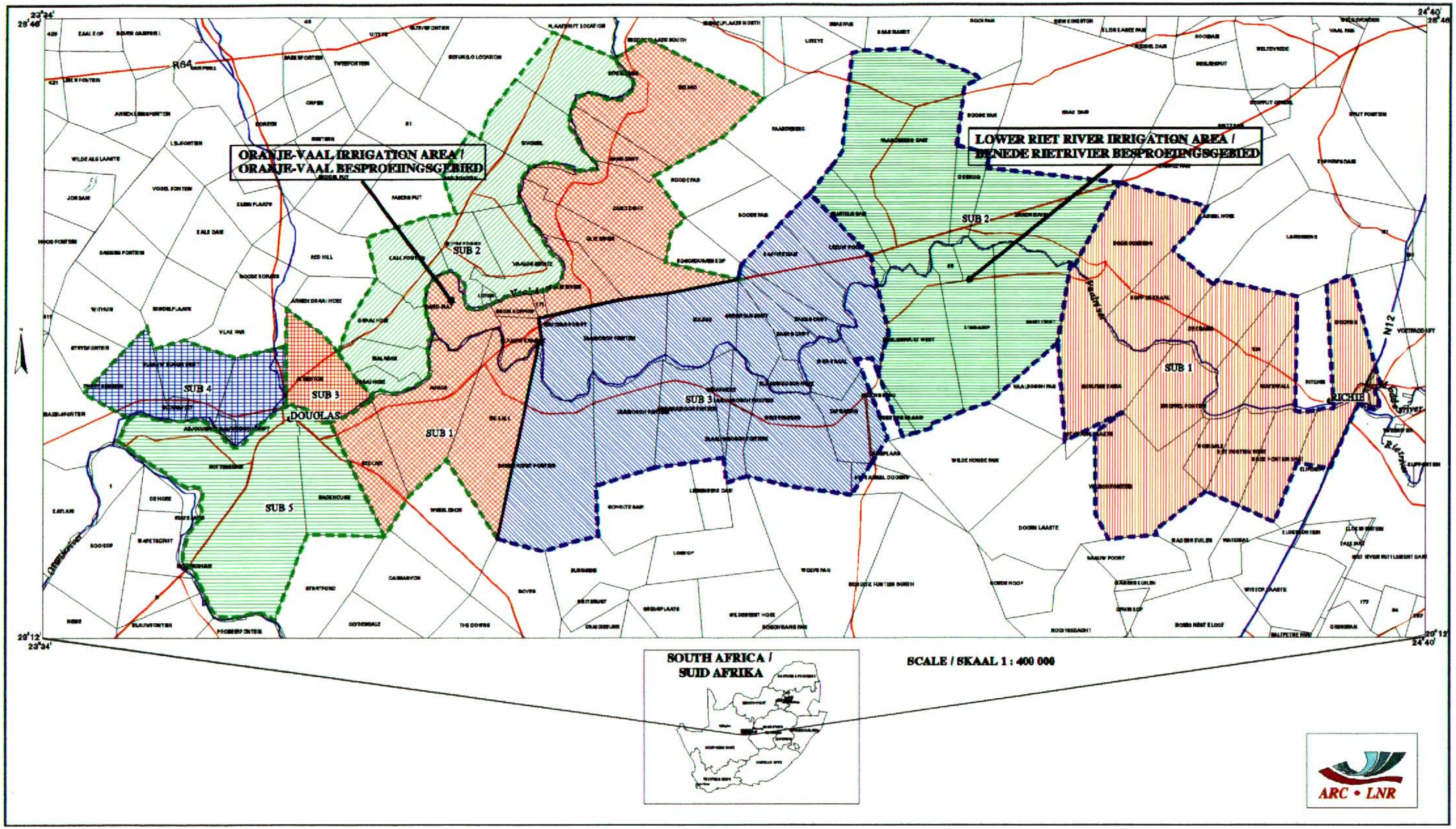


Figure 2.1.1 Location map of irrigation areas and sub-areas in the study area

The Louis Bosman canal runs through land on which the Bucklands farmers had a grazing right. Government bought out this right and in 1993 new farmers were settled along the canal on this land. Each new farm had a water right of 100 ha. Precedence for settlement was given to farmers who had farmed in the Bucklands area and who could not survive because their irrigation farms were too small to be economically viable. Farmers who remained in Bucklands were given a chance to consolidate their farms into economic units by giving them a first option to buy newly vacated land.

The farmers, who are not provided with water out of a canal, pump their water out of the Douglas weir basin. 5 662 ha are irrigated in this way. Flow meters are not installed on the pumps, but the areas covered by crops are monitored and water allocation and payment is determined on the basis of agreed crop water requirements.

There are indications that lucerne, wheat and cotton were grown in the area during 1918, the lucerne mainly as fodder for the mules that were used as draught animals on the diamond mines. The growing of potatoes has increased substantially during the late 1950's and early 1960's on soils with lower clay content. Up-to-Date seed potatoes were originally imported from Scotland. Watermelons and apricots also increased in importance, the fruit mainly as result of a canning factory of one Delport at Modder River which was in operation from about 1960 to the early 1970's. The incorporation of maize into the crop pattern increased significantly after the erection of the first centre pivot systems in 1978. Wine grapes were introduced into the area in the late 1980's, but the limited availability of quotas, as well as the relatively high price of R533 and more per ton for the purchase of such a licence, will most probably limit the increase in area under wine grapes in the short term. Vegetables have always been grown on a small scale in the area, but a limited local market and the distance to bigger markets has restricted production.

The present scheduled area is 8 113 ha with a quota of 1 140 $m^3.ha^{-1}$. 177 farmers, including 71 on smallholdings (<5 ha), farm in the area. The area is subdivided into 5 sub districts. Particulars are provided in Table 2.2.1.

Table 2.1.1 Hectares scheduled, number of farms per sub district and average scheduled areas of the Orange Vaal WUA, 1999.

Sub district	**Ha**	**Farms/ Small holdings**	**Average scheduled areas (ha)**
Sub district 1 (Olierivier)	3 124.7	24	130
Sub district 2 (Vaallus)	2 659.1	15	177
Sub district 3 (Atherton)	349.4	11	32
Sub district 4 (Bucklands)	1 341.5	120	11
Sub district 5 (New Bucklands)	617.4	7	88
Total	8 092.1[4]	177	46

Sub district 4 (Bucklands, including the smallholdings known as The Plots) includes 69 smallholdings with a scheduled area of 0 – 5 ha each. Many of the smallholding owners

[4] This figure is not the same as the official (8 113 ha) scheduled area on the books of DWAF. The WUA and DWAF are discussing the matter.

are people who work in town and for whom the smallholding is mainly a place of residence. The same applies to the 39 farms with scheduled areas of 6 – 10 and of 11 – 25 ha found in the area. Some of the smallholdings and farms are also not used for farming purposes. 22 of the 177 farms in the WUA area are scheduled for more than 100 ha. Refer to Appendix 2.1 for more particulars about scheduled areas.

Most of the farms in the area are used almost exclusively for irrigation purposes.

The farmers were, from the outset, responsible for water management on the Bucklands and Atherton canals. Maintenance of the canals was also the responsibility of the farmers. From about 1970, DWAF assumed more control over water usage. A part of the control was the issuing of works permits that limited pump capacities to that which could supply the irrigated area with water. The Orange-Vaal WUA took over the control of water management and canal maintenance with its founding in 1983.

Douglas co-operative was founded in 1947, originally with the intent to market the lucerne that was produced in the area. During the mid 1950's the potato seed growers association and the co-operative joined forces, and since then the co-operative was also responsible for the marketing of seed potatoes. As irrigation in the area increased, the co-operative started marketing wheat and other agricultural products. Amalgamations followed, and today the co-operative is part of GWK.

The Kimberley-Douglas-Prieska main road runs through the area and it is relatively easy to reach Bloemfontein, Johannesburg, Cape Town and Durban from here. However, the 550 km to Johannesburg, 900 km to Durban and 1 300 km to Cape Town limit marketing in those areas.

2.2 ORANGE-RIET WUA

This WUA area is situated from the confluence of the Vaal and Riet Rivers, upstream along the Riet River over a direct distance of about 70 km and a river distance of about 120 km. The area lies between the towns of Douglas and Jacobsdal. See Fig. 2.1.1.

It is not known when the first irrigation in the area took place, what crops were grown, nor where it took place. The start of significant irrigation in the area is generally accepted as the early 1950's.

All irrigation water is pumped out of the river.

Irrigation in the area really started to develop after the completion of the Orange Riet River Canal during 1988. Before that the water supply was sporadic and permanent development could not really take place, although the water used to be less saline than it is today. The building of the Krugersdrift Dam during 1968 – 1969 did stabilise the water supply, but had the unfortunate effect of increasing the salinity of the water. During the early 1980's many of the flood irrigation lands were converted to centre pivot systems.

The basic scheduled area was 37 ha per farm, but after water from the Orange Riet River canal reached the area, farmers were allowed to buy water rights of up to 120 ha each. The quota was originally 5 080 $m^3.ha^{-1}$ for 2 698 ha scheduled under the Krugersdrift dam, but since 1988, after the completion of the Orange Riet River canal, the quota was increased to the present 11 000 $m^3.ha^{-1}$.

Wheat used to be the main crop, with a small amount of lucerne in between. Small plantings of vegetables were also found. Seed potatoes had also been produced in the early years, mainly the cultivar Up-to-Date, out of material imported from Scotland.

33 of the 67 farms in this area are scheduled for 51 – 100 ha each. Eight smallholdings, with scheduled areas 0 – 5 ha, are situated in the vicinity of Modder River. Refer to Appendix 2.1 for more detail.

Irrigation farming in this area has traditionally been supplementary to livestock farming. In the majority of cases, the present farming pattern reflects a continuation of this practice.

Area water management has been the responsibility of the farmers themselves. From about 1970 the Department of Water Affairs became more conspicuous in the controlling of water usage. Part of the control was the issuing of works permits that limited pump capacities to that which could supply the scheduled area with water. The Orange-Riet WUA took over the management of water in this area with its founding in 1984.

Presently 3 938 ha are scheduled with a quota of 11 000 $m^3.ha^{-1}$. 67 farmers farm in the area. It is subdivided into 3 sub areas. Particulars are provided in Table 2.2.1.

Table 2.2.1 Hectares scheduled, number of farms per sub area and average scheduled areas of the Orange-Riet WUA, 1999.

Sub area	**Ha**	**Farms/small holdings**	**Average scheduled area (ha)**
Sub area 1	723.7	24	30
Sub area 2	1 376.7	19	72
Sub area 3	1 837.5	24	77
Total	3 937.9	67	59

Both the Kimberley-Douglas-Prieska main road and the N1 between Kimberley and Hopetown runs through the area and it is relatively easy to reach the traditional markets of Johannesburg, Cape Town and Durban from here, although the 550 km to Johannesburg, 900 km to Durban and 1 300 km to Cape Town limit marketing in these areas. Products are also marketed occasionally in East London.

3 NATURAL RESOURCES

3.1 CLIMATE

The climate of the area is semi-arid, summer rainfall, with warm, dry summers and cold winters (Van den Berg, 2000). Average daily temperatures during January are 26.3°C and 25.9°C for Douglas and Riet River respectively, while it is 10.5°C and 9.5°C for the two stations during June. The highest and lowest temperatures recorded were 42.2°C and -6.5°C for Douglas and 41.5°C and -8.0°C for Riet River respectively (AGROMET, undated). Fig. 3.1.1 shows how temperatures vary over a year.

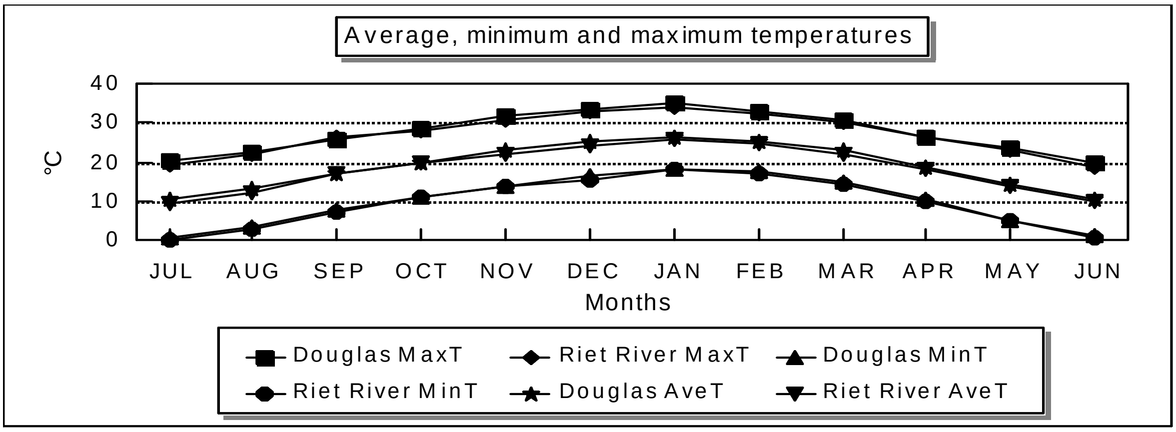


Figure 3.1.1 Average, maximum and minimum temperatures for the Douglas and Riet River weather stations.

Average expected day of first frost is 18 May for Douglas and 21 May for Riet River, while the last expected day of frost is 31 August for Douglas and 1 September for Riet River. Over this period of 105 days, frost can be expected on 41 days. Frost has occurred as early as 25 April and as late as 14 September (AGROMET, undated).

The average annual rainfall for Douglas is 335 mm with February and March as the months with the highest precipitation. The total A-pan evaporation is 2 517 mm.a^{-1}, with 340 mm (10.8 mm.day^{-1}) and 97 mm (3.2 mm.day^{-1}) for January and June respectively. The average rainfall for Riet River is 361 mm and here the highest precipitation is also found during February and March. Die total A-pan evaporation for Riet River is 2 292 mm.a^{-1}, with 310 mm (10 mm.day^{-1}) and 90 mm (3 mm.day^{-1}) for January and June respectively (AGROMET, undated).

The big difference between monthly average evaporation and rainfall can be seen in Fig. 3.1.2.

The average hours of sunshine are 9.5 and 9.3 hours.day^{-1} for Douglas en Riet River respectively.

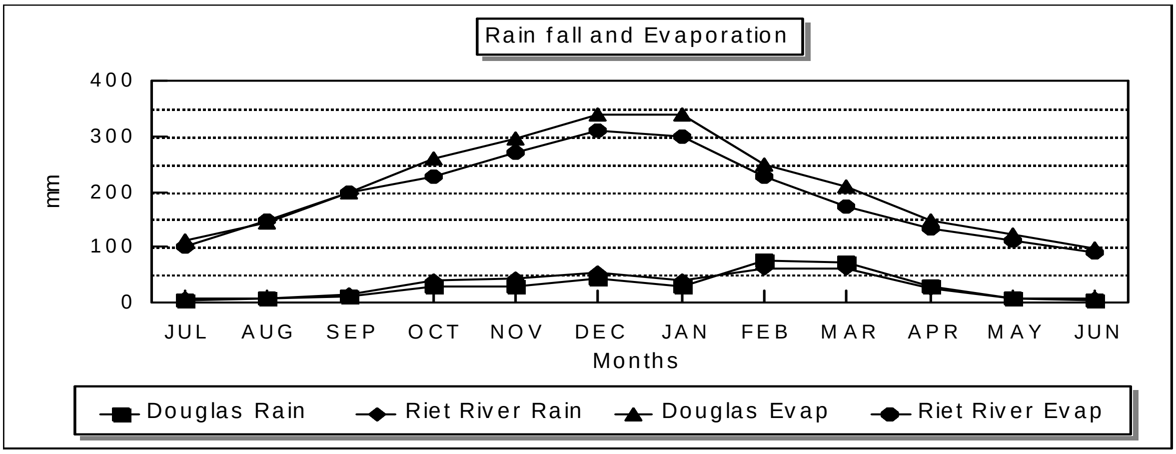


Figure 3.1.2 Average monthly rainfall and total monthly A-pan evaporation for the Douglas and Riet River weather stations.

November is the windiest month with an average of 126 and 119 $km.day^{-1}$ for the two stations respectively.

Detail weather data for the two stations that can be used for the two irrigation areas are shown in Appendix 3.1.1.

3.2 TOPOGRAPHY AND PLANT GROWTH

The topography is relatively flat, with 87% of the area having an average slope of less than 2%. In the immediate vicinity of the rivers, steeper slopes are found between the surrounding land and the lower lying flood plains and watercourses (ISCW, undated).

The natural plant growth is semi-arid, open to sparse tree and shrub veld with dwarf shrubs and grass in between. Trees and shrubs are small because of the negative water balance of the area. The exceptions are trees and shrubs on the riverbanks, which are tall because of the abundance of water found there.

3.3 WATER

Fig. 3.3.1 is a schematic representation of the water supply to the area. Both Bloemhof and Vaal Dams are situated upstream from the study area on the Vaal River. All water that is used for irrigation in this area is surface water, with the Orange, Vaal, Riet and Modder Rivers being the main sources of supply.

Orange River water is supplied to the Riet River Irrigation Scheme out of the Vanderkloof Dam, through the Scheiding pumping station and the Orange-Riet canal. At present this scheme supplies 189 x 10^6 $m^3.a^{-1}$ to the Riet River (Department of Water Affairs and Forestry, 1997). At the bottom end of this canal water is let into the Riet River for use by farmers of the Orange-Riet WUA. This supply of water is regulated in such a way that outflow into the Vaal River is kept to a minimum.

Orange River water is also supplied to the Douglas weir through the Bosman canal for use by irrigators and the community of Douglas. On average, this scheme supplies 52 x 10^6 m^3

Orange River water annually to the lower Vaal River (Department of Water Affairs and Forestry, 1997). Canal capacities will be described more fully at a later stage.

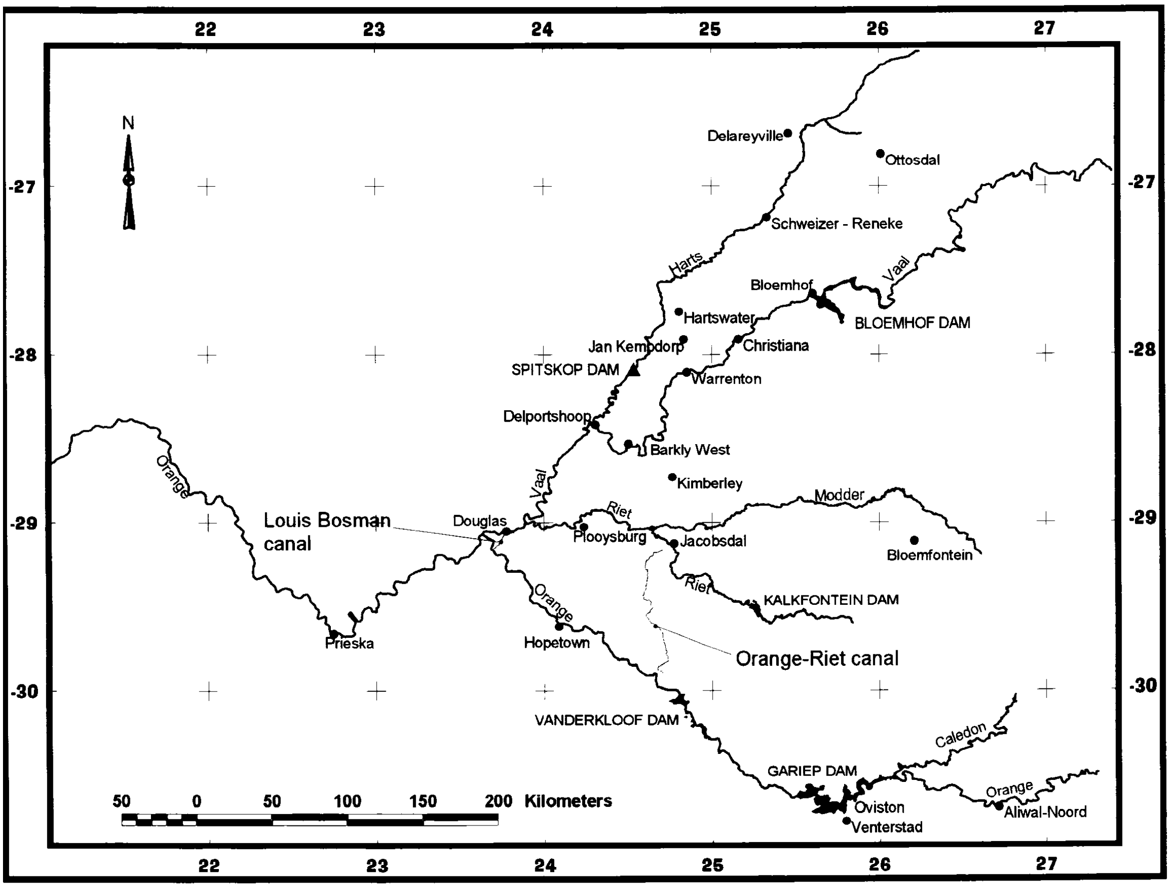


Figure 3.3.1 Water supply to the study area, with specific reference to the Orange-Riet and the Louis Bosman canals that supply Orange River water to the area.

Irrigation takes place by means of irrigation systems as shown in Table 3.3.1, and in more detail in Appendix 3.3.1.

Table 3.3.1 Irrigation systems and their relative importance in the study area, 1999.

Irrigation systems	**%**
Flood and furrow systems	30
Sprinkler systems	68
Micro and drip systems	2

Irrigation return flow, deep drainage (percolation) and water out of artificial drainage systems end up in the river systems. The quantity has not been determined, but it does contribute meaningfully to the salination of downstream water (Du Preez, Strydom, Le Roux, Pretorius, Van Rensburg & Bennie, 2000).

3.3.1 Orange-Vaal WUA area

The Vaal River and the Orange River through the Louis Bosman-canal are the sources of irrigation water for this area. The quality of the Vaal River water is relatively low because of the influence of the industries of the PWV area and of drainage water out of upstream irrigation areas, the biggest of these being Vaalharts. The system is managed as a closed system with the aim of minimizing pumping costs and water loss. Replenishment out of the Bloemhof Dam is limited to such an extent that only floodwater passes Douglas weir. The result is a slow salinisation of the water in the Douglas weir, so much so that the yields of more sensitive crops are suppressed (Du Preez, et al, 2000). The irregular floods of the Vaal River temporarily decrease the level of salinity of the water in the weir basin.

The fresh Orange River water that is supplied to the Douglas weir, reduces the salinity level of the water immediately in front of the weir because this water is let into the weir to close to the wall to allow mixing of water throughout the basin. The Atherton and Bucklands areas that get their irrigation water through canals out of the weir are supplied with relatively fresh water. Farmers that pump their water out of the weir basin get water with a relatively high salt content.

The scheduled irrigation area is 8 113 ha, with an annual quota of 9 140 $m^3.ha^{-1}$. There are 178 farmers in the area.

The Louis Bosman-canal is 24 km long and has a capacity of 6,6 $m^3.s^{-1}$. Apart from supplying water to the Douglas weir, it also supplies irrigation water to farmers along its length. Its characteristics, and that of the other two canals in the area, are given in Table 3.3.1.1.

Table 3.3.1.1 Distribution canals of the Orange-Vaal WUA and their dimensions.

Canal	**Feature**	**Dimension**
Louis Bosman canal	Length	24 km
	Capacity	6,6 $m^3.s^{-1}$
Bucklands-canal, on the left bank, cemented	Length	23,7 km
	Capacity at inlet	1,8 $m^3.s^{-1}$
	Capacity at end	1,1 $m^3.s^{-1}$
Atherton-canal, on the right bank, unlined	Length	8 km
	Capacity	0,8 $m^3.s^{-1}$

Irrigation farmers withdraw water for irrigation as is shown in Table 3.3.1.2.

Table 3.3.1.2 Water-extraction for irrigation in the area of the Orange-Vaal WUA, 1999.

Water-extraction	**Hectare**
Directly out of the Louis Bosman-canal	626
Pumping out of the weir basin	5 662
Out of the Bucklands-canal	1 355
Out of the Atherton-canal	350

The town of Douglas and some mines are the only other major water users within the boundaries of this WUA.

Seasonal water allocation for farms is based on the water requirement of the crops, which is calculated by means of S-pan evaporation figures and relevant crop factors. At the beginning of each season the farmers must hand in their planned cropping pattern to the WUA, who will calculate the expected water requirement for the season. The total water requirement should be within the quota of 9 140 $m^3.ha^{-1}$, but if farmers should need more, they are allowed to buy it provided that surplus water is available. If the requirement exceeds 9 140 $m^3.ha^{-1}$, but does not exceed 11 000 $m^3.ha^{-1}$ the farmers pay the determined price. If the requirement exceeds 11 000 $m^3.ha^{-1}$, the price for the extra water is increased by 50% for the first 1 000 $m^3.ha^{-1}$ extra, 100% for the second 1 000 $m^3.ha^{-1}$ and 200% for the third 1 000 $m^3.ha^{-1}$ extra.

The present price of irrigation water is 1.9 $c.m^{-3}$. The price is calculated in such a way that the selling of 80% of the quota would cover the cost of managing the scheme. The Bucklands and Atherton farmers pay a premium on the normal price to provide for upkeep of their canal.

Flow measuring structures are installed at the beginning and end of the Louis Bosman canal and at the beginning of the Atherton and Bucklands canals. Water management of the scheme is based on mutual trust.

Water distribution on farms is indicated in Table 3.3.1.3 and in more detail in Appendix 3.3.1.

Table 3.3.1.3 Irrigation systems and their relative importance in the area of the Orange-Vaal WUA, 1999.

Irrigation systems	**%**
Flood and furrow systems	28
Sprinkler systems	70
Micro and drip systems	2

DWAF bases hydrological planning on quaternary drainage areas. With this in mind, the subdivision of this area into quaternary drainage regions is given in Table 3.3.1.4.

Table 3.3.1.4 Subdivision of the area of the Orange-Vaal WUA into quaternary drainage regions.

Drainage region	**Ha**	**Sub areas**
C92B	5 784	1 & 2
C92C	1 690	3 & 4
D33K	617	5

3.3.2 Orange-Riet WUA area

Traditionally, this area got its water from the Modder River. The Riet River was never really a factor in the supply of water, even after the completion of the Kalkfontein Dam in 1938 because the existing Riet River scheme and other irrigators upstream of the area used all the available water. After the completion of the Krugersdrift Dam, the water supply was more stable, but not enough for the area. It was only after the completion of the Orange-Riet canal, which delivered Orange River water to the Riet River near Jacobsdal, that the Orange-Riet area got an adequate and stable supply of irrigation water.

This system is managed in such a way that a minimum amount of water flows out of the system at Zoutpansdrift. The result is a periodic high saline level in the water, to such an extent that the yield of sensitive crops can be suppressed (Du Preez, et al, 2000).

Outflow out of this area, flows into the Douglas weir.

Some mines use water within the boundaries of this irrigation area.

The scheduled irrigation area is 3 938 ha, with an annual quota of 11 000 $m^3.ha^{-1}$. There are 67 farmers in this area.

Seasonal water allocation for farms is based on the water requirement of the crops which is calculated by means of S-pan evaporation figures and relevant crop factors by the Orange-Vaal WUA. At the beginning of each season the farmers must hand in their planned cropping pattern to the WUA, who will then determine the expected water requirement for the season. Farmers who need more water than their quota can buy extra water, provided that surplus water is available.

Water management is based on mutual trust. No water meters are installed on the pumps. Flow measuring structures are installed at the point of inflow at Jacobsdal, in the Modder River just upstream from the confluence of the Riet and Modder Rivers and on the farms Ritchie, Aucampshoop en Zoutpansdrift.

Water distribution on the farms is indicated in Table 3.3.2.1 and in more detail in Appendix 3.3.1.

Table 3.3.2.1 Irrigation systems and their relative importance in the area of the Orange-Riet WUA, 1999.

Irrigation systems	**%**
Flood and furrow systems	34
Sprinkler systems	65
Micro and drip systems	1

DWAF bases hydrological planning on quaternary drainage regions. With this in mind, the subdivision of this area into quaternary drainage regions is given in Table 3.3.2.2.

Table 3.3.2.2 Subdivision of the area of the Orange-Riet WUA into quaternary drainage regions.

Drainage region	**Hectare**	**Sub area**
C52L	724	1
C51M	3 215	2 & 3

3.4 SOIL

Most of the irrigation in this area is found on the alluviums next to the rivers, whilst a small proportion is found on the adjoining reddish and brownish sandy soils (ISCW, undated).

Appendix 3.4.1 is the detailed information of the soils of the land types in the immediate vicinity of the present irrigation areas while Fig. 3.4.1 shows their location. Judged on the general guidelines for the determination of physical irrigation potential, there are 25 823 ha of irrigable soils in the area. This is much more than the scheduled area of 12 030 ha because the Land Types cover a much bigger area than the irrigation districts. Interviews with farmers and personnel of the WUAs indicated that the present development on the irrigable alluviums along the rivers (Land Types Ia126, Ia3 and Ia4) within the boundaries of the WUAs has been developed to full potential. The only extra potential within the boundaries of the WUAs is on the adjoining sandy soils (Land Types Ae15, Ae277, and Ah92). This possible potential is not necessarily situated within an economic distance from the river and there is also no extra water available for additional irrigation development. A general physical irrigation classification, based on Land Type descriptions, indicate that only 246 ha of these Land Types are irrigable. More detailed soil surveys and situation specific irrigation classification could possibly give a bigger irrigation potential. This was experienced with the development of the new Bucklands irrigation area (sub area 5 of the Orange-Vaal WUA).

Soils with a relatively high clay content are found in the lower lying areas. Typical of most of the higher lying areas is the relatively low clay content of the soils, combined with a dominant fine sand fraction. Soils of this combination easily develop compacted layers, a problem commonly experienced by the farmers of the area. Efforts to manage their water within the limitations of this problem is reflected in the following:

- Relatively small centre pivots, 35 ha or smaller, to ensure that application rates on the perimeter stay within the limits of the lower infiltration rates of the compacted soil layers

- The managing of the problem through the use of drop pipes with wobblers that spray at lower working pressures

- The management of water in such a way that the soil water content stay as close to field capacity as possible in an effort to prevent high application rates during peak periods

- Short cycle irrigation, to ensure that water application stays within the infiltration rate of the soil.

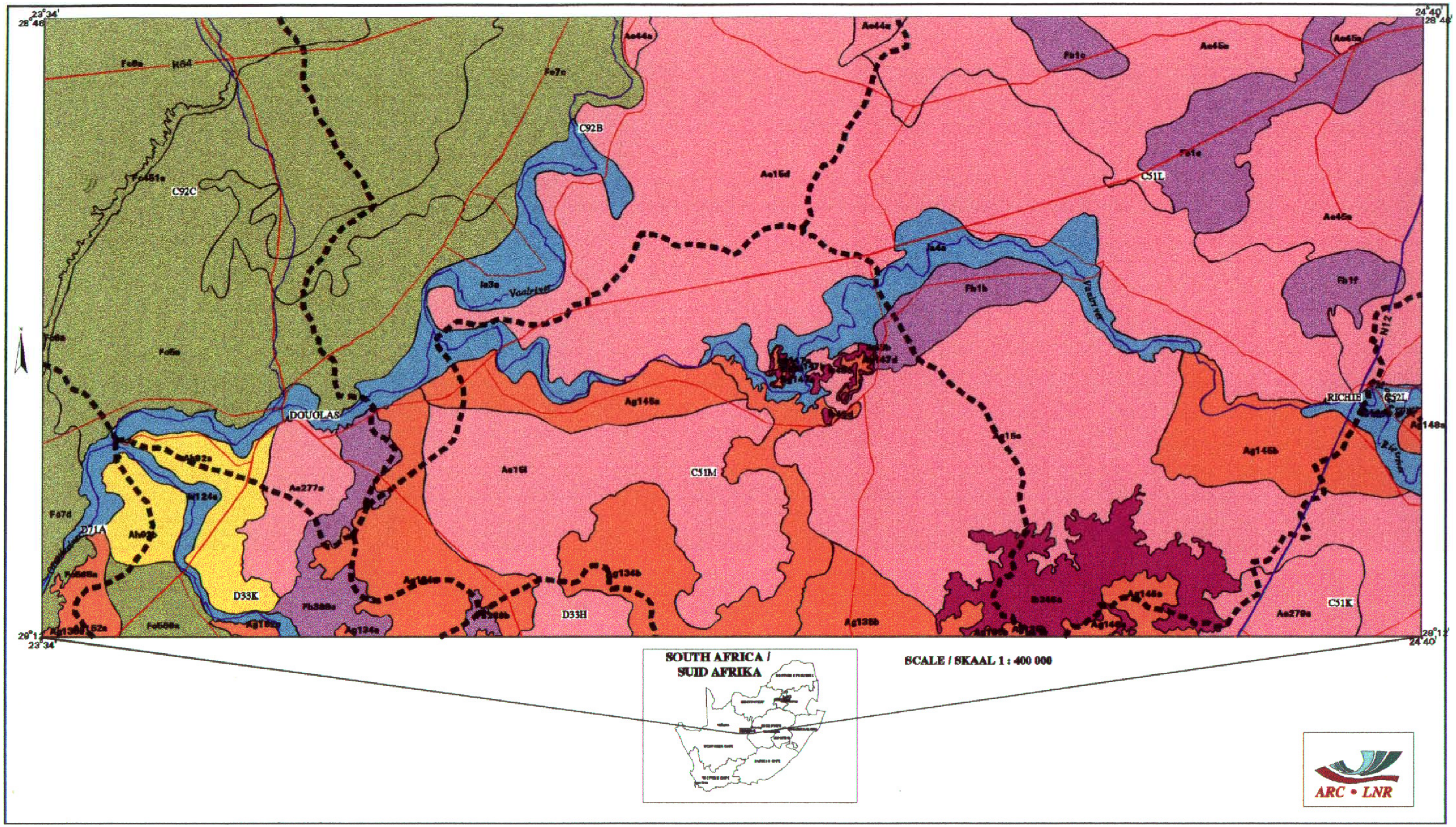


Fig 3.1.4.1 Land Types found in the study area

The present irrigation management can result in a saline layer developing at wetting depth if leaching is not provided for. Du Preez, et al (2000) found evidence of such saline layers at depths that varied from 400 to 1 000 mm in their study on the influence of water quality on crop production in the lower Vaal River irrigation areas. The authors recommended that enough water should be applied during irrigation to also satisfy leaching requirements. If the present irrigation practices are not adapted to provide for a 10% to 20% leaching requirement, the danger exists that the irrigation soils can become so saline that crop production and choice of crops become limited to uneconomic levels. This problem potential is greater for farmers who pump their water out of the weir basin in areas where the salt content of the water is not diluted by the fresher Orange River water that is brought into the system.

In general the soils in the area are chemically suitable for irrigation, although some SAR values do indicate that gypsum applications might be necessary on about 25% of the soils in the Orange-Riet irrigation area (SIRI, 1988). Individual soil analyses will determine the exact gypsum requirement.

The respondents were asked to classify the irrigable soils into high, medium and low potential soils. This classification was done subjectively against the background of the suitability to grow all crops and the potential yield as experienced by the farmers. Factors taken into account in the downgrading of soils were mainly salinity and real or potential danger of water logging. Appendix 3.4.2 shows the detail and Table 3.5.1 is a summary of this classification.

Table 3.5.1 Irrigation potential of the soils in the study area as perceived by the respondents.

WUA	**High (%)**	**Medium (%)**	**Low (%)**
Orange-Riet	64	36	1
Orange-Vaal	51	36	13
Total	55	36	9

According to this classification most of the soils that are irrigated is of a high potential. Irrigation systems are integrated on the farms and covers soils of different potential. Because of practical considerations most of the crops are grown on all three potential soil classes. However, farmers do try to select higher potential soils for the growing of some vegetables, potatoes and vineyards.

Appendix 3.4.3 shows the degree of different levels of waterlogging and salinity in the study area as perceived by the respondents. This shows that 12% of the area is moderately and 19% is seriously water logged and/or saline. This perception of the respondents agrees, to some extent, with the findings of SIRI (1988) that some high SAR values indicate that gypsum applications might be required on about 25% of the soils in the Orange-Riet irrigation area.

One case was mentioned of a soil that had become completely unsuitable for crop production because of serious waterlogging and salinity problems, which had improved to such an extent after the installation of an artificial drainage system, that the same soil could presently be classified as high potential irrigation soil.

4 CROPS

The respondents do recognize different potential soils, but as can be seen in Appendix 4.1 this has little influence on whether cash crops, including perennial crops, or pastures will be planted. Two possible explanations are: Firstly, few farmers in the area farm with livestock on irrigated pastures, and secondly, the irrigation systems include soils of different potentials within the same system because the soils of different potential are too fragmented to allow separate irrigation systems for different soil potentials. A further reason is that the crop rotation system is applied on the whole farm, and, except in the case of some vegetables, potatoes and vineyards, a crop is planted on the land on which its turn it is, irrespective of the soil potential of the specific land.

Appendices 4.2 en 4.3 show the present cropping patterns in the area. Wheat, maize, lucerne, potatoes and sunflowers are the most important crops and comprise 84% of the total cropping pattern. Individually, all other crops comprise less than 5% of the total cropping pattern. There is also very little difference between the cropping patterns of the two irrigation areas included in the study. In total the cropping pattern covers 136% of the scheduled area, whilst it is 147.6% and 130.4% for the Orange-Riet WUA and the Orange-Vaal WUA areas respectively. This high coverage is possible by alternating wheat with maize, potatoes and sunflower in one season. The Bucklands sub district, which includes the smallholdings, "The Plots", is the only area where this pattern differs substantially, with a total coverage of only 56% of scheduled area. This phenomenon can be ascribed to a reasonable number of smallholdings that are used for other purposes than pure farming. The sub districts Bucklands and Atherton also differs from the other sub districts in the sense that lucerne, and not wheat, is the most important crop in these areas. Atherton is also notable for the high percentage vineyards (wine grapes), 23% of total cropping pattern, compared with 5% or less for the other areas.

A comparison was also made between the present cropping pattern and that published in 1990 as part of a food strategy (Department of Agricultural Development, 1990). As can be seen in Appendix 4.4, changes in the importance of crops did take place, but overall the cropping pattern is still the same. Wheat, maize, lucerne and potatoes are still the most important crops in the Orange-Riet WUA area, but their importance declined from 86% of the total cropping pattern in 1990 to the present 76%. In the area of the Orange-Vaal WUA, the importance of these crops has increased from 78% to 81%. Cotton has decreased drastically, especially in the Orange-Vaal WUA area, a phenomenon that could mainly be ascribed to lower profitability of the crop over the past number of years. In the Orange-Riet WUA area, wheat, maize and sunflowers increased in importance, while lucerne, potatoes and cotton decreased in importance. In the Orange-Vaal area lucerne and sunflower increased in importance, while wheat, maize, potatoes and cotton decreased in importance.

The present survey was much more intensive than the 1990 survey, which could be a reason for some of the differences found.

The respondents do not expect major changes in existing cropping patterns, mainly because:

- The marketing opportunities for fresh vegetables and fruit in the near vicinity are too limited to allow farming with fruit and vegetables on a large scale. Although the Kimberley-Douglas-Prieska and N1 tarred roads run through the area and bigger markets can be reached relatively easily, the 550 km to Johannesburg, 900 km to Durban and 1 300 km to Cape Town make the marketing of fresh produce in these areas relatively uneconomical because of high transport costs

- Quotas have to be bought at the cellars for the cultivation of wine grapes, but the limited availability of such licenses, as well as the relatively high price of R533 or more per ton that these licenses cost on the open market, will probably limit an increase in the growing of wine grapes in the short term

- Present market prices are such that the existing cropping pattern gives a big enough income to the farmers, and although respondents did indicate that they do strive for a bigger income, they feel comfortable with their present level. Furthermore, they experience the markets of the more important crops as being relatively stable, a factor, which is very important. A change in market prices can influence cropping patterns, but drastic changes are not expected in the short term

- The present cropping pattern has a relatively low labour requirement, and against the background of present labour laws, farmers are cautious to change to crops that are labour intensive

- The present cropping pattern is in harmony with the climate, soils, water distribution systems, system management and water quality of the area

- Olives are considered as an alternative, but it is doubtful whether it will ever constitute more than 3% of the total cropping pattern. One of the main reasons for this point of view is the present oversupply of olive oil on the world market. Another alternative could be herb farming, but its specialist nature, as well as a very limited market potential, leads to the conclusion that it is highly unlikely that herb farming will ever constitute more than 1% of a total cropping pattern. One case was mentioned where tilapia farming is being considered.

The quick follow-up of crops that characterize the area, and which enable the farmers to get a coverage of 130% and more, requires that a practice of double cropping be followed on relatively large areas of the lands. The result is that there is little chance to work the crop residues into the ground and to allow it to rot to improve the soil fertility. The practice of burning crop residues, specifically wheat straw, is followed to allow the farmer to get the next crop into the ground as soon as possible. Although this practice cannot be unreservedly recommended, it must be accepted as probably being the only practical solution. There is the possibility of planting in stubble (minimum tillage), but local experience is that there is usually too much residue to allow for the successful application of this practice. It is doubtful whether the few times that crop residue can be worked into the ground, will be enough to maintain soil fertility.

The experience is that the quick rotation of crops, particularly wheat, maize, sunflowers and potatoes leads to the increase of weeds, especially wild oats, thorn apple and nut grass. Apart from the use of herbicides, this problem is also managed by the breaking of the cropping pattern through the cultivation of different crops for a few years.

Under this quick crop rotation, common scab and eelworm in potatoes can become a problem. Allowing a reasonable time lapse before potatoes is replanted on the same ground controls it. Chemical control of eelworm costs in the region of R2 000 to R3 000 per hectare. "Take all" and *Fusarium* can also become a problem in wheat. Once again, this problem can be managed by planting a different crop for a period. It does seem as if plant diseases are increasing.

The slow infiltration rates of most of the soils, a fear of a decrease in yield as a result of moisture stress and the quick crop rotation which is generally practised in the area, resulted in the following adaptation of irrigation management by the farmers:

- Short cycles with low applications per cycle

- To ensure that the soil is wet enough for the following crop, a crop on the land is irrigated at a very late stage of ripening, at a time when irrigation would normally not be necessary or recommended.

Farmers do make use of a neutron probe scheduling service supplied by the local cooperative. The practice is that the farmers keep their soil moisture level as close to field capacity as possible and the scheduling service then confirms that the soil is “wet”. The text book example of periodic decreasing and recharging of profile available water is not found here. One of the main reasons for the present approach in water management is a fear that the farmers have that the slow infiltration rates of the soils would not allow them to fully recharge the soil moisture after the lower boundary of available moisture had been reached and that the real danger then exists that moisture stress could decrease potential yield.

On the other hand, farmers are careful not to over irrigate and would not do so on purpose. According to them the cost of water is so high that any over irrigation will lead to unnecessary cost and would thus decrease profit. Furthermore, too much water can have a negative effect on crop quality, which will decrease potential income. The real danger of leaching of plant nutrients and a greater susceptibility to plant diseases that crops are prone to when they get too much water, are also factors taken into account in the decision not to over irrigate.

5 SAPWAT

5.1 INTRODUCTION

The need to rehabilitate existing irrigation schemes and to plan new schemes, as well as the implementation of CMAs and WUAs, accentuates the importance of the effective management of irrigation water. The estimation of crop water requirement is an important starting point when both farm and larger irrigation schemes are planned or upgraded.

The past two decades have seen a noticeable improvement in irrigation technology. Moving systems, mainly centre pivot systems, have been installed in their thousands for the irrigation of field crops, while micro and drip systems, many of them computerized, dominate horticulture. Similarly, there is presently more of an appreciation for the efficiency of flood irrigation systems used by small farmers. There was a parallel development in on-farm irrigation management with the incorporation of automatic weather stations and the measuring of soil water content by means of neutron probes.

Unfortunately, the methodology for the determination of crop water requirements did not keep up with this development. The first publication on the estimation of crop water requirement for South Africa was the Green Book (Dept of Agricultural Technical Services, 1973). This was expanded, updated and published under the title "Estimated irrigation requirements of crops in South Africa", a publication known as the Green Book (Green, 1985). The models used for the development of this publication, while suitable for conventional flood and sprinkler irrigation, did not have the adaptability to provide for new, short cycle techniques. This contributed to the loss in credibility of these requirement calculations. At times this tendency was aggravated because users found it difficult to interpret the outputs.

The SAPWAT project addressed these needs and did, to a large extent, overcome problems attached to the existing aids. A user-friendly methodology, described in this report, has been developed to assist designers and planners to make reasonable estimates by way of a structured approach.

5.2 OBJECTIVES

A pilot study (Crosby, 1996) was undertaken with the aim of developing a decision-making aid for the estimation of crop water requirements by irrigation engineers, planners and agricultural scientists. The supposition was that the aid should be suitable for all users, should be in line with present international approaches, and it should include both interpreted research results and the practical experience of specialists.

The result of the pilot study was the formulation of the following objectives:

- The development of a program that can estimate irrigation requirements, which will retain the desirable characteristics of CROPWAT (Smith 1992) and will be compatible with it, whilst at the same time providing for the Southern African situation

- The provision of a comprehensive, built-in database which will make it unnecessary to look for climatic and crop data elsewhere

- An approach that resembles present practices to such an extent that it will be readily accepted by users

- The reaching of a level of accuracy that will satisfy practical requirements

- The transfer of technology developed by research and modern farm level scheduling techniques

- Provide for the specific circumstances and requirements of developing irrigation farmers and community gardens.

The computer program SAPWAT, which is the result of this research, satisfies these requirements. This includes a comprehensive help function (Crosby & Crosby, 1999).

SAPWAT is not a crop growth model. It is a planning and management aid that relies heavily on an extensive South African climate and crop database. It is general in its applicability in the sense that the same procedures are used for horticulture and field crops, annual and perennial crops, pastures and trees. It is possible to simulate planting in beds, between crop plantings and different irrigation methods. The influence of soil water management options, such as planned deficit irrigation, can also be evaluated. It expands the possibilities of CROPWAT and is an aid that can facilitate "design for management". It also facilitates consultation and interaction between farmers and advisors.

5.3 THE DEVELOPMENT OF SAPWAT

The development process can best be appreciated if one starts with the Green Book of 1985 (Green, 1985). For many years this was the accepted South African standard for the estimation of irrigation requirements of crops for planning and design purposes.

5.3.1 The Green Book (1985)

The introduction of this publication gives a summary of factors that influences the evapotranspiration process and of the limitations of the accepted procedures to estimate crop water requirements. Applicable extractions are:

- The water requirement of different crops grown under the same environmental conditions might vary considerably, depending upon genetic factors, plant density and plant configuration. For a given crop, with a leaf canopy that provides complete ground cover, or which has a constant leaf area index, the rate of water use will depend mainly on external factors. These are, broadly speaking: atmospheric factors that provide the energy for the evapotranspiration process; and soil factors that regulate the provision of water to the roots.

- At and above the soil surface, the leaf area index influences the ratio of the two processes that make up evapotranspiration, that is, transpiration of the crop itself and evaporation from the soil surface.

- Ideally speaking, there is a large number of meteorological, soil, water, management and even economic factors that must be considered when crop irrigation requirements are estimated. At present the ideal solution is out of reach as a result of a shortage of enough general mathematical models and because of a lack of input data.

The method that is still generally used in South Africa for the determination of daily water requirements is explained further:

- Of the empirical methods available for the estimation of evapotranspiration, the one that has been most widely tested and used in South Africa, is the method based on evaporation, specifically the American Class A pan;

- This method presupposes that over a given period, evapotranspiration (ET_{crop}) is in direct relation with pan evaporation (E_0). Stated otherwise, $ET_{crop} = f.E_0$, where f is the empirical constant of ratio, known as the crop factor.

There is a pertinent warning about the limitations of crop factor values:

- As a general rule crop factors, as used in the manual, could not be adapted for differences in climate or growing season because of a lack of knowledge at the time of development. In other words, the crop factors that were seen as applicable to deciduous fruit in the Western Cape, were also used to estimate the water requirements for deciduous fruit in the Transvaal. Furthermore, estimates for a given vegetable crop was based on crop factors that stayed the same, irrespective of whether the crop was planted in summer, winter, autumn, or spring;

- This inability to adapt crop factors for specific seasonal and climatic situations, is a shortcoming that cannot be ignored. Once decided upon, the crop factors were used unchanged in all production areas over all growing seasons;

- Because of this, estimates of evapotranspiration and irrigation requirements must still be seen as first approach working calculations, with a reasonable potential for refinement.

It is accentuated that the accuracy of the evapotranspiration estimates are not only dependant upon the validity of crop factors, but also upon the use of strictly representative (pan) evaporation data.

5.3.2 The FAO Irrigation and Drainage Report No 24 (1977)

This report “Guidelines for Predicting Crop water requirements” (Doorenbos & Pruitt, 1977), included two important concepts which had the potential to eliminate some of the shortcomings that were identified in the introduction to the Green Book. It recognized the limitations of the use of A-pan evaporation and recommended short grass as reference evaporation, in association with the linked and less empirical four-stage approach for the development of crop factors. This reference evaporation is in harmony with the growing plant, so that there is automatic compensation for climatic differences. When full effective ground cover is reached, the crop factor would be 1.0.

The four stages of crop development are described as follows:

1. Initial stage: germination and early growth, when the ground surface is barely covered by the crop (ground cover <10%)

2. Crop development stage: from the end of the initial stage to the reaching of effective full ground cover (ground cover 70 – 80%)

3. Mid season stage: from reaching full effective ground cover, till the beginning of maturity, as indicated by colour change of leaves and leaf drop

4. Late season stage: from the end of the mid season stage to full maturity or harvest.

The basic approach for the estimation of crop water use did not change.

> **Now $ET_{crop} = K_c * ET_0$, where ET_0 is the short grass reference evaporation and K_c is the equivalent of the crop factor.**

The value of ET_0 was originally determined with the aid of weighing lysimeters and different methods for the calculations of these values from climatic data have been developed. These include methods that derive ET_0 from A-pan evaporation (E_0). Eventually the Penman-Monteith equation for the calculation of ET_0 has been internationally recognized and has been published as the standard calculation method in the FAO Irrigation and Drainage Report No 56 (Allen, Pereira, Raes & Smith, 1998).

5.3.3 FAO consultation/CROPWAT: The FAO Irrigation and Drainage Report No 46

Smith (1991) reported on the expert consultation with the aim of evaluating FAO No 24 that took place in Rome during 1990:

- In the series of Irrigation and Drainage reports the FAO methodology for the estimation of crop water requirements has proved itself as exceptional. FAO 24 became the international standard, and irrigation engineers, agronomists, hydrologists and environmentalists are using it on a worldwide scale. More than 200 000 copies have already been distributed in four languages.

FAO 24 was combined with FAO Irrigation and Drainage Report No 33 “Yield responses to water” (Doorenbos & Pruitt, 1979), and was published as a computer program CROPWAT (Smith, 1992). This program further enhanced the acceptance of the FAO procedures.

The consultation decided that crop factors are still valid, but that updating is justified and that the following should be considered:

- Review, with specific reference, crop factors for trees and fruit crops, as well as several of the perennial crops

- Review crop factors, specifically during the initial stage, by evaluating soil evaporation and basal crop transpiration separately

- Review the effect of climate and advective conditions on the crop factor

- Review and update the length of the different growth stages, possibly also the incorporation of a growth function coupled to temperature and dry matter yield.

Since the consultation, progress has been made on these aspects. Recommended procedures and data are published in FAO No 56. As far as is known, this progress has not yet been directly integrated into design and planning programmes.

5.3.4 SAPWAT and reference evaporation (ET_0)

During the development of the pilot program SAPWAT 1.0, (now replaced by SAPWAT), Crosby (1996) made use of the estimated irrigation requirements of 712 climatic zones for specific crop factors, applied on equivalent A-pan evaporation, as calculated by Dent, Schulze & Angus (1988). Crosby (1996) converted the A-pan evaporation to short grass reference evaporation by adjusting the crop factor with a factor of $^5/_7$, derived from the Linacre equation (1977). This approach has been recognized as being only of a temporary nature. It was generally believed that not enough data is available to calculate the Penman-Monteith ET_0 values for a significant number of places in South Africa. This is the main reason why short grass reference evaporation has not been accepted in South Africa.

In the meantime, the FAO database CLIMWAT (Smith, 1993) had become known and it contained monthly ET_0-data for several weather stations in South Africa. These stations were not necessarily situated in irrigation areas, but the monthly ET_0 values were compared to A-pan values. It was found that the ratio varied from month to month for the same station, as well as from one region to another. It was possible to derive reasonable values for ET_0 from these ratios, which made it possible to develop an extensive ET_0 network. Schulze (1997) refined this procedure further and ET_0 values are included in the "South African Atlas of Agrohydrology and -Climatology".

Average monthly ET_0 values can be calculated directly for a station, provided maximum and minimum temperatures, relative humidity, wind and radiation data (which can be measured directly, or can be derived from hours of sunshine) are available. About 350 strategically situated weather stations with ten or more years of applicable data have been identified. This eliminated the need to make use of indirect ET_0 data and monthly Penman-Monteith ET_0 values have been calculated for these stations by making use of the FAO recommended procedure. The availability of data over a reasonable period allows a limited statistical output. An increasing number of automatic weather stations, with hourly and daily output, are now operational and it is possible to validate monthly values of conventional weather stations. The results are satisfactory.

5.3.5 SAPWAT and crop factors

Smith (1994) strongly recommended that the four-stage FAO procedure for the determination of crop factors be applied in SAPWAT to ensure a transparent and internationally comparable methodology. He acknowledged that the standard crop factors had to be adjusted to provide for the climatic conditions of regions, new cultivars, and deviations in planting density as well as for the full range of irrigation methods. One of the shortcomings of similar programmes was that they were designed in the days of long cycle flood and sprinkler irrigation and did not reflect techniques applied by developing farmers, such as wide spaced, short row, surface irrigation.

Separate evaluation of soil evaporation and plant transpiration: The need for this has been identified during the expert consultation (Smith, 1991), and a recommended methodology was published later (Allen, et al, 1998). At about the same time a similar procedure was developed for SAPWAT, based on the work done by De Jager and Van Zyl (1987) and by Strooisnijder (1987). The SAPWAT procedure has the advantage that it is independent of soil texture.

If the soil evaporation and plant transpiration are considered, it becomes possible to manipulate the basic crop factors to provide for ground cover, wetted area, frequency of irrigation, cover crops, fruit trees, perennial crops, and different irrigation systems. SAPWAT is the first program that applies this possibility in a user-orientated crop irrigation program.

"Growing" crop factors: A lot of attention needs to be given to crop factor values, specifically peak values. There is a tendency to accept the default crop factor curve or table as a given physiological characteristic of a crop. Nothing is further from the truth. Unrealistic or incorrectly applied crop factors are probably the main reasons for inaccurate estimates of irrigation requirements.

During the development of SAPWAT, specific attention was given to crop factors. The ideal would have been to let the crop grow, similar to growth models, so that stage length will react to planting date and climate. However, this is not possible in a program of this nature because of the comprehensive inputs required to simulate crop growth. The use of short grass reference evaporation reduces the impact of climatic change on crop water use, but has no influence on the length of growth stages.

The solution was to subdivide South Africa into seven agro-climatic regions and to develop default crop factors for each of these regions. Default planting dates for each region and crop is also specified. Where planting date has a noticeable influence on growth stages, individual crop files were developed according to planting month per region. Where noticeable differences between cultivars (e.g. early or late) are found, each is handled as a separate crop. The crop factor file was developed according to "rules" derived with the help of crop scientists. Validation of these values takes place continuously and is based on practices in the field and on the experience of irrigation consultants. The default crop factor files provide for manipulations as discussed.

At present there are about 100 individual crop files for each region and there are seven regions. Not all crops are grown in all the regions, but based on the tenet that crops are found in at least five regions, means that there are about 500 sets of default crop factors. This still does not cover the full need for the country, but the program allows the user to draw up his own crop factor files for specific areas with the help of an editor.

5.3.6 ET_{crop}, ET_0, effective rainfall and irrigation requirement

Monthly reference evaporation values for each year on record for about 350 weather stations that are presently in use have been calculated and are on file. The ET_{crop} for each month was calculated by using ET_0 and crop factors that were calculated by the program according to the parameters already discussed. Effective rainfall is calculated for every month by making use of the Soil Conservation Service routine as described by Jensen, Burman & Allen (1989). This method considers the extraction of water by the crop from the soil profile to arrive at a value for effective rainfall. Subtracting the effective rainfall from evapotranspiration derives monthly irrigation requirements.

As an aid to judgement, the monthly 20th percentile, median and 80th percentile evapotranspiration, effective rainfall and irrigation requirements are calculated. A similar calculation is done for the full season. This gives an indication of the situation of a favorable, normal and severe season.

5.3.7 Balance between a management and a planning aid

In a report Smith (1994) expresses the opinion that it is sometimes very difficult to differentiate between a planning and a management aid. To include all management options in a planning aid might make it too complicated for the user and a limit must be set somewhere. He makes the following recommendation:

- It is recommended that a careful evaluation be made of the different management options that must be standardized in a planning aid. The solution given in CROPWAT warrants possible further attention. A standard procedure for the calculation of irrigation requirement is based on the calculated crop water requirement and on effective rainfall only. In a separate water balance procedure, several management options are included, which indicate different irrigation (management) options.

SAPWAT was developed in accordance with these recommendations as a planning aid, whilst retaining compatibility with CROPWAT. Field evaluations show that the planning function is not complete if it is not integrated with management. It is possible to link SAPWAT to the CROPWAT management module and to get good results. However, this linkage is awkward and the needs identified during field-testing showed that the development of a management module for SAPWAT was justified.

It was found that for purposes of the management module it would be possible to concentrate on inputs and outputs on one "irrigation scheduling" screen. This facilitates sensitivity evaluations ("what if" questions). Rainfall values sent from the planning module, conforms to the favorable, normal and severe seasons, and provision is made for the editing of the expected number of days with rain for a specific month. Attention was given to the exporting of SAPWAT output to conventional spreadsheet programs so that the output can be manipulated for specific situations.

5.4 USE OF SAPWAT

An overview on the use of SAPWAT and the functional value of the output is given in this section. Instructions on the use and handling of the program can be obtained through pressing a "What to do" button on each screen, while a right click on items on a screen will give more detailed information. SAPWAT requires Microsoft® Windows 95/98/NT, about 10 MB disk space and of 8 MB memory capacity.

5.4.1 Climatic data

Select one or more weather stations out of the 350 that are shown on a map on screen (Fig. 5.4.1.1) by clicking on or near it. The user MUST use his judgement and experience when selecting a representative station.

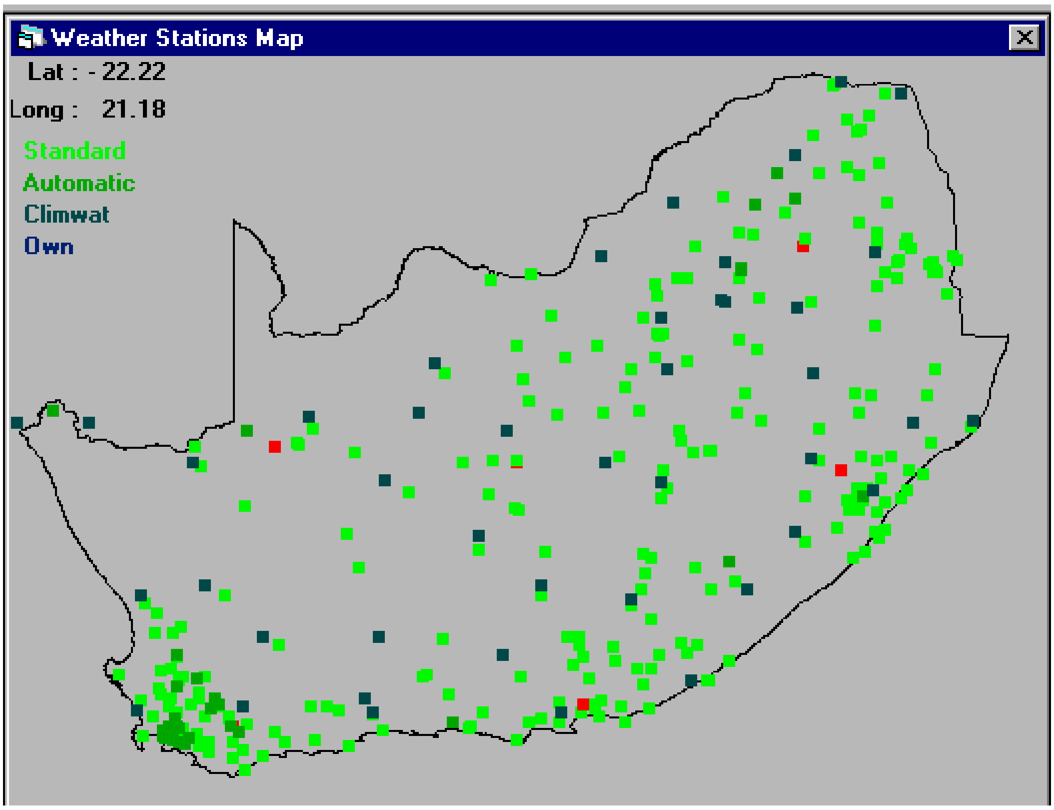


Figure 5.4.1.1 Map of weather stations out of which relevant stations can be selected.

It is important to select a weather station which will be representative of the weather conditions in the area of interest, even though it might not be the nearest station. The effect of microclimate is significant, and must be kept in mind.

For purposes of comparison, the results of six stations can be shown simultaneously. Stations include:

- First order conventional weather stations;
- Automatic weather stations;
- CLIMWAT (FAO) data files;
- Localized data provided by the user.

5.4.2 Short grass reference evaporation

Calculated Penman-Monteith reference evaporation values are plotted for all the weather stations selected from the map. A-pan values are also plotted for a weather station selected from a drop down menu. As a further aid in the choice of a representative weather station, the height above sea level and the average annual rainfall (mm) is also shown. See Fig. 5.4.2.1.

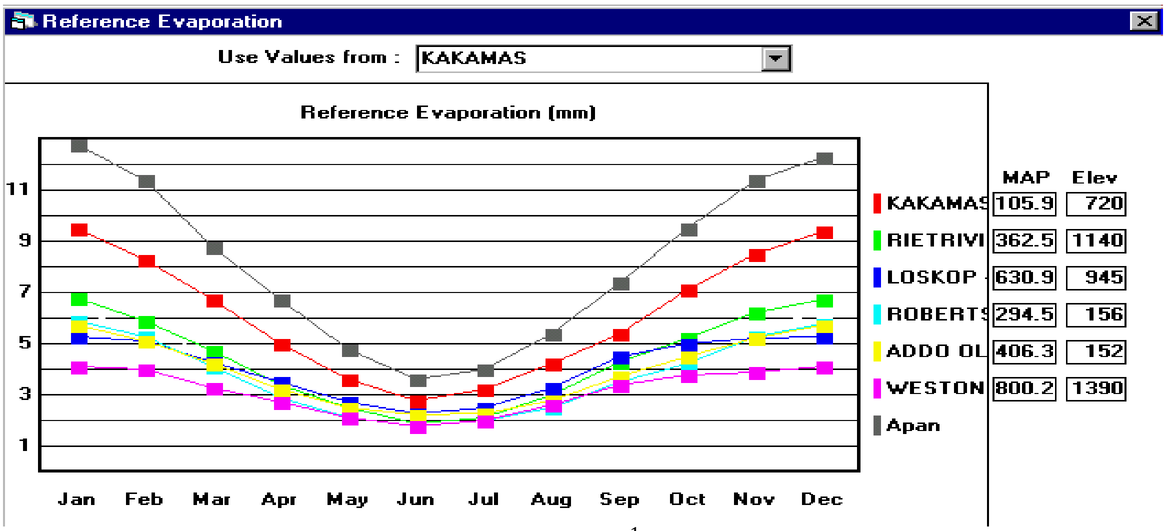


Figure 5.4.2.1 Reference evaporation (mm.day^{-1}) of a few stations, as well as Class A pan evaporation for Kakamas.

There is a button access to a graphic representation of long-term average and real rainfall for each month of each year included in the weather records. Refer to Fig. 5.4.2.2. This enables the planner and the designer to form an idea of the extent to which rainfall should be considered in irrigation and scheduling planning.

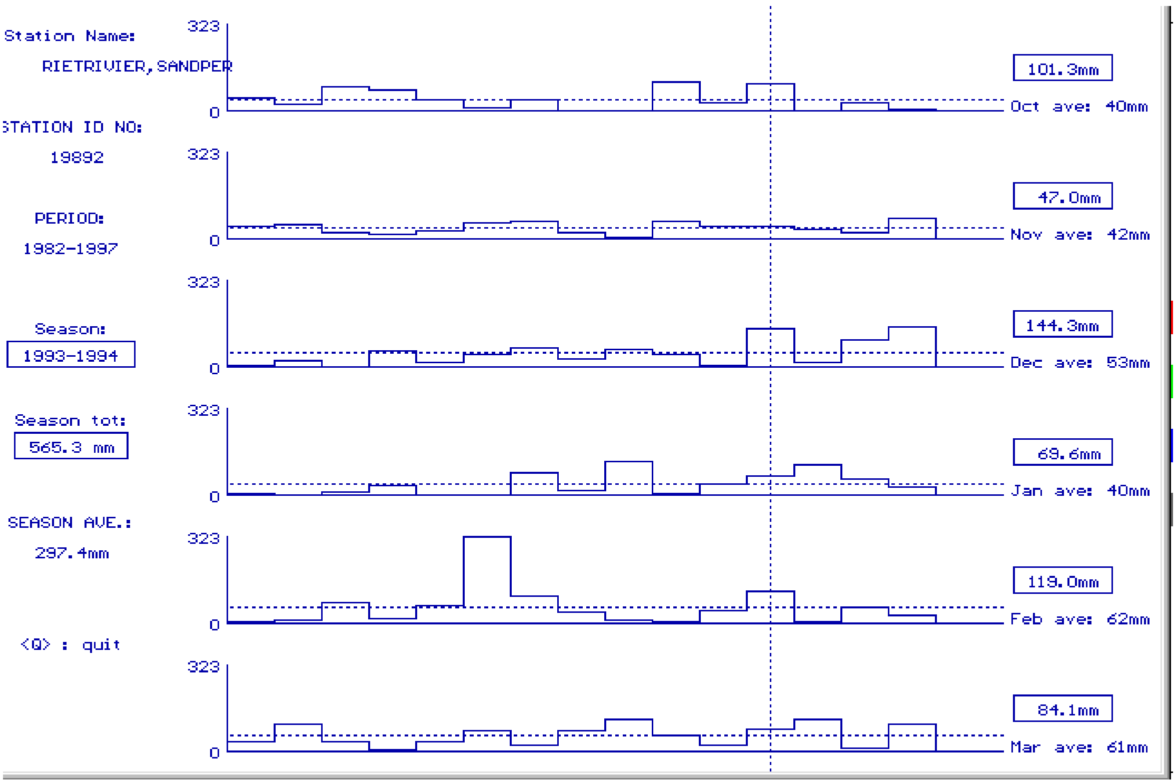


Figure 5.4.2.2 Monthly and long-term rainfall for the weather station Riet River Sandpersele for the period 1982-1997 and for the 1993-1994 season as SAPWAT represents it.

5.4.3 The creation of own weather data

At times it might become necessary to create one's own weather station. This might become necessary if a standard weather station is not available for an area, or because of a specific microclimate situation. This function is also handy for setting up "real time" weather data for a place for comparison to longer-term data which SAPWAT can provide.

SAPWAT incorporates the facility to create own weather data, based on the calculation procedures of FAO 56. In Fig. 5.4.3.1 the standard SAPWAT weather station data for Prieska, Douglas and Riet River are included, but there are also plots that reflect the 1999-2000 weather situation. These own weather data can be used to evaluate and update irrigation scheduling programmes through the course of a season.

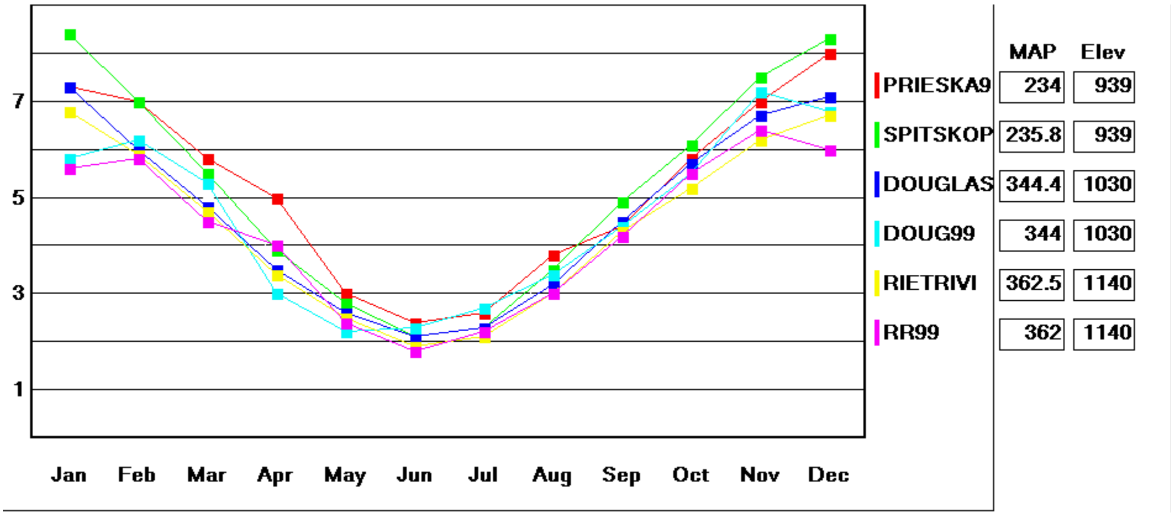


Figure 5.4.3.1 Daily ET_0 for weather stations and for own values for the same localities.

The input screen for the creation of SAPWAT weather data is shown in Fig. 5.4.3.2. The recommendation in FAO 56 is that it is better to apply the Penman-Monteith calculation methodology with limited data, instead of using any other known formula. Even inputting maximum and minimum temperatures only will give an approximate value.

5.4.4 Default crop factors

The crop factor screen enables the user to select the required crop and to adjust the crop factors to provide for operational conditions. A click on the "Plot" button updates the crop factor graph, which shows how the crop factor changes during the season. Applicable detail, including Crop type, Options, Geographic region and Planting date must be selected from drop down menus before the crop factor can be plotted. See Fig. 5.4.4.1.

5.4.5 Changing of crop factors

It is possible to simulate the influence of different irrigation methods and production practices by adapting the crop factor. The crop factor can be adjusted by the following inputs:

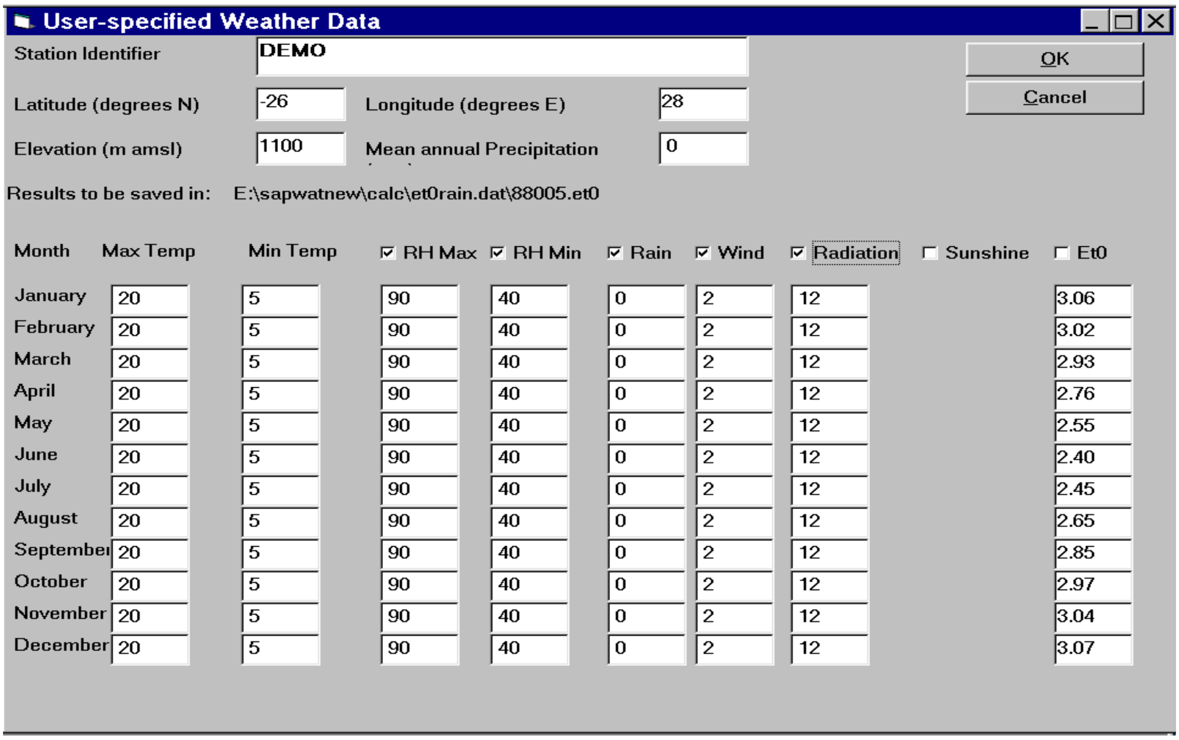


Figure 5.4.3.2 The SAPWAT input screen for the creation of own weather data.

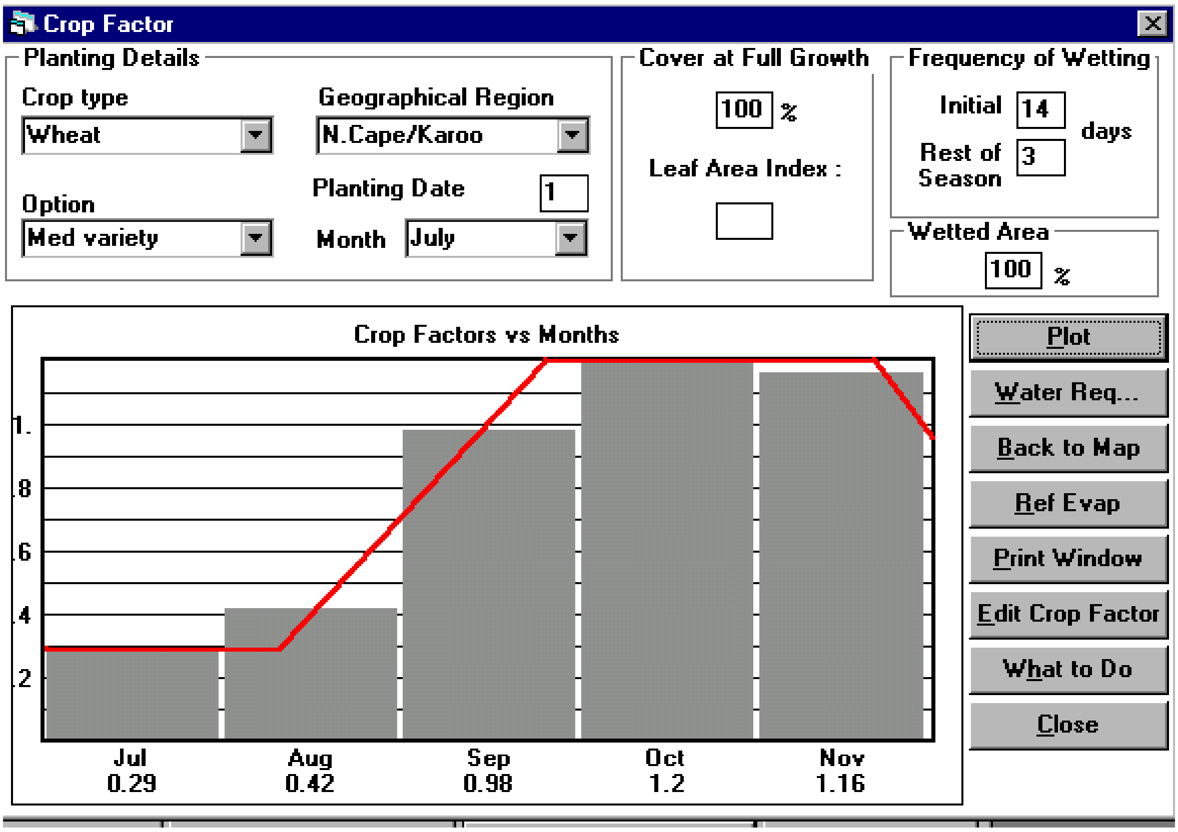


Figure 5.4.4.1 The crop factor screen for the crop wheat of a medium growing variety for the region North Cape / Karoo, planted on 1 July.

- If the times between irrigations are lengthened and the soil is allowed to dry out, which will decrease soil evaporation, the crop factor will decrease during the first growth stage. Wetting frequencies for the initial and later growth stages can be specified separately for annual crops

- If the ground cover at full growth is less than full cover, the effective leaf area index is reduced, resulting in a lower maximum crop factor

- Decreasing the wetted area to smaller than 100% reduces evaporation from the soil surface, and also results in a lower crop factor. This effect has the most influence during the early growth stages when evaporation from the soil surface dominates.

Default values for almost all crops grown in South Africa, are available on drop-down menus. The FAO system and SAPWAT encourages the users to adapt existing crop factors for local conditions by the application of simple rules, or to develop crop factors for new cultivars.

The time taken by a crop to reach maturity, and the length of the different stages, vary from area to area and as a result of different planting dates. Different cultivars also have unique characteristics. Menus available provide this for the user. The country is subdivided into seven regions, and a range of options is available for each crop. The user is free to adapt these options to his situation.

The cover during maturity and the area wetted must also be shown. This is important in the case of orchards, furrow, drip and micro irrigation systems. It is also handy if non-standard practices are applied. Evaporation from the soil surface and crop transpiration is covered elsewhere, whilst irrigation frequency is important because of the influence on the result.

5.4.6 Irrigation requirements

The water requirement screen (Fig. 5.4.6.1) shows the results of the water requirement calculations. These calculations are done by making use of the crop factors generated by the crop factor screen and the weather data of the selected weather station. Results are calculated on a monthly basis for the historical weather data. The user can select one of three possible "Season" options. A "Normal" season shows median values. "Favorable" represents a "one-in-five" favorable season, and "Severe" represents a "one-in-five" unfavorable season.

The conventional application efficiency factor that is used to convert crop evapotranspiration to irrigation requirement, is subdivided into two components, which are "spray losses" and "uniformity coefficient" (distribution losses). The first includes run off and any other losses that might be found on a farm before the land edge is reached, such as leakage out of pipes and canals. Distribution losses include deep drainage (percolation) and a lack of uniformity in system distribution and deviations in land uniformity.

Crop evaporative demand, rainfall, effective rainfall and irrigation requirement are shown as histograms, while seasonal totals are shown in a table. It must be noted that the values do not necessarily add up, because a median season is not necessarily made up of a series of median months.

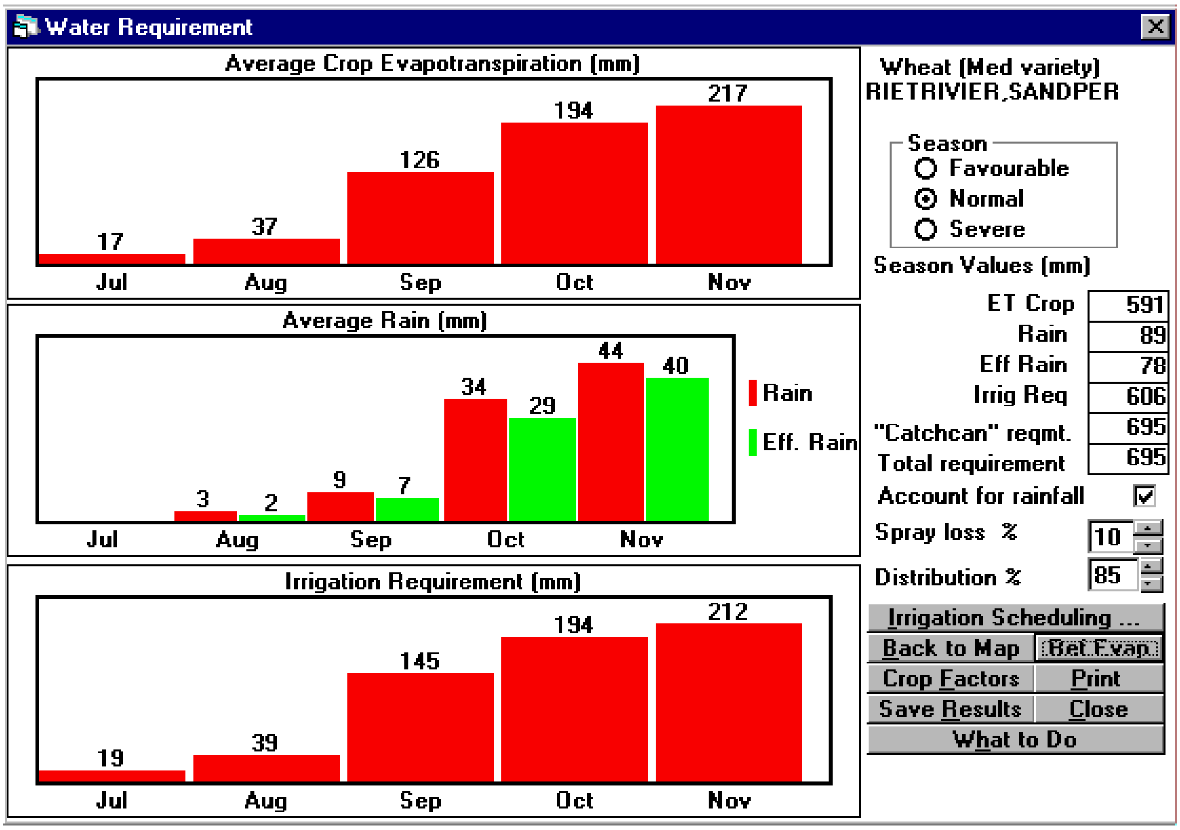


Figure 5.4.6.1 The SAPWAT water requirement screen.

The top window shows ET_{crop} or crop evapotranspiration per month. The second window shows rainfall and effective rainfall and the bottom window shows the irrigation requirement. Effective rainfall is subtracted and irrigation efficiency has been included in the calculation.

This screen completes the normal procedure for the development of the irrigation requirement of a crop. Most designers do not want to go beyond this point.

5.5 THE MANAGEMENT MODULE

The irrigation-scheduling screen that is used to simulate the effect of different scheduling strategies is shown in Fig. 5.5.1.

5.5.1 Soil

The user can select one of five internationally-recognized soil types that have been included as defaults for irrigation planning. In this case the relevant soil characteristics are shown, but cannot be changed. Over and above the default values, provision is made for the inputting of own soil values and the accompanied soil water capacity.

The initial percentage extraction and the effective rooting depth can be specified. It is important to note that the initial extraction does have a very large influence on total irrigation requirement.

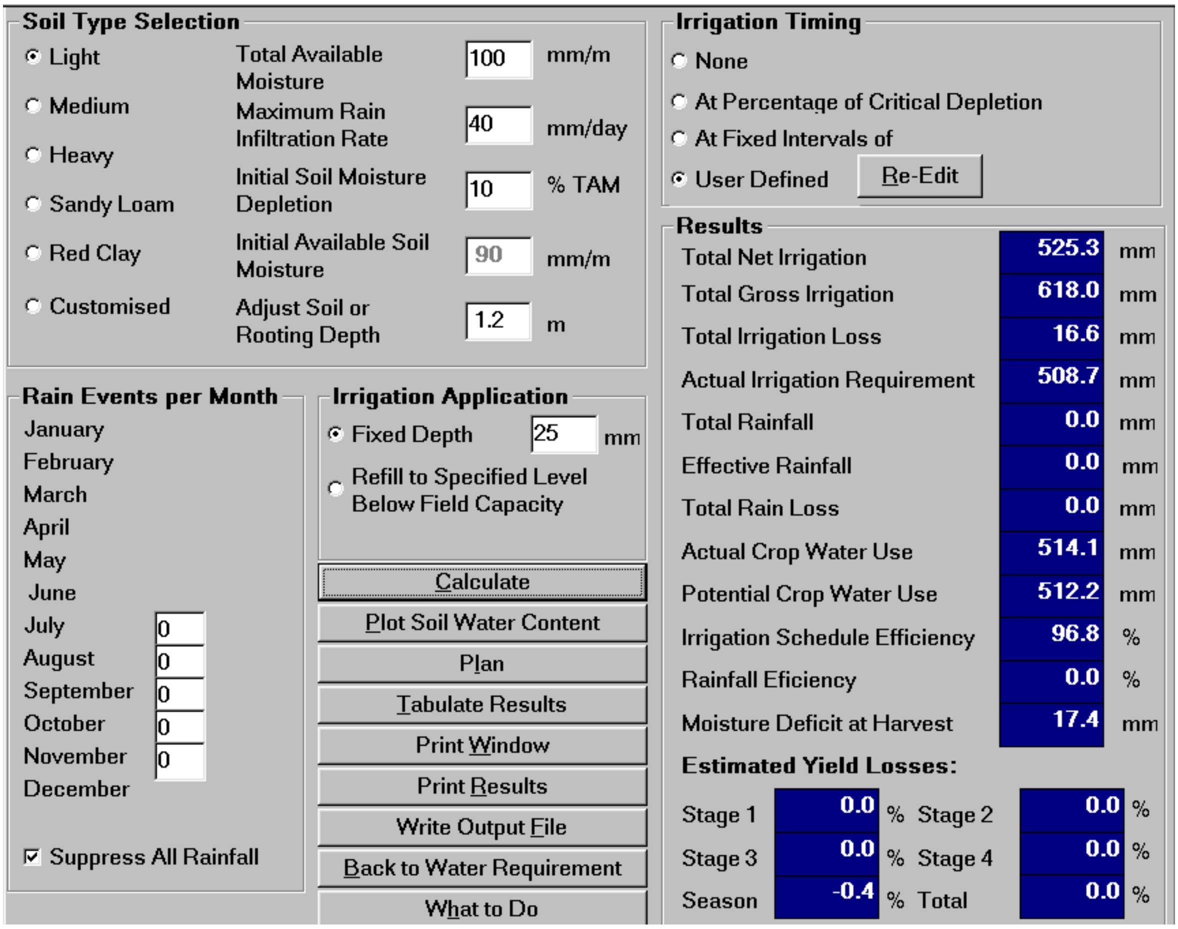


Figure 5.5.1 The SAPWAT screen for scheduling planning.

5.5.2 Rainfall frequency

The user can change the number of rainfall occurrences per month, or rainfall can be suppressed completely. Monthly rainfall is divided equally between occurrences. By setting the number of showers at zero, rainfall is completely suppressed for that month.

5.5.3 Irrigation strategies

Three strategies are available:

- If a fixed depth is selected, a specific depth is applied during each irrigation, irrespective of the soil water content. The time of irrigation is specified by the irrigation timing option that is selected.

- The alternative strategy is "Refill to Specified Level Below Field Capacity". In this case, water is applied in such a way that a specified level of soil water deficit is reached. If the profile is full, for example as result of rain, no irrigation is applied. Replenishment to a specified depth under field capacity (say 40 mm to allow for rain) and at times as determined to reach a specific level of extraction, say 80%, gives a very close to optimum irrigation strategy against which other strategies can be compared.

- Select "User Defined" irrigation if an irregular irrigation schedule is required. An irrigation-scheduling window will be shown within which the irrigation strategy can be specified. Applicable default values are shown in the window. The use of this option enables the user to investigate the effect of, for example, a lost irrigation due to failed equipment. Farmer irrigation patterns can also be investigated.

The initial output is a table on the screen that specifies how suitable the proposed strategy is for obtaining water-use efficiency.

5.5.4 Effective rainfall

Water use is tabulated in the scheduling window as an output. Total rainfall is the rain that fell during the growing period. It will differ only significantly from the figure shown in the water requirement window if rainfall has been suppressed for one or more months. Rainfall suppression can be accomplished by using the "Rain Events per Month" input. The total rain loss is the rain that is lost through deep drainage and run off. This does not include rainwater that is stored between the present rooting depth and maximum rooting depth. Effective rainfall is the difference between total rainfall and total rain losses and is calculated explicitly, compared to the figure shown in the water requirement window that is calculated empirically. Rainfall efficiency is the ratio of effective rainfall compared to total rainfall, expressed as a percentage. This efficiency can be improved upon by not filling the profile to capacity and leaving space for the storage of rainwater.

5.5.5 Crop production losses

These values are calculated by multiplying the loss coefficient (K_y) for a given stage with (real water use / potential water use). If the plant never undergoes stress, that is, the soil water content never drops below the bottom boundary of readily available water, no crop loss will occur.

5.5.6 Evaluation of results

The soil water content is plotted on a graph (Fig. 5.5.6.1) and can be edited or printed. The lines that are plotted, are: soil water deficit; readily available water; total available water; and an evened out curve of soil water content. This, together with crop production losses, enables the user to evaluate the implications of management strategies. Alternative scenarios can be evaluated.

It takes only seconds to change the inputs for the testing of different strategies. Two graphs that show soil water balance – irrigation strategies are produced. This makes it possible to evaluate and demonstrate the interactions among atmospheric demand, crop evapotranspiration, soil water capacity and application. These are of particular interest for irrigation designers, scheduling consultants and extension personnel who are in direct interaction with farmers.

5.5.7 Scheduling and planning outputs

The water balance module of SAPWAT uses average monthly inputs, but calculation is done on a daily basis. The output of the simulations can be exported to a spreadsheet (Fig. 5.5.7.1) and can then be manipulated by the user for purposes of specialized application.

The main output file, with its graphics, can be exported to Excel and other compatible spread sheets. It can be used for daily or weekly-based real time scheduling with provision for ET_0 and profile water content. This facility is still "rough and ready" but can complement real time scheduling programmes.

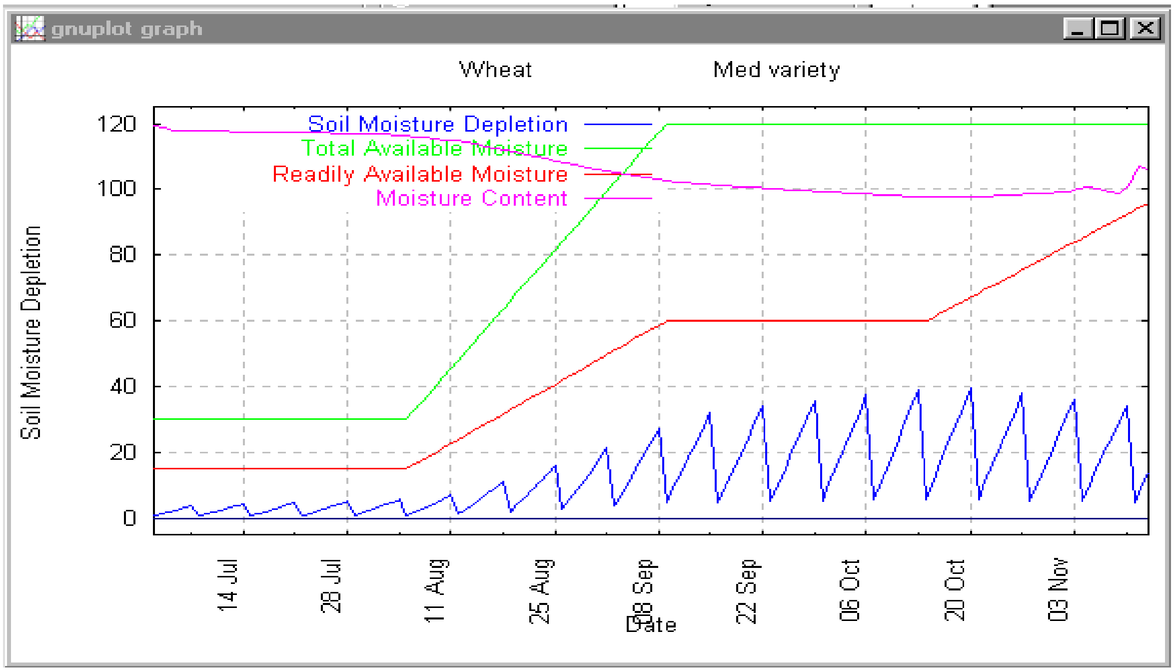
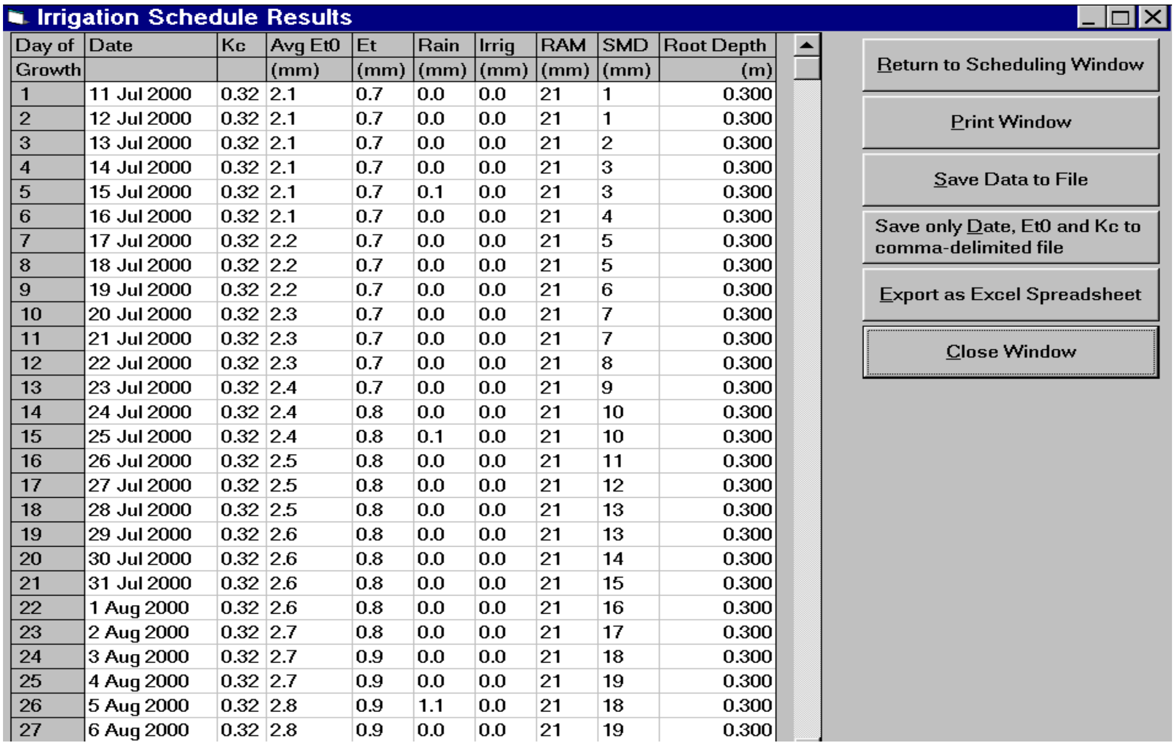


Figure 5.5.6.1 Graph that shows the expected soil water balances.



Irrigation Schedule Results

Day of Growth	Date	Kc	Avg Et0 (mm)	Et (mm)	Rain (mm)	Irrig (mm)	RAM (mm)	SMD (mm)	Root Depth (m)
1	11 Jul 2000	0.32	2.1	0.7	0.0	0.0	21	1	0.300
2	12 Jul 2000	0.32	2.1	0.7	0.0	0.0	21	1	0.300
3	13 Jul 2000	0.32	2.1	0.7	0.0	0.0	21	2	0.300
4	14 Jul 2000	0.32	2.1	0.7	0.0	0.0	21	3	0.300
5	15 Jul 2000	0.32	2.1	0.7	0.1	0.0	21	3	0.300
6	16 Jul 2000	0.32	2.1	0.7	0.0	0.0	21	4	0.300
7	17 Jul 2000	0.32	2.2	0.7	0.0	0.0	21	5	0.300
8	18 Jul 2000	0.32	2.2	0.7	0.0	0.0	21	5	0.300
9	19 Jul 2000	0.32	2.2	0.7	0.0	0.0	21	6	0.300
10	20 Jul 2000	0.32	2.3	0.7	0.0	0.0	21	7	0.300
11	21 Jul 2000	0.32	2.3	0.7	0.0	0.0	21	7	0.300
12	22 Jul 2000	0.32	2.3	0.7	0.0	0.0	21	8	0.300
13	23 Jul 2000	0.32	2.4	0.7	0.0	0.0	21	9	0.300
14	24 Jul 2000	0.32	2.4	0.8	0.0	0.0	21	10	0.300
15	25 Jul 2000	0.32	2.4	0.8	0.1	0.0	21	10	0.300
16	26 Jul 2000	0.32	2.5	0.8	0.0	0.0	21	11	0.300
17	27 Jul 2000	0.32	2.5	0.8	0.0	0.0	21	12	0.300
18	28 Jul 2000	0.32	2.5	0.8	0.0	0.0	21	13	0.300
19	29 Jul 2000	0.32	2.6	0.8	0.0	0.0	21	13	0.300
20	30 Jul 2000	0.32	2.6	0.8	0.0	0.0	21	14	0.300
21	31 Jul 2000	0.32	2.6	0.8	0.0	0.0	21	15	0.300
22	1 Aug 2000	0.32	2.6	0.8	0.0	0.0	21	16	0.300
23	2 Aug 2000	0.32	2.7	0.8	0.0	0.0	21	17	0.300
24	3 Aug 2000	0.32	2.7	0.9	0.0	0.0	21	18	0.300
25	4 Aug 2000	0.32	2.7	0.9	0.0	0.0	21	19	0.300
26	5 Aug 2000	0.32	2.8	0.9	1.1	0.0	21	18	0.300
27	6 Aug 2000	0.32	2.8	0.9	0.0	0.0	21	19	0.300

Figure 5.5.7.1 Spreadsheet format in which results are tabulated.

SAPWAT can be used to draw up pre-season irrigation scheduling programmes, similar to some aspects of BEWAB. However, there are the additional advantages that the programmes can be adapted during the course of a year as the season develops. This is of value where organisations provide farmers with weekly information about atmospheric demand and crop water use of the previous week.

5.6 THE APPLICATION OF SAPWAT IN PRACTICE

During the course of the development and the field testing of the program, it became clear that the impact of the original objective, that is, updating and refining of the methodology for the estimation of crop irrigation requirements, was underestimated. The two most important aspects are the recognition of the Penman-Monteith based international standard for reference evaporation in South Africa and the FAO four-stage crop factor methodology. For the first time there is the opportunity to develop crop irrigation requirement estimates on a countrywide scale, based on a basis, which are both transparent and defendable. SAPWAT is an aid for this process. Based on field-testing and workshops, it is possible to give a preview of possible applications.

5.6.1 Macro-planning

Irrigation uses more water than the other user sectors; therefore the irrigation component is important in catchment planning. SAPWAT principles are recognized by the DWAF and are incorporated in the irrigation inputs of the national water-balance model. It is foreseen that further refining of the model may take place in the future and that SAPWAT can make a big contribution. A similar approach was accepted for the lower Colorado River in the southwest USA where evapotranspiration of not only crops, but also the riverine vegetation, is part of the water accounting system. Evaporation from dams, rivers and canals are also estimated with Penman-Monteith ET_0 and applicable coefficients (Jensen, 1998). This "one-stop" approach can be incorporated into SAPWAT and has a lot of potential.

5.6.2 Tariff policy in terms of the water-pricing strategy

In terms of the National Water Act, users of irrigation water must register for purposes of charging for water use. Furthermore, DWAF indicated that the SAPWAT computer program would be the accepted method for the estimation of annual water requirements. In the absence of water measurement, SAPWAT enables a water authority to evenly quantify planned water use so that cost recovery can be done evenly and systematically.

5.6.3 Water demand management strategy

In future, the WUAs will be expected to develop water management plans on a regular basis. The impact of irrigation practices and strategies of water budgeting demands the evaluation of the impact of crops on irrigation requirements. This is one of the functions for which SAPWAT was developed.

5.6.4 Small farmer irrigation schemes and community gardens

One of the primary objectives of the SAPWAT program development was the provision for the specific situations and needs of the developing irrigation small farmers and community gardens. Specific attention was given to this aspect and presently consultants are busy under the Land Care initiative of the National Department of Agriculture with the designing for the sustainable rehabilitation of irrigation schemes based on SAPWAT estimates.

5.6.5 Irrigation planning and management

The planning of how much water is needed when, is a prerequisite for irrigation farmers, designers, WUAs, irrigation schemes and reservoir management. The power of SAPWAT lies in the extensive database which saves the user the task of hunting for figures, as well as the built-in routines for the undertaking of sensitivity analyses for different strategies.

5.6.6 Support for irrigation scheduling

SAPWAT is not a real time scheduling model, but it can be a valuable complement for existing instrumental soil water methods. It is recognized that scheduling can be expensive and labour intensive for farmers, advisors and consultants. An atmospheric demand based program can provide pre-seasonal irrigation programmes that are based on historical weather data, and this can go a long way in the alleviation of the urgency of short term, real-time scheduling. SAPWAT is designed to accommodate updated, historical weather data if it should be necessary.

Appendices 5.6.6.1 to 5.6.6.3 are annotated figures of different SAPWAT screens, which give an indication of how the program can be used in a planning phase. Appendix 5.6.6.4 is a composite page, with cotton as an example, to show the potential use for planning of water management for support of scheduling.

For purposes of scheduling in this area, water added through rainfall or irrigation is measured in a rain gauge. In the case as shown in Figs. 5.6.6.1 to 5.6.6.4, spray losses are set at "zero" to duplicate this situation. Irrigation scheduling planning does not provide for these losses, but the farmer must consider it when planning his irrigation strategy.

6 THE EVALUATION OF SAPWAT IN THE TEST AREA

6.1 INTRODUCTION

To determine the applicability of SAPWAT, three functions have been evaluated in the test area. The three functions tested were weather data, crop factors and scheduling. For practical purposes the evaluation of crop factors and scheduling have been done simultaneously.

6.2 WEATHER DATA

SAPWAT is driven by atmospheric demand and the availability of applicable weather data is important. Judgement is an important element of irrigation planning, design and management. Therefore, an understanding of weather characteristics that influence irrigation is an integral part of the process.

It is important to determine if the long-term ET_0 values included in the SAPWAT data files agree with real time values that would have been calculated from automatic weather station data of the 1999-2000 season. This is of particular importance, because the majority of data files in the program are based on long-term weather data that come from conventional weather stations.

6.2.1 Weather stations

Both conventional and automatic weather stations are found in the area. The data of conventional weather stations are collected daily, while the data of automatic weather stations can be collected for specific periods, usually hourly. An important input into atmospheric demand calculations is radiation, which is not measured by conventional stations. However, radiation can be derived from hours of sunshine, which is measured at conventional stations. Daily ET_0 fluctuations are mainly the results of differences in cloud cover.

Average monthly long term ET_0 values calculated from data of first order weather stations, compare favourably with those derived from automatic weather station data.

Weather stations used for the study area are Riet River and Douglas, while attention has also been given to Prieska. There are 15 weather stations in the area. Each week the daily ET_0 values of the previous week are faxed to participating cooperatives and WUAs.

6.2.2 Variability and extreme values of ET_0 for the 1999-2000 season

The reliability of reference evaporation is important when an evaporation-based program such as SAPWAT is used. In the past there was uncertainty about the reliability and general credibility of automatic weather station data.

Table 6.2.2.1 covers 15 automatic weather stations in the Free State and Northern Cape and shows the daily ET_0 values in mm per day. The period selected was from 19 December 1999 to 20 January 2000, when the weather was very unstable and when unprecedented heavy rains were experienced over the eastern parts of the study area.

Table 6.2.2.1 Daily ET_0 values of selected weather stations.

Date	Augr	Blskp	Chrstn	Dougl	Glen	Ghoop	Hopetn	Kakms	Petrsb	Priska	Rietriv	Sndvt	Tbnchu	Upngtn	Vlharts
19 Dec-99	5.4	2.76	2.41	3.1	3.3	4.79	2.89	5.7	3.95	3.55	3.6	4.21	3.18	5.5	2.2
20 Dec-99	7.2	3.79	2.62	3.4	2.9	5.58	4.06	7.1	4.36	5.47	3.4	2.25	2.55	6.31	4.38
21 Dec-99	8.8	6.73	4.28	6.12	3.8	6.82	6.88	7.8	7.3	7.85	5.62	4.56	4.06	7.07	5.86
22 Dec-99	7.8	2.83	2.21	2.03	5.3	4.88	2.93	7.61	3.81	3.46	2.29	4.47	3.21	6.22	2.25
23 Dec-99	5.7	3.25	1.64	3.3	1.9	5.5	3.84	5.66	2.05	6.06	2.66	2.11	2.17	5.74	1.68
24 Dec-99	6.7	5.84	5.15	6.14	4.5	6.7	6.2	6.38	6.34	6.37	5.14	3.11	3.19	6.34	5.23
25 Dec-99	7.9	5.32	3.03	4.72	2.7	7.1	6.08	7.83	3.68	7.64	4.21	2.03	2.93	7.12	3.42
26 Dec-99	7.3	7.54	5.5	6.16	6.3	6.28	8.61	7.46	6.24	7.86	5.56	6.07	5.76	7.61	5.1
27 Dec-99	6	5.11	4.03	3.06	3.7	3.48	4.57	6.04	3.99	3.11	3.66	3.03	2.85	4.85	4.24
28 Dec-99	6.8	6.73	5.84	6.73	5.9	6.51	7.34	6.68	6.49	7.3	6.27	5.58	4.79	7	5.86
29 Dec-99	8	6.48	4.85	6.26	6.2	7.25	6.54	7.29	7.36	7.68	6.17	5.87	5.96	7.89	4.31
30 Dec-99	9.2	8.35	5.5	6.41	6.4	7.27	8.99	8.58	8.83	9.23	6.13	4.94	6.48	7.19	5.51
31 Dec-99	8.4	7.89	6.08	7.52	7.4	7.55	7.87	8.66	7.56	8.64	6.08	6.64	6.91	7.29	6.59
01 Jan-00	8.1	7.56	4.54	6.48	6.7	7.88	7.57	8.46	6.93	7.24	5.81	5.15	5.57	7.04	4.85
02 Jan-00	7.3	8.04	5.81	7.59	6.9	7.28	8.48	7.45	7.54	8.8	6.52	5.81	6.44	6.63	6.59
03 Jan-00	7.9	6.31	6.08	5.14	6.5	7.04	7.45	7.68	6.56	7.87	5.63	6.83	5.55	6.55	6.07
04 Jan-00	7.3	7.16	5.59	6.86	6	5.89	7.51	5.53	7.13	6.93	6.72	6.04	5.41	7.81	5.88
05 Jan-00	6.8	5.36	1.45	5.16	2.6	6.1	5.72	6.97	3.56	6.77	3.82	2.01	2.12	6.41	2.04
06 Jan-00	7.3	6.92	2.97	6	5	6.83	7.19	7.05	5.78	8.02	5.65	4.12	4.88	6.65	3.16
07 Jan-00	8.9	7.94	4.42	7.89	5.7	6.26	8.49	8.68	6.58	6.93	6.43	5.01	5.22	6.9	5.36
08 Jan-00	7.8	7.8	6.47	7.84	7.5	7.25	8.03	7.61	8.54	7.88	6.75	6.96	6.46	6.92	6.46
09 Jan-00	8.4	8.2	5.42	7.31	5.8	7.26	8.2	8.4	7.03	8.54	6.96	5.21	5.18	7.55	6.33
10 Jan-00	8	7.91	6.8	5.44	7	7.44	8.16	7.91	8.05	8.85	7.11	6.32	6.49	7.44	7.1
11 Jan-00	9	6.76	6.45	6.17	6.3	8.32	7.9	9.41	7.53	8.89	6.84	7.3	6.56	7.93	6.98
12 Jan-00	8.6	3.92	3.42	5.28	4.2	8.37	5.23	9.17	4.89	7.83	3.94	4.73	3.92	7.87	4.04
13 Jan-00	10	6.18	3.77	5.94	2.9	7.53	7.69	9.64	4.77	7.89	5	3.37	2.71	7.53	4.21
14 Jan-00	9.2	2.48	2.24	2.42	3.3	7.83	3.33	8.91	2.64	3.33	3.21	2.65	2.63	7.34	3.86
15 Jan-00	8.5	3.64	2.11	3.97	1.9	6.32	4.42	9.36	2.56	5.99	3.28		1.43	5.93	2.93
16 Jan-00	8.6	6.17	5.07	5.36	5.7	6.98	6.18	9.36	6.21	6.26	4.87		5.2	6.91	5.34
17 Jan-00	8.8	7.92	5.93	6.36	6	7.63	8.43	9.77	7.35	7.96	6.36		5.53	8.05	5.32
18 Jan-00	8.1	6.62	6.6	7.1	5.2	6.66	7.63	8.52	6.51	8.07	6.14		5.21	6.78	6.66
19 Jan-00	7.9	7.11	5.46	6.71	6.4	6.72	7.96	8.08	7.22	8.17	6.21		6.13	6.97	5.92
20 Jan-00	5.7	7.02	5.99	6.56	7.1	5.41	7.68	4.79	6.89	7.44	6.31		6.65	4.74	6

The influence of the weather was very noticeable on Christmas day. Places such as Thaba Nchu, Sandvet, Glen and Douglas were clearly in the rain belt. Augrabies, Kakamas and Prieska had ET_0 values of just less than 8 $mm.day^{-1}$, in comparison with the about 3 $mm.day^{-1}$ of the stations influenced by rainfall. On New Year's day a similar situation, but with less deviation, was experienced, whilst 19 January 2000 should be seen as a fairly normal day with a relatively high water demand.

What is encouraging is that these figures make sense. It is possible to explain the differences between stations, and there are no signs of serious differences or disfunctioning of the weather stations, and in general the picture is satisfactory. If this standard could be maintained, it looks as if it would be possible to operate satisfactory scheduling systems based on atmospheric demand and supported by periodic soil moisture measurements.

The peak reference evaporation values are relatively small in comparison with what one has become accustomed to, but this is compensated for by the application of the FAO crop factor methodology.

6.2.3 Daily variation in ET_0

We have become used to designing and planning on average monthly evaporation data. One develops a perception of a relatively constant value for evaporation over a shorter period. However, if one looks at the daily values, nothing is further from the truth. Great daily fluctuations are experienced. To form a picture of trends, it is necessary to look at seven-day and 30-day moving averages. The seven-day moving average eliminates many of the fluctuations, but the 30-day moving average comes much closer to the values to which one has become accustomed.

Generally speaking, the similarities of ET_0 values in SAPWAT and those of the automatic weather stations are encouraging. The daily variation of ET_0 was surprising, and not really expected. In Fig. 6.2.3.1 the daily variation in ET_0, seven-day and 30-day moving averages are shown. The seven-day moving average reduces the big daily fluctuations, but it is the 30-day moving average that gives an even curve that is similar to the weather data that is normally used in planning and design. Notice must be taken of this. It is applicable on all the stations where measuring takes place and could possibly be expected during all growing seasons. This characteristic, which is ignored in most of the cases, does have important implications when scheduling procedures and methods are considered.

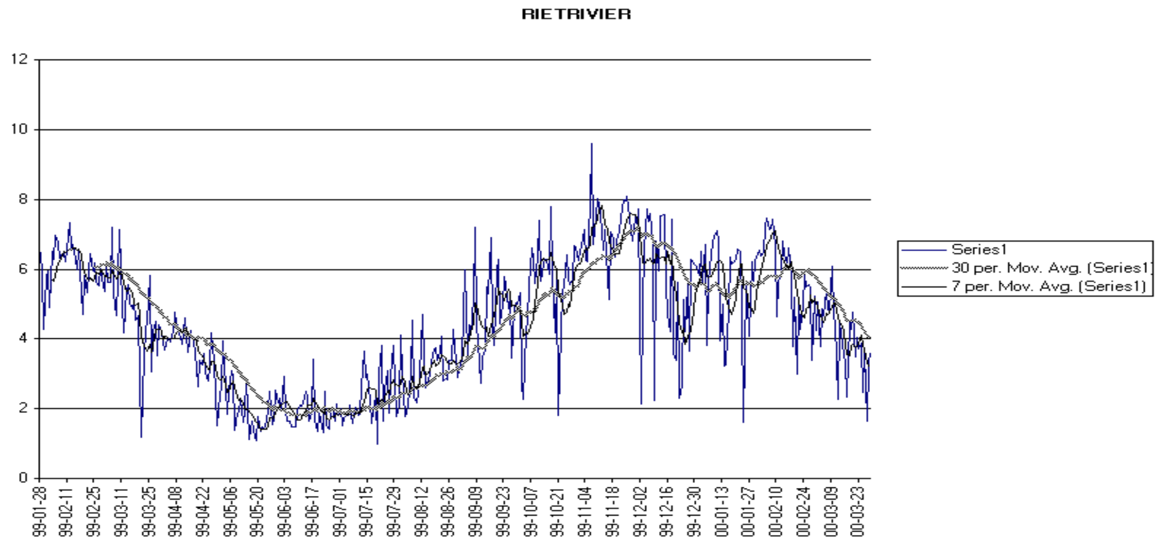


Figure 6.2.3.1 Rietrivier ET_0: Daily, seven-day and 30-day moving averages.

It is also necessary to differentiate between the first and second halves of months, because noticeable difference in average values is experienced. SAPWAT climate files includes this approach.

The weather data system, compiled and managed by the ARC, is in the process of being updated. It is expected that the ET_0 values of a wide range of weather stations, calculated according to internationally standardized procedures, will be drawn down on a daily basis and will be available electronically to the public on request. The daily fluctuations in ET_0 imply that where prediction systems are based on atmospheric demand, a measure of lumping is indispensable. It is not possible to follow the daily variations, and the combination of a week's data is possibly a more practical solution. Water is ordered on a weekly basis from the supplier and scheduling services also work on a weekly basis.

6.3 CROP FACTORS AND SCHEDULING

6.3.1 Introduction

The primary function of SAPWAT is to estimate crop evapotranspiration (ET_{crop}) so that the irrigation requirement applicable to planning, design and management could be deduced (Crosby & Crosby, 1999). In this function SAPWAT will replace the "Green Book" of Green (1985).

Secondary functions of SAPWAT are the development of programmed irrigation and the evaluation of irrigation strategies.

6.3.2 Testing of K_c and the validity of SAPWAT estimates

A number of summarized scheduling data pages for crops grown in the area, were supplied by Dup Haarhof[5]. Wheat is the most important crop in the area and because it was near the beginning of a new wheat season, it was used as the main test crop and was also used as an example.

The data, specifically the irrigation and rainfall records, collected from rain gauges near neutron water meter tubes, is known to be reliable. These rain gauge quantities represent "water on the ground" and are accepted as the real quantity applied. It does not account for losses in the system, such as leakage, or in the case of sprinkler and micro irrigation, spray losses to the atmosphere. Water on the ground does not represent crop evapotranspiration (ET_{crop}), because provision must be made for run off, for the unavoidable variation in uniformity of distribution of the irrigation system and for variation in soil conditions.

The planning of water requirements, as presently applied by the WUAs in the study area, does not include rainfall and irrigation efficiency, but does incorporate it in practice by the use of crop factors into which these aspects have been built in. There is nothing wrong with this approach, but it complicates the issue when comparisons to other approaches have to be made. It is important to be very clear as to what is compared to what.

Table 6.3.2.1 shows information of 21 measuring points where wheat has been planted. Some of these measuring points have been used in the detail analyses that follow.

In general the farmers who attended the discussion groups, indicated that their normal planting time for wheat is mid June and that they usually planted varieties with a growing season of 140 days. GWK, in their advice to farmers, specify planting dates for wheat which range from 14 June to 9 August, depending on cultivar.

Water applied does not take into consideration changes in soil water content or irrigation before the beginning of the measuring process at the beginning of the season, a period that usually lasts about 30 days. Irrigation during this period is strategic and nominal. Rain is considered to be completely effective and is treated as an irrigation.

[5] Dup Haarhof, agricultural scientist, GWK, Kimberley.

Table 6.3.2.1 Water used by wheat with different growing seasons.

Growing season	Planting date	Irrigation ends	Days	Water applied (mm)
Short	Early August	Late November	105	485
				405
				463
	Late July	Early November	105	518
Medium	Mid July	Mid November	130	530
				470
				485
				478
				515
				608
				556
				533
				420
	Mid June	Early November	135	578
Long	Mid June	Mid-Late November	145-150	575
				562
				680
				636
				625
				484
				600

It was decided to subdivide wheat into three groups according to growing season, namely short, medium and long, for the development of crop factors and to accommodate the given planting dates and irrigation periods. **There is no question of calibrating SAPWAT; the aim was to evaluate whether SAPWAT could be adapted to give realistic estimates of what really happens within the bounds of reasonable limits**. It must be possible to explain changes.

It was expected that SAPWAT estimates of "water on the ground" must be compatible with planning and scheduling values that are presently being used. However, SAPWAT calculates evapotranspiration (ET_{crop}), and to provide for the influence of distribution, soil variability and top yield aims, distribution efficiency, based on some analytical considerations, of 85% were accepted as a first approach. All indications are that this was very near to correct, and therefore this value was retained. To coincide with present approaches to planning and management, rainfall was excluded from the calculations.

The scheduling records cannot be seen as reflecting an overall average. The relevant farmers are probably some of the most efficient in the area and they have the advantage of a scheduling service. The general standard of irrigation management on the farms in the area is high, with expected yields of 7 – 8 $ton.ha^{-1}$ for wheat. The irrigation requirements of the crop, as specified as a norm by the WUA, indicate a satisfactory level of water use efficiency.

The first group investigated, is the medium growing season group with 14 measuring points for different planting dates and soils that vary from light to heavy. The results of eight of the 14 points are described in the following sections. Similar results have been obtained at the other six measuring points.

6.3.2.1 <u>Wheat (medium), Farm W</u>

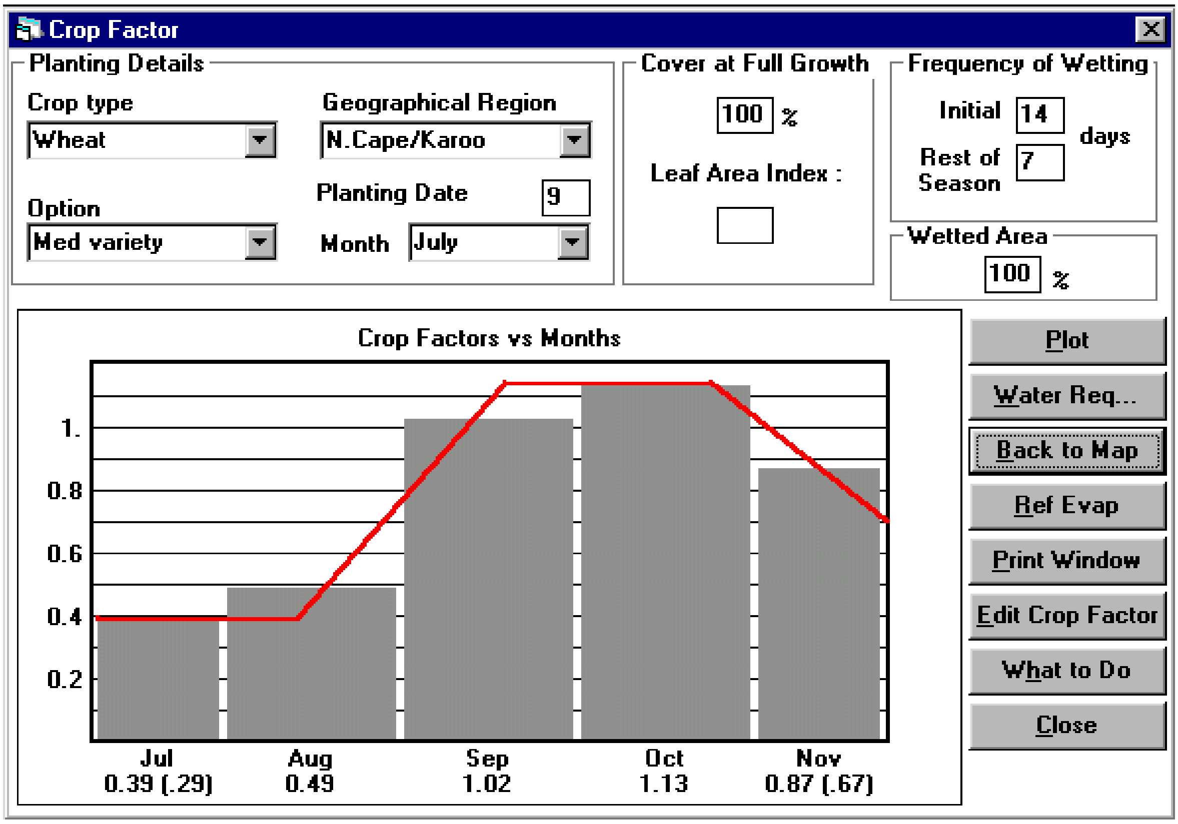


Figure 6.3.2.1.1 Crop factors for wheat, medium growing season, planted on 1 July, as used for the initial testing of SAPWAT.

The first centre pivots on the farm W were planted on 9 July and the last irrigation was during middle November. These centre pivots were referred to as 38E, 38F, 38G and 39H. As can be seen in Fig. 6.3.2.1.1, the crop factor curve is standard. Originally, the peak value for K_c was set at 1.2, but as a result of this investigation, it was reduced to 1.15. In the Riet River area this is an acceptable value. Values of 1.15 were determined for Yuma on the Colorado River in the southwestern USA, and there are indications that this value could also be acceptable for the Douglas-Riet River area.

The similarity between the SAPWAT cumulative water requirement curve and two of the centre pivots are remarkable (Fig. 6.3.2.1.2). Centre pivot 38G stopped on the same level as the others, but from September to middle October it was in front of the others. On closer inspection it was determined that this centre pivot started "dry" and that bigger applications were given in order to raise the soil water level to a satisfactory level. In the case of 38F, which got more than 100 mm more than the others, the original soil water content was very high and there are signs of deep drainage (percolation).

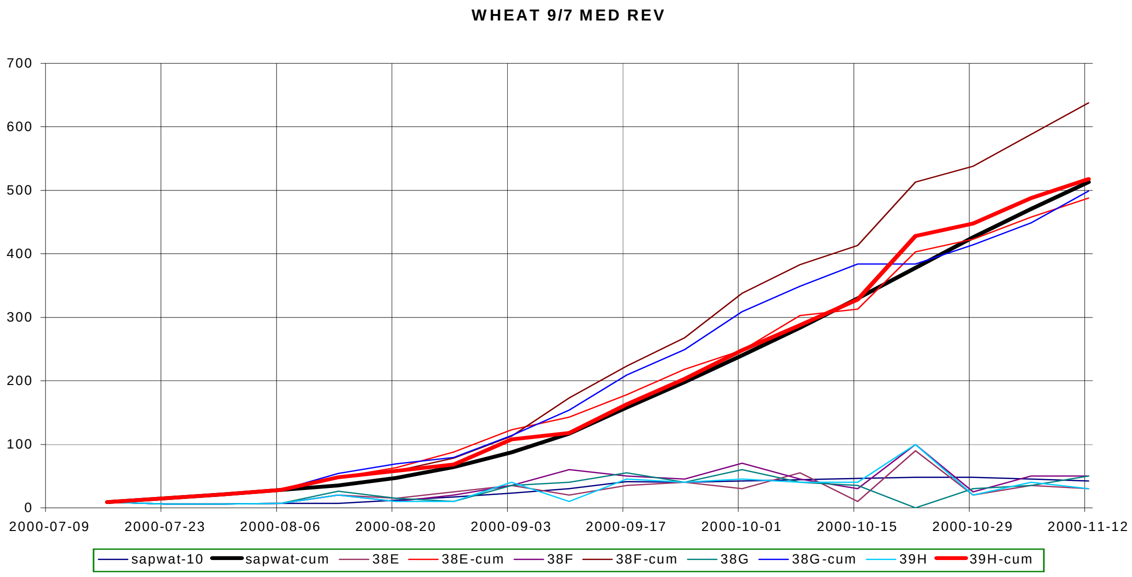


Figure 6.3.2.1.2 The similarity between the SAPWAT weekly and cumulative water requirement curves and those of centre pivots 38E, 38F, 38G and 39H.

These and similar graphs that will be considered, are significant in that the water applied during the season, corresponds with the FAO four-stage crop factor approach.

The even seasonal cumulative curves are in strong contrast with the weekly applications, which are shown at the bottom of the graph. Farmers tend to keep track of water requirement, but the weekly variation is too big for practical operational purposes.

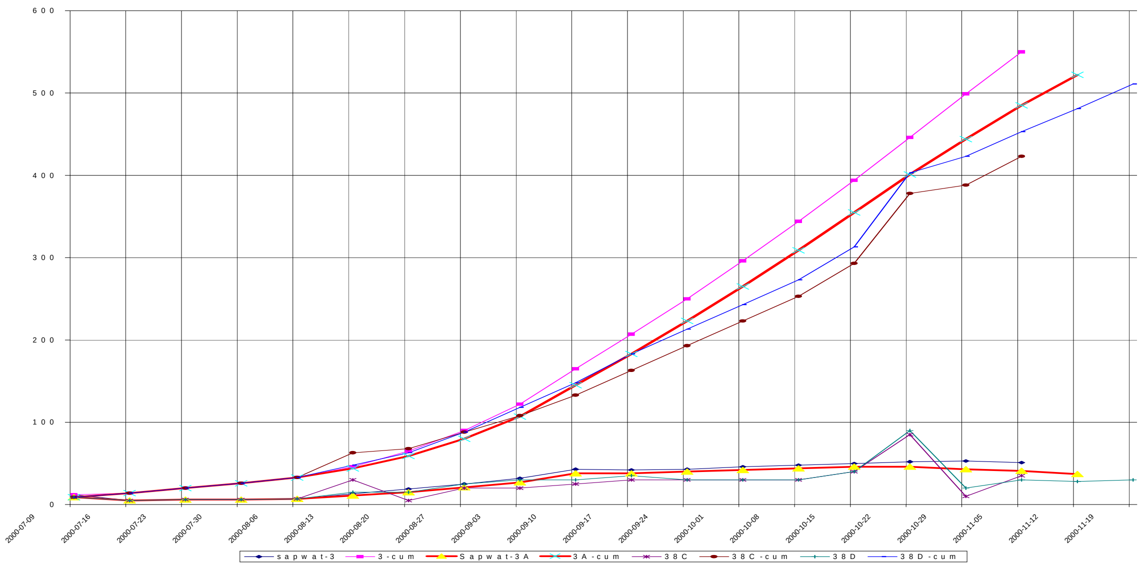
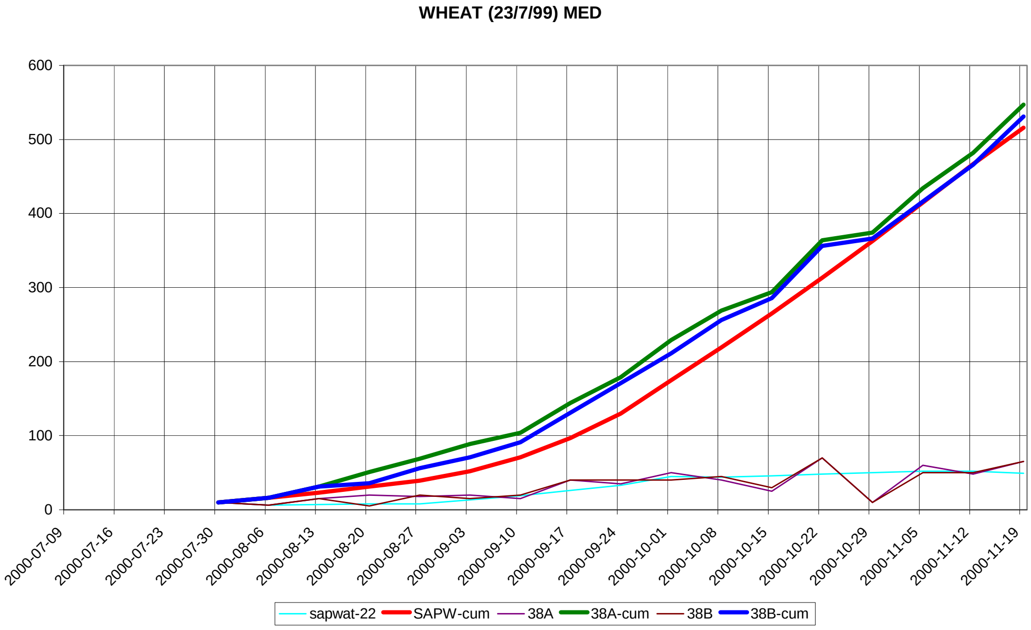


Figure 6.3.2.1.3 Coincidence between SAPWAT and actual applied water for wheat planted on 9 July.

If the same crop factor curve is applied on a planting date of 3 July, as in the case of centre pivots 38C and 38D, it also gives a good fit. The scheduling record shows that from early September the irrigation quantities were lower than the SAPWAT estimates, but there was a comparative withdrawal out of soil reserves (Fig. 6.3.2.1.3).

Wheat was planted on 23 July under centre pivots 38A and 38B (Fig 6.3.2.1.4). Once again the fit between the SAPWAT curve and the water application curve was satisfactory. In this case the SAPWAT curve was somewhat lower for the largest part of the period. It must be remembered that SAPWAT uses long-term weather data and not on-site real time data. Therefore, the results in this case are extremely good.



Figuur 6.3.2.1.4 Coincidence between SAPWAT and actual applied water for wheat planted on 23 July.

6.3.3 Conclusions

The evaluation that was done, indicate that SAPWAT is capable of estimating crop water requirements of wheat by using long-term weather data and the theoretical crop factor curve, with small adaptations. It seems as if the in-season distributions are valid and this should increase the accuracy of water supply planning.

Presently the WUAs accept a seasonal requirement of 660 mm for wheat. No differentiation is made for planting date or cultivar. Example values developed in this report by making use of SAPWAT and Riet River weather data (Douglas values will be somewhat higher), are 580 mm for medium, 625 for long and 472 mm for short growing varieties. If we accept that medium values are representative, where do we stand?

The 660 mm accepted by the WUAs was calculated by using crop factors and is the total quantity water delivered to a farmer through canal sluices or by pumping out of the river. It includes losses from farm boundary up to "water on the ground".

6.3.3.1 Scheduling

The supporting role that SAPWAT can play has already been discussed. The estimated irrigation requirement of the previous week that is distributed to farmers by Griqualand West cooperative, is a very handy aid. The present formats of the pages that are distributed are excellent. This information is based on daily automatic weather station Penman-Monteith-derived reference evaporation (ET_0). In future, there will be complete compatibility between these ET_0 calculations and those that were used to develop the SAPWAT database. The crop factors used in the calculation of ET_{crop} are the standard values, which are used for the development of monthly planning values. The recommendation is that the crop factors that are presently used are to be replaced by the FAO/SAPWAT crop factors.

Once the crop factor curve has been determined for a specific situation, SAPWAT can supply a daily crop factor value in a format suitable for direct inclusion in a spreadsheet. What must still be done to complete the ET_{crop} advising is to download the daily or weekly values from automatic weather stations to the spreadsheet.

6.3.3.2 Real time profit and loss water balance

The scheduling module of SAPWAT sets the values of crop water use and soil water content based on simplified assumptions and losses of rain water and irrigation water through deep drainage for the full season. Although this is based on long-term monthly weather data, the calculations are based on daily interpolations and the output is available on a daily basis as graphs and tables. This information can be transferred directly to a spreadsheet for use by advisors, managers or farmers.

The original intent was that the farmer and his advisor would develop a strategy for the season that would be regularly monitored by the input of daily, or preferably weekly, actual irrigation applied, the evaporation figures as derived from automatic weather station data and the neutron probe measured water content as supplied by the scheduling service. The original tables and graphs are then automatically updated, which means that actual irrigations could be evaluated against the planned irrigations.

7 THE APPLICATION OF SAPWAT IN WATER MANAGEMENT PLANNING

7.1 INTRODUCTION

To apply water management effectively on scheme or farm level, it is necessary that the manager should know how much water crops require. Furthermore, he must know which portion is added by rain, and what must be added as irrigation. He must also know how much provision should be made for the leaching of salts and for system efficiency.

For efficient water management on a farm or at scheme level, it is also necessary that the farmer and WUA, or other water management body, must know how much water will be for irrigation and how the water requirement is distributed over a year.

As was shown in Chapters 5 and 6, SAPWAT can be used for the reliable determination of water and irrigation requirements of crops. The process is done in three phases:

- Determine the irrigation requirements of individual crops
- Determine the irrigation requirements of sub areas
- Determine the irrigation requirements of bigger areas.

Phases 2 and 3 follow the same approach, the only difference being the scale and complexity that must be provided for.

The following information is necessary for the determination of irrigation requirements and for the planning of alternatives:

- Crops grown, planting dates and the growing season of each crop, as well as the reasons why farmers grow these crops.
- For planning purposes the same information must also be collected for the most probable alternative crops that could be grown in the area.
- Real and expected production levels, with differentiation between average and top farmer performance. This can be a useful indicator of what is achievable and how much improvement could be expected by the improvement of production techniques, and also whether it is really worth the effort to change to alternatives.
- General production practices followed, which crops follow which and how the land is prepared for the following crop, anything that can have an influence on the choice of the following crop, such as chemical weed control, handling of crop residues, the prevalence of weeds, pests and diseases and the availability of water.
- Profitability and marketing potential.
- The area scheduled, cultivated and the average area covered by each crop per year.

- Position and identification of weather stations.

- General climatic information, specifically factors that have an influence on choice of crops and yield, such as evaporation, occurrence of frost, temperature changes, wind, humidity, etc..

- Soil characteristics, specifically those that influence water holding capacity, choice of crops and irrigation management, such as texture classes, profile depth, potential or real compaction layers, water logging and/or salination.

- Special management or cultivation practices applied to manage problem situations.

- The amount of leaching necessary.

- Irrigation systems in use, the general level of maintenance and management, specifically the preferences of the farmers and the reasons for their preferences.

- Where applicable, scheme management, with special reference to adaptability and limitations.

- In the case of the planning of new scheme, or the re-planning of existing schemes, the acceptability of proposed crops, the complexity of their cultivation and their management requirements, as related to the preferences and capabilities of the target group. The sophistication of the irrigation systems and their management should also be measured against the same criteria.

It is imperative that the investigator should develop a "feeling" for the area under investigation.

7.2 THE DETERMINATION OF THE IRRIGATION REQUIREMENTS OF CROPS

It is possible, but not practically achievable, to calculate the irrigation requirement for each planting date for each crop that is grown in an area, and also to provide for all possible variables in terms of soil, climate, water and crops. This problem is managed by making assumptions based on the information collected in an area. The aim is to define representative farming patterns that can be used for purposes of area planning and for water management.

The water requirement of each crop grown in this study area was determined by applying the following assumptions:

- A normal climatic year was used.

- A distribution efficiency of 85% and spray losses of 10% were accepted for this area where centre pivot systems are the most important. It seems as if results obtained agree, to a large extent, with the general values accepted by the WUAs and which, for all practical purposes, takes general efficiency into account.

- Where planting dates differed within reasonable limits, the planting dates were consolidated into a single date to reduce the number of calculations to manageable levels.

- A weekly irrigation cycle was accepted because that is the cycle that is generally found in the area in relation to scheduling and to the ordering of water.

- For water-balance studies for the areas, an initial profile available level of 75 mm was accepted. This is based on an acceptable profile available water capacity of 100 mm for the soils of the area (Bennie, 2000), as well as the initial soil water status as indicated by the respondents. (SAPWAT has its own changeable default values for individual crops, which are based on soil and crop characteristics).

- To agree with the present management approach of the WUAs, no provision was made for leaching as a preventative measure against salination.

- Because of the same reason, rainfall was not taken into account.

It must be kept in mind that all calculations done by the WUAs, and water delivered to the irrigators, are representative of one season only, while SAPWAT calculations are based on long-term average data. Differences can be expected and if found, would not necessarily represent faulty calculations.

The implications of some of the above assumptions will be discussed later.

7.2.1 Calculating the irrigation requirements of crops

The basis for the calculation of the irrigation requirement of a crop is the standard soil water balance equation as described by Bennie, Strydom, & Vrey (1998):

$$\Delta W = P + I \pm DP - RO - E - T$$

where ΔW = change in soil water content
P = precipitation
I = irrigation
DP = deep percolation (or inflow from a water table)
RO = runoff
E = evaporation from the soil surface
T = water up-take by plant roots

This formula can be rewritten in terms of irrigation requirement as:

$$\text{Irr Req} = ET_{crop} - P_{tot} + RO \pm DP \pm \Delta W$$

Where: Irr Req = Irrigation requirement
ET_{crop} = crop evapotranspiration
P_{tot} = effective rainfall
RO = runoff
DP = deep percolation
ΔW = change in soil water content

SAPWAT applies this formula in the calculation of irrigation requirement as follows:

- For the calculation of the basic irrigation requirements the crop evapotranspiration is calculated, effective rainfall is subtracted and deep percolation as well as runoff is accounted for in the efficiency levels selected by the user. Changes in soil water content are ignored during this calculation.

- Effective rainfall can be excluded from this calculation.

- The management module of SAPWAT, where different irrigation strategies can be compared, includes changes in soil water content in its calculations.

The irrigation requirements of all crops grown in the study area were calculated with the aid of SAPWAT against the background of the assumptions as described above. Examples of some of the SAPWAT screens for the most important crops of the area are shown in Appendices 7.2.1.1 and 7.2.1.2. The table showing irrigation dates is a spreadsheet refinement of one of the outputs of SAPWAT.

7.2.1.1 Orange-Riet WUA

The calculated monthly irrigation requirements are tabled in Table 7.2.1.1.1 and also in Appendix 7.2.1.1.1. These values were obtained from SAPWAT calculations as shown in Appendix 7.2.1.1.

In Table 7.2.1.1.1 the columns show the crop, the planting date or starting date for perennial crops, the percentage of total crop composition, the irrigation requirements in $mm.ha^{-1}$ for each of the twelve months and total irrigation requirement in $mm.ha^{-1}$ for the growing season or per annum in the case of perennial crops.

As can be seen in Table 7.2.1.1.1, the total irrigation requirement varies from 449 $mm.ha^{-1}$ for annual winter pastures and 451 $mm.ha^{-1}$ for sweet corn, to 1 246 $mm.ha^{-1}$ for lucerne and 1 265 $mm.ha^{-1}$ for perennial pastures. The highest monthly requirements are in the order of 250 to 300 $mm.ha^{-1}$ for potatoes, peanuts, cotton and maize and occur during January, February and March.

7.2.1.2 Orange-Vaal WUA

The calculated monthly irrigation requirements are tabled in Table 7.2.1.2.1 and also in Appendix 7.2.1.2.1. These values were obtained from SAPWAT calculations as shown in Appendix 7.2.1.2.

In Table 7.2.1.2.1 the columns show the crop, the planting date or starting date for perennial crops, the percentage of total crop composition, the irrigation requirements in $mm.ha^{-1}$ for each of the twelve months and total irrigation requirement in $mm.ha^{-1}$ for the growing season or per annum in the case of perennial crops.

As can be seen in Table 7.2.1.2.1, the total irrigation requirement varies from 471 $mm.ha^{-1}$ for dry beans and 479 $mm.ha^{-1}$ for annual winter pastures, to 1 244 $mm.ha^{-1}$ for lucerne, 1 363 $mm.ha^{-1}$ for perennial pastures and 1 726 $mm.ha^{-1}$ for pecan nuts. The highest monthly requirements are 296 to 355 $mm.ha^{-1}$ for cotton and peanuts and occur during January.

The differences in especially peak requirements of crops between the two WUA areas can be ascribed to differences in planting dates and in climate, as measured by the two weather stations.

Table 7.2.1.1.1 Estimated irrigation requirements for crops grown in the Orange-Riet WUA area, rainfall excluded from the calculations

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	01 Mar	1.1			63	78	85	67	75	81					449
Pastures, perennial	01 Aug	1.9	170	129	116	81	60	45	51	76	102	127	147	161	1 265
Potatoes	10 Jan	10.7	73	197	209	137									616
Potatoes	22 Sep	3.0	280	134							15	85	211	266	991
Dry beans	02 Jan	2.4	73	198	192	8									471
Ground nuts	22 Oct	5.8	316	238	101							16	68	191	930
Ground nuts	10 Dec	1.0	126	233	215	49								44	667
Cotton	15 Oct	3.3	296	243	182	13						29	76	179	1 018
Cabbage	15 Mar	0.5			37	75	88	74	25						299
Cabbage	01 Jul	0.4							44	99	167	181			491
Wheat	10 Jul	66.1							23	60	170	239	173		665
Lucerne	01 Aug	9.0	211	160	134	29				51	118	159	184	200	1 246
Maize	01 Nov	1.7	307	243	195	60							60	150	1 015
Maize	13 Dec	21.4	216	243	171									40	670
Cucurbits	30 Aug	1.3									87	175	206	63	531
Sunflower	07 Jan	11.0	61	158	225	75									519
Sweet corn	20 Dec	1.3	161	204	57									29	451
Onions	10 Apr	3.1				32	43	60	84	126	164	113			622
Vineyards	01 Aug	0.7	154	108	46					47	67	105	134	147	808
Carrots	15 Sep	1.9									31	142	217	90	480

Table 7.2.1.2.1 Estimated irrigation requirements for crops grown in the Orange-Vaal WUA area, rainfall excluded from the calculations

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	15 Mar	1.6			65	80	91	73	84	86					479
Pastures, perennial	01 Aug	2.3	189	133	120	83	64	49	57	80	107	141	162	178	1 363
Potatoes	10 Jan	9.6	80	202	216	140									638
Beetroot	01 Sep	1.1									75	232	184		491
Dry beans	10 Jan	0.4	73	198	192	8									471
Ground nuts	15 Oct	1.5	355	232	63							33	91	253	1 027
Ground nuts	15 Dec	0.3	112	227	226	75								38	678
Cotton	15 Oct	3.7	296	243	182	13						29	76	179	1 018
Wheat	15 Jul	51.4							20	57	164	268	239		748
Lucerne	01 Aug	16.8	233	164	138	30				55	124	176	202	222	1 344
Maize	15 Dec	32.1	197	248	85									39	569
Pecan nuts	01-May	0.7	237	167	151	104	81	62	74	105	136	179	205	225	1 726
Cucurbits	15 Oct	0.8	188									51	182	262	683
Sunflower	12 Jan	4.5	48	125	249	101									523
Onions	15 Apr	2.0				26	44	61	95	134	174	162			696
Vineyards	01 Aug	3.3	171	111	48					50	71	117	148	162	878
Carrots	05 Sep	2.6									63	190	231	29	513

7.3 THE CALCULATION OF THE IRRIGATION REQUIREMENTS OF CROP ROTATION SYSTEMS

The determination of the irrigation requirements of crop rotation systems is a logical next step after the determination of the irrigation requirements of individual crops. The irrigation requirements of the crops are calculated and the monthly irrigation requirements[6] of the crops are totalled in the same ratio in which the crops are grown. This gives a total irrigation requirement in mm per hectare for each month for the relevant area. The monthly calculation is thus:

$$\text{Irrigation requirement} = (\text{crop requirement}_1 * f_1 + \ldots. + \text{crop requirement}_n * f_n)$$

where: crop requirement$_x$ = irrigation requirement of crop$_x$

f_x = ratio of crop in crop rotation system

Under irrigation of especially annual crops the land coverage is usually more than 100% because of double cropping. Therefore, the sum of f_x need not necessarily be 100%.

7.4 THE IRRIGATION REQUIREMENTS OF CROP ROTATION SYSTEMS OF SUB AREAS

The water of each of the sub areas of both WUAs is managed individually. Therefore, the irrigation requirement of each sub area should be calculated separately.

What is noticeable in the following discussions is that, despite sub areas that vary in size and in crop composition, there is generally a similarity between the SAPWAT calculation approach and that which is already applied by the WUAs. The farmers readily accept the values calculated with the aid of SAPWAT. Furthermore, deviations can be explained in terms of the assumptions and also on the basis of practical management considerations. This indicates credibility and the possibility of acceptance of the SAPWAT calculation methodology in other irrigation areas.

7.4.1 Orange-Riet WUA area

The irrigation requirements of these sub areas are tabled in Appendices 7.4.1.1.1 to 7.4.1.3.1. For purposes of comparison the monthly irrigation requirements, as calculated by the WUA, are also shown in Figs. 7.4.1.1.1 to 7.4.1.3.1.

7.4.1.1 Sub area 1

This sub area is the smallest of the three WUA sub areas. Less wheat and more lucerne than the average for the area are grown in this sub area. In spite of this, the similarity between the calculated irrigation requirement of the WUA and that that was calculated with SAPWAT is very good. The annual irrigation requirement is 1 025 $mm.ha^{-1}$, compared to the annual quota of 1 100 $mm.ha^{-1}$.

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[6] SAPWAT provides for the calculation of these values with or without the influence of rainfall. Different options for efficiencies and for soil characteristics are also available. Refer to Chapter 5.

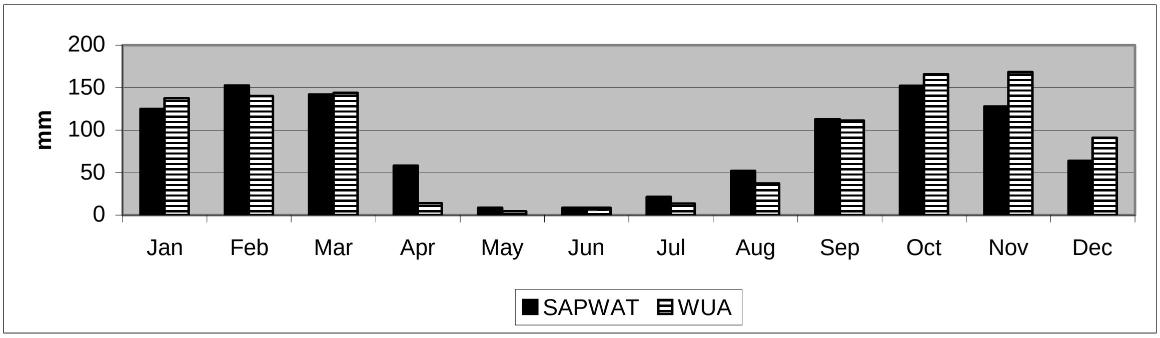

Figure 7.4.1.1.1 The irrigation requirements for sub area 1 of the Orange-Riet WUA as calculated with SAPWAT and as the WUA calculated it.

7.4.1.2 Sub area 2

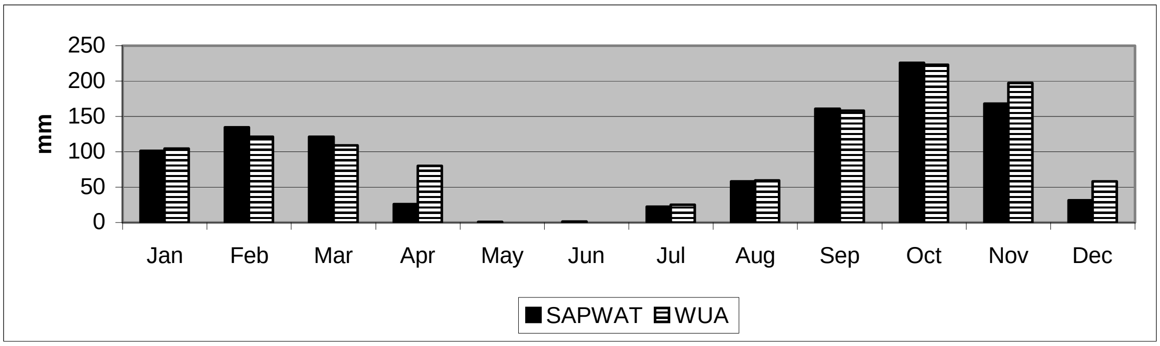

Figure 7.4.1.2.1 The irrigation requirements for sub area 2 of the Orange-Riet WUA as calculated with SAPWAT and as the WUA calculated it.

This sub area covers about one third of the total WUA area. Substantially more wheat and sunflower than the average for the area are grown in this sub area, whilst significantly less potatoes are grown. This is the sub area with the biggest area under cotton, which covers 4%. The similarity between the irrigation requirement as calculated by the WUA, and that which was calculated by SAPWAT, is obviously good. The annual irrigation requirement is 1 054 mm.ha^{-1}, compared to the annul quota of 1 100 mm.ha^{-1}.

7.4.1.3 Sub area 3

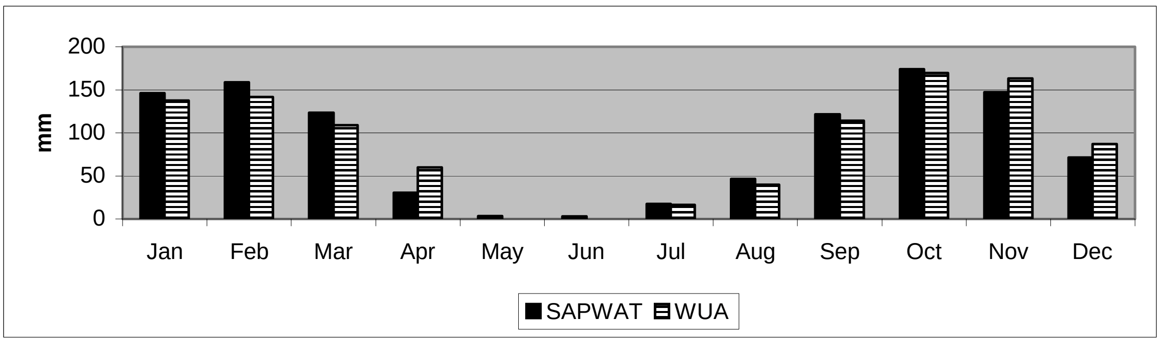

Figure 7.4.1.3.1 The irrigation requirements for sub area 3 of the Orange-Riet WUA as calculated with SAPWAT and as the WUA calculated it.

This sub area covers about half of the total WUA area. The 58% of the area under wheat is somewhat less than the average for the area, while potatoes and peanuts are grown on a larger area. Once again, the similarity between the calculated irrigation requirement of the WUA and that of SAPWAT is very good. The annual irrigation requirement is 1 044 mm.ha^{-1}, compared to the annual quota of 1 100 mm.ha^{-1}.

7.4.2 Orange-Vaal WUA area

The irrigation requirements of the five sub areas of this WUA are tabulated in Appendices 7.4.2.1.1 to 7.4.2.5.1. For the purposes of comparison, the monthly irrigation requirements as calculated by the WUA are also shown in Figs. 7.4.2.1.1 to 7.4.2.5.1.

7.4.2.1 <u>Sub area 1 (Olierivier)</u>

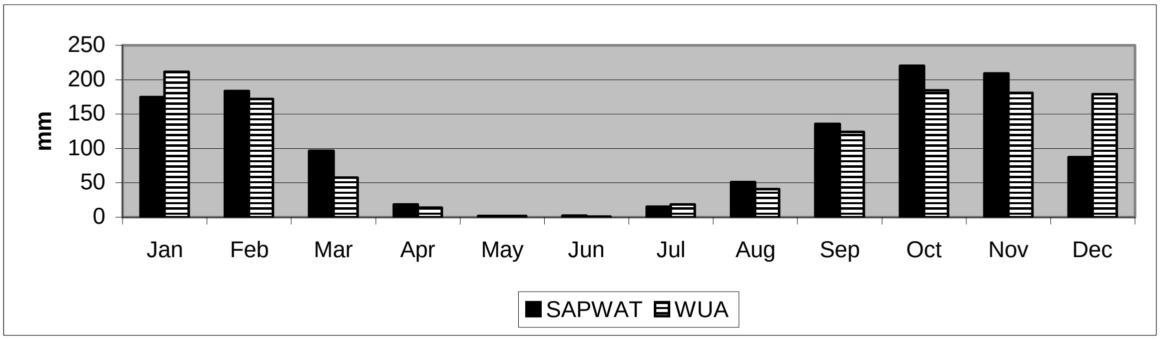

Figure 7.4.2.1.1 The irrigation requirements for sub area 1 of the Orange-Vaal WUA as calculated with SAPWAT and as the WUA calculated it.

This sub area covers slightly less than 40% of the Orange-Vaal WUA area. Wheat is the most important crop and is grown on 60% of the area, compared to an average of 51% for the total area. Maize, lucerne and potatoes are grown on a larger than average area. During October and November the SAPWAT calculated irrigation requirements are noticeably more than that calculated by the WUA, while an opposite trend is true for December and January. The biggest deviation is found in December. The annual irrigation requirement is 1 196 mm.ha^{-1}, much more than the annual quota of 914 mm.ha^{-1}, but this WUA makes provision for the sale of extra water, provided that it is available.

7.4.2.2 <u>Sub area 2 (Vaallus)</u>

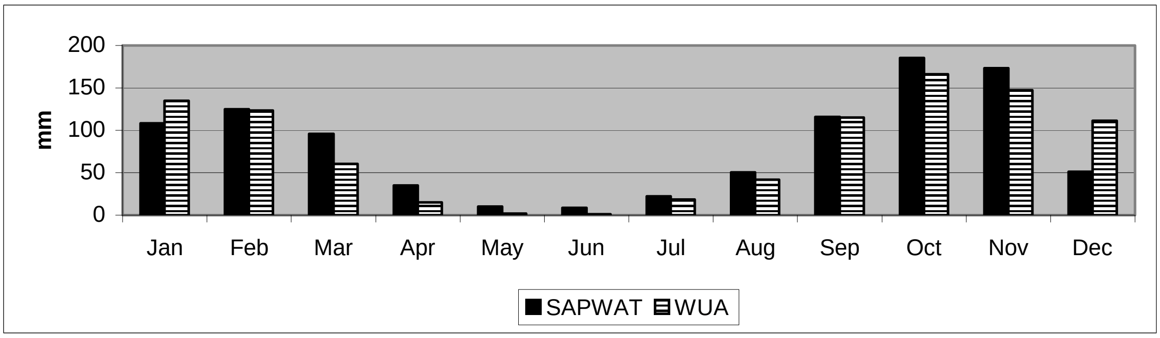

Figure 7.4.2.2.1 The irrigation requirements for sub area 2 of the Orange-Vaal WUA as calculated with SAPWAT and as the WUA calculated it.

This sub area covers about two-thirds of the total area of the WUA. Wheat is the most important crop and is grown on 58% of the area, compared to an average of 51% for the total area. Sunflowers and potatoes are also grown on a bigger area than average, while maize and lucerne are grown on a smaller area than the average. During October and November the SAPWAT irrigation requirements are noticeably more than the WUA calculations, while the reverse tendency is seen for December and January. The biggest deviation is found in December. The annual irrigation requirement is 980 mm.ha^{-1}, just more than the annual quota of 914 mm.ha^{-1}, but this WUA makes provision for the sale of extra water, provided that it is available.

7.4.2.3 Sub area 3 (Atherton)

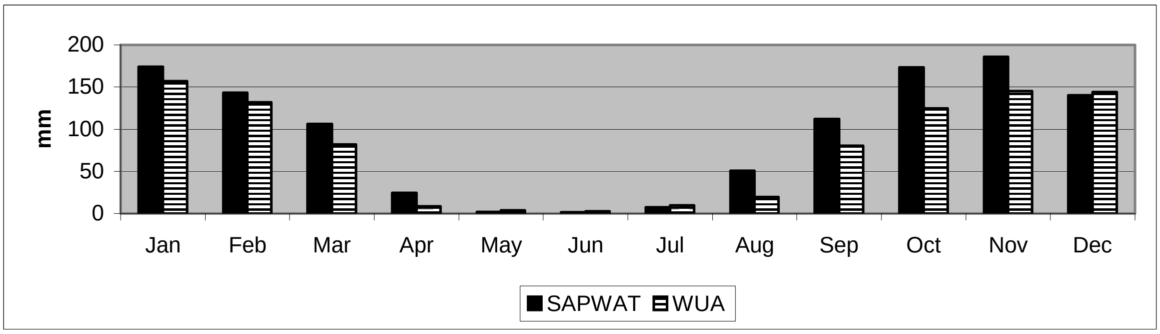

Figure 7.4.2.3.1 The irrigation requirements for sub area 3 of the Orange-Vaal WUA as calculated with SAPWAT and as the WUA calculated it.

This sub area is the smallest of the five sub areas of the WUA and covers about 4% of the total area. Lucerne is the most important crop and is grown on 39% of the area, compared to 17% for the total area. Vineyard deviates completely from the normal pattern in the sense that it is grown on 23% of the area compared to an average of only 3% for the total area. Wheat is grown on 27% of the area, much less than the total average. During October and November the SAPWAT irrigation requirements are noticeably more than the WUA calculations, while there is a good correspondence for the rest of the year. The annual irrigation requirement is 1 120 mm.ha^{-1}, substantially more than the annual quota of 914 mm.ha^{-1}, but this WUA makes provision for the sale of extra water, provided that it is available.

7.4.2.4 Sub area 4 (Bucklands and Die Erwe)

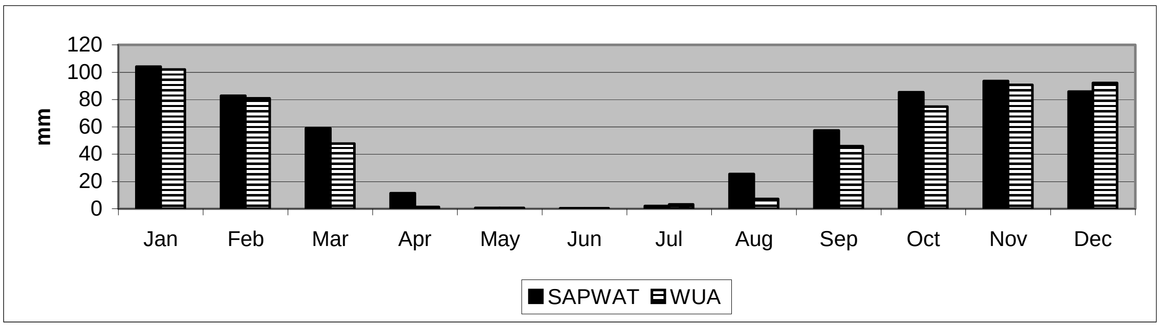

Figure 7.4.2.4.1 The irrigation requirements for sub area 4 of the Orange-Vaal WUA as calculated with SAPWAT and as the WUA calculated it.

This sub area is also small and covers about one-sixth of the total area. This area deviates further in the sense that it consists mostly of smallholdings, with many of the owners who use the smallholdings as a place of residence. This explains the phenomenon that only 56% of the scheduled area is cultivated, as compared to 100% or more which is the norm for irrigations farms. Lucerne is the most important crop and is found on 32% of the area, compared to an average of 17% for the total area. During August, September and October the SAPWAT calculated irrigation requirement is noticeably more than that calculated by the WUA, with the reverse phenomenon being noticeable for December. During the rest of the year there is a good correspondence between the two methods of calculation. The annual irrigation requirement is 624 $mm.ha^{-1}$, substantially less than the annual quota of 914 $mm.ha^{-1}$, mainly because the farming pattern of this area deviates from that found in the other sub areas.

7.4.2.5 Sub area 5 (New Bucklands)

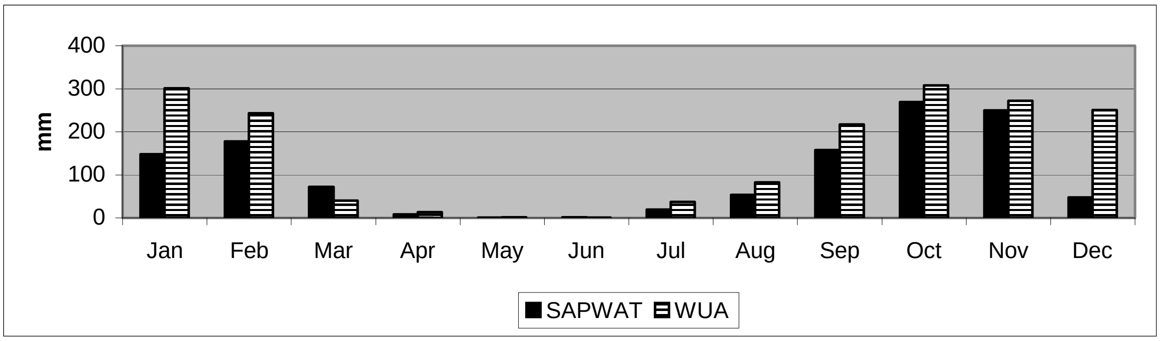

Figure 7.4.2.5.1 The irrigation requirements for sub area 5 of the Orange-Vaal WUA as calculated with SAPWAT and as the WUA calculated it.

This sub area is small and covers about 8% of the total area. It is a relatively newly developed area, although farming patterns seem to have stabilized. Wheat, with maize as a follow-up crop, is by far the most important combination and this combination covers 151% of the area, compared to a general pattern of 83% for the WUA area as a whole. This has the result that this area is the most intensively cultivated of all the areas, with an annual coverage of 181%. This area also differs form the other sub areas in the sense that the WUA calculated irrigation requirement is higher than the SAPWAT calculations for most of the months of the year. The annual irrigation requirement is 1 206 $mm.ha^{-1}$, substantially more than the annual quota of 914 $mm.ha^{-1}$, but this WUA makes provision for the sale of extra water, provided that it is available.

7.5 THE DETERMINATION OF THE IRRIGATION REQUIREMENTS OF CROP ROTATION SYSTEMS OF LARGER AREAS

The determination of the irrigation requirement of crop rotation systems of larger areas follows the same approach as that which is used to determine the irrigation requirements of smaller areas. The crop composition is determined and the irrigation requirement is then calculated.

7.5.1 Irrigation requirements of the Orange-Riet WUA area

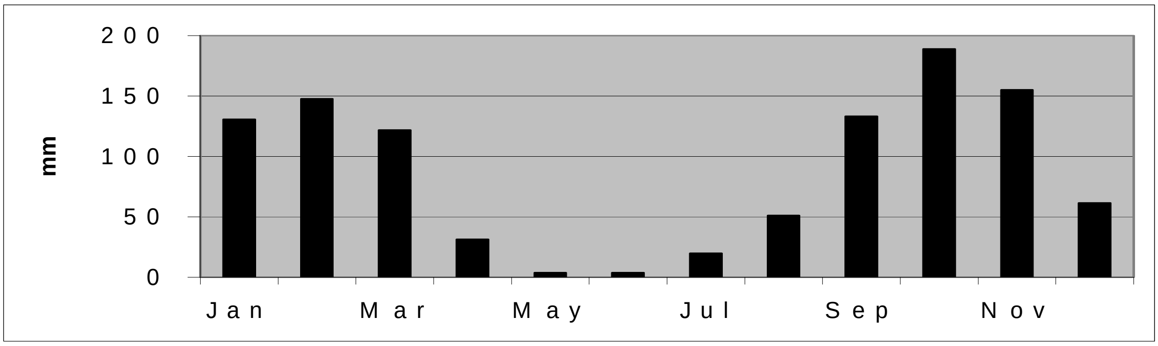

Figure 7.5.1.1 Monthly irrigation requirements for the Orange-Riet WUA area.

The calculated irrigation requirement for the Orange-Riet WUA can be seen in Appendix 7.5.1.1. Fig. 7.5.1.1 is a presentation of how much the water requirement varies over a year. In the figure it can be seen that the water requirement varies from 4 $mm.ha^{-1}$ for June and July to 148, 155 and 189 for February, November and October respectively. The total system requirement is 1 051 $mm.ha^{-1}.a^{-1}$, which is just less that the water quota of 1 100 $mm.ha^{-1}.a^{-1}$.

7.5.2 Irrigation requirements of the Orange-Vaal WUA area

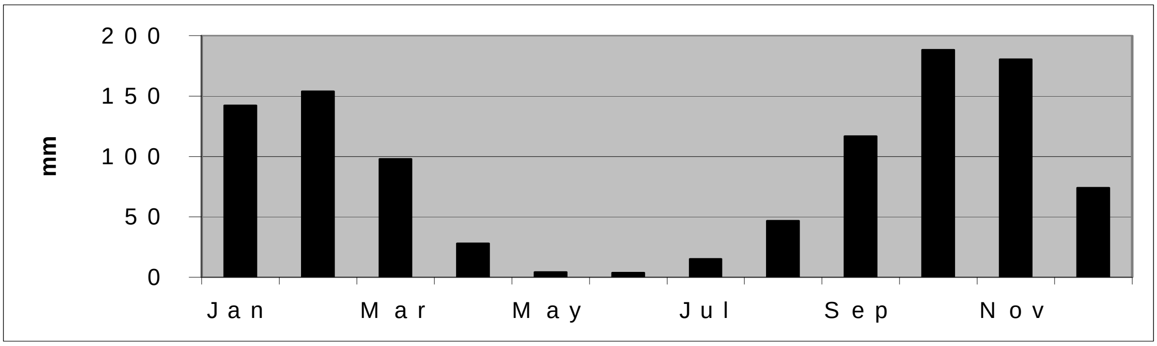

Figure 7.5.2.1 Monthly irrigation requirements for the Orange-Vaal WUA area.

The calculated irrigation requirement for the Orange-Vaal WUA can be seen in Appendix 7.5.2.1. Fig. 7.5.2.1 is a presentation of how much the water requirement varies over a year. In the figure it can be seen that the water requirement varies from 4 $mm.ha^{-1}$ for June and July to 189 and 181 for October and November respectively. The total system requirement is 1 053 $mm.ha^{-1}.a^{-1}$, which is substantially more than the water quota of 914 $mm.ha^{-1}.a^{-1}$.

7.6 THE CALCULATION OF THE IRRIGATION REQUIREMENTS OF CROP ROTATION SYSTEMS, INCLUDING ALLOWANCE FOR RAINFALL, LEACHING REQUIREMENT AND EFFICIENCY

The two WUAs do not consider rainfall when the irrigation requirements of crops are calculated for planning purposes. They also do not include distribution losses, inefficiency of pumps and canal systems, and leaching requirements in their calculations. The crop factors that the WUAs apply include these elements. This approach simplifies water management, but does it give a valid answer?

The theoretical procedure would be to calculate the net irrigation requirement, add a leaching requirement, and then provide for the inefficiency that is inherent to all systems.

By applying the different management options that SAPWAT provide for and then by selecting the most efficient management option through inspection, one can plan for the most efficient irrigation depth.

Unfortunately there is a tendency to "forget" the other half of the efficiency equation, which is the farmer's responsibility of applying the correct amount of water at the right time. This implies that the irrigation system in use must be correctly designed, installed and maintained, and that the farmer must know how much water is applied at a time and what the irrigation requirements of his crops are.

The question could be asked, and with some justification, as to what this irrigation requirement picture would look like if the two WUAs in the study area were to account for rainfall and for leaching. To investigate this aspect, the five most important crops were taken, their irrigation requirements were calculated according to the approach of the WUAs, and the results were compared to the correct approach of calculation where leaching requirement and rainfall were accounted for. The leaching requirements of 10% and 20%, as determined by Du Preez et al (2000), were taken as lower and upper boundaries and were added to an irrigation requirement that accounted for rainfall to get a new irrigation value. It must be remembered that the SAPWAT calculations already include efficiency values of 10% for spray losses and 85% for distribution.

7.6.1 Orange-Riet WUA

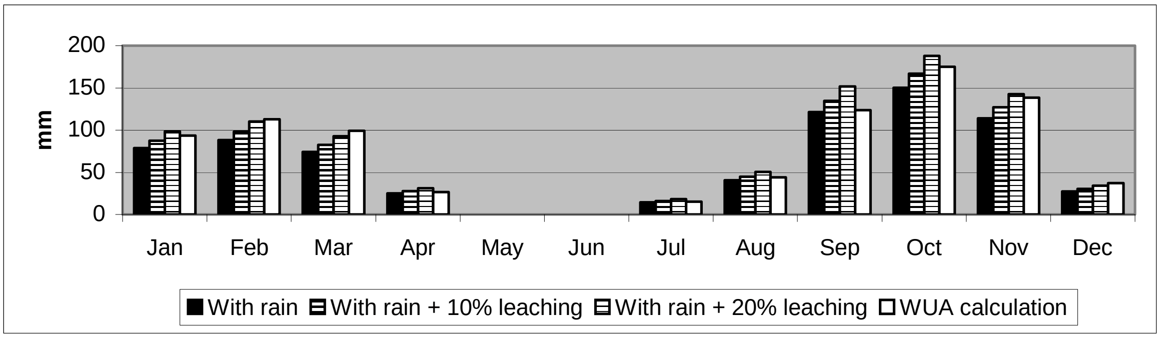

Figure 7.6.1.1 Comparison of water requirement for the crop rotation system of the Orange-Riet WUA, with inclusion of rainfall and with a 10% and 20% leaching requirement, compared to the WUA values.

The calculated values of the five most important crops are tabulated in Appendix 7.6.1.1 and are shown in Fig. 7.6.1.1. The small differences between the values are quite noticeable. It is only during the months of February, March and December that the irrigation requirement, as calculated in the way that the WUA does it, is more than the upper boundary as calculated by SAPWAT, with the inclusion of rainfall and leaching requirement. The differences are not big- 3, 6 and 3 $mm.ha^{-1}$ for each of the three months. During April and September the difference is 4 and 12 $mm.ha^{-1}$ less than the lower boundary set by the 10% leaching requirement. None of these differences are obviously significant. Generally speaking, the WUA's calculations fall between the 10% and 20% leaching requirement boundaries recommended for the area.

7.6.2 Orange-Vaal WUA

The calculated values of the five most important crops are tabulated in Appendix 7.6.2.1 and are shown in Fig. 7.6.2.1. The small differences between the values are quite noticeable. It is only during the months of February, March and December that the irrigation requirement, as calculated in the way that the WUA does it, is more than the upper boundary as calculated by SAPWAT, with the inclusion of rainfall and leaching requirement. The differences are not big- 20, 7 and 8 $mm.ha^{-1}$ for each of the three months. During April, August and September the difference is 1, 1 and 1 $mm.ha^{-1}$ less than the lower boundary set by the 10% leaching requirement. None of these differences are obviously significant. On total requirement, the WUA calculation is 25 $mm.ha^{-1}$ less than the 10% lower boundary leaching requirement- a difference that does not seem to be significant.

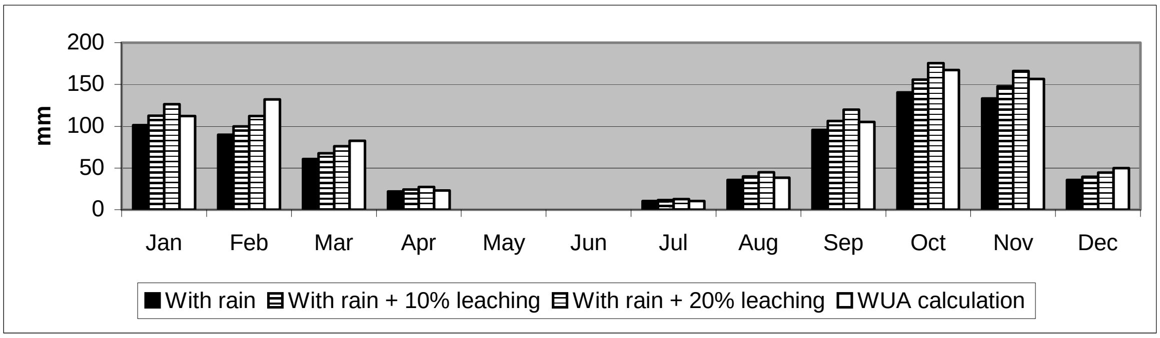

Figure 7.6.2.1 Comparison of water requirement for the crop rotation system of the Orange-Vaal WUA, with inclusion of rainfall and with a 10% and 20% leaching requirement, compared to the WUA values.

Judging the above results, it does seem as if the calculation approach of the two WUAs, although not quite correct, does give answers that are very close to the correct.

7.7 SAPWAT CALCULATIONS COMPARED TO THE APPROACH OF THE WUAS

The WUAs in the study area base their calculations of irrigation requirements on evaporation out of an S-pan and related crop factors. This raises the question of how well the WUAs' calculations compare with that of SAPWAT. It must be accentuated that any differences found is the result of differences in approach and does not necessarily indicate "right" or "wrong" calculations.

7.7.1 Orange-Riet WUA

The detail can be seen in Appendix 7.7.1.1, while Fig. 7.7.1.1 gives a good idea of the good agreement between the different calculation methods. Obvious deviations are April (+27 mm), November (+21 mm) and somewhat less, February (-24 mm) and December (-16 mm).

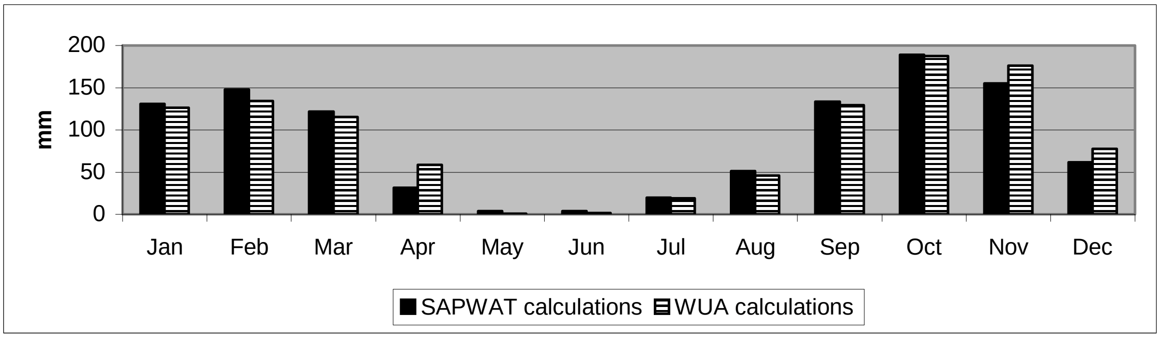

Figure 7.7.1.1 The comparison of irrigation requirements as calculated with SAPWAT and by the Orange-Riet WUA with the aid of the S-Pan.

The total irrigation requirement, calculated with the S-pan approach of the WUA, is 1 072 $mm^{-1}.ha.a^{-1}$, compared to the SAPWAT calculation of 1 051, a difference of only 21 $mm.ha^{-1}.a^{-1}$.

7.7.2 Orange-Vaal WUA

Detail can be seen in Appendix 7.7.2.1, while Fig. 7.7.2.1 shows the agreement between the different calculation approaches. December shows a very big deviation, where the WUA calculation is 52 $mm.ha^{-1}$ more than the SAPWAT calculation. January shows a similar pattern, but with a smaller difference. With the exception of July, the WUA calculated values are lower than the SAPWAT calculated requirements, with values that differ from 1 $mm.ha^{-1}$ for June to as much as 42 $mm.ha^{-1}$ for April.

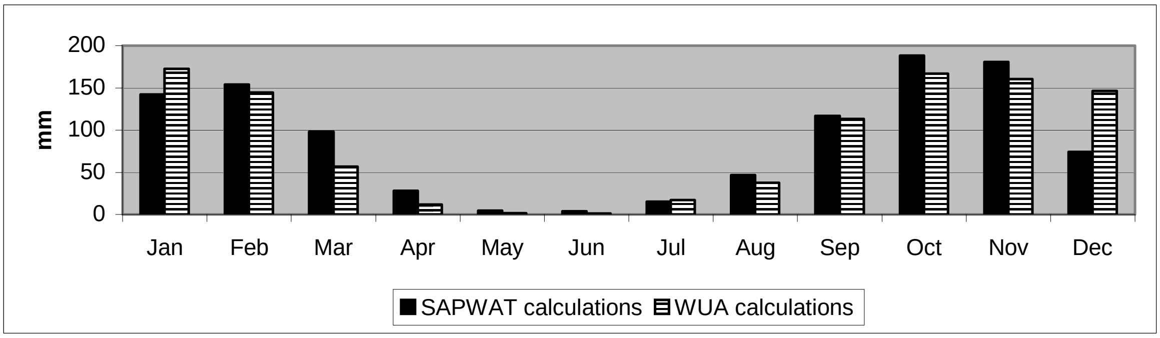

Figure 7.7.2.1 The comparison of irrigation requirements as calculated with SAPWAT and by the Orange-Vaal WUA with the aid of the S-Pan.

The total irrigation requirement, calculated according to the S-pan method of the WUA, is 1 030 $mm^{-1}.ha.a^{-1}$, compared to the SAPWAT calculation of 1 116, a difference of only 14 $mm.ha^{-1}.a^{-1}$.

7.8 SCENARIOS

The respondents indicated an interest in other crops. Olives and pecan nuts were mentioned and some experimental plantings on a small scale have been done. It was also mentioned that the area penetration of these crops would probably not exceed 3%. Furthermore, it is probably the relative difficulty in getting quotas for the cultivation of wine grapes that limit the expansion of this crop. If licences were more readily available, the experience was that expansion would take place fairly rapidly. Experience in other irrigation areas along the Orange River indicates that large-scale expansion in the growing of grapes is the most probable.

Because of these reasons, it was decided to investigate the water requirements of an alternative scenario, as calculated with SAPWAT, and to compare that with the present situation. This scenario assumes that the growing of wine grapes will increase to the extent where it will make up 50% of the crop rotation system.

The results can be seen in Appendix 7.8.1 and is also shown graphically in Figs. 7.8.1 and 7.8.2.

If this future scenario should materialize, it would result in obvious changes in the water requirement pattern of the system. The total water requirement decreases from 1 051 to 930 $mm.ha^{-1}.a^{-1}$ for the Orange-Riet WUA area, and decreases from 1 053 to 997 $mm.ha^{-1}.a^{-1}$ for the Orange-Vaal WUA area. The months with the highest use remain January, October and November and, to a degree, February, but the requirement decreases with as much as 42 and 46 $mm.ha^{-1}$ for October for the Orange-Riet and Orange-Vaal irrigation areas respectively.

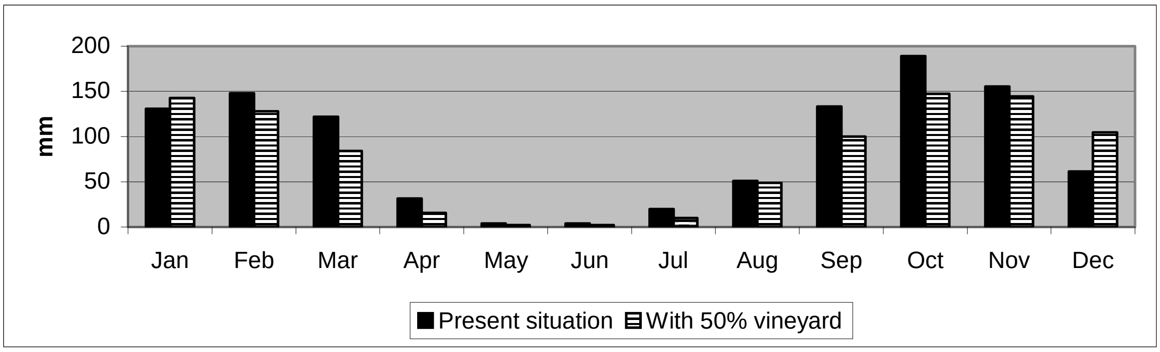

Figure 7.8.1 A comparison of the monthly irrigation requirements of the present crop rotation system of the Orange-Riet WUA, compared to a crop rotation system where vineyards will constitute 50% of the system.

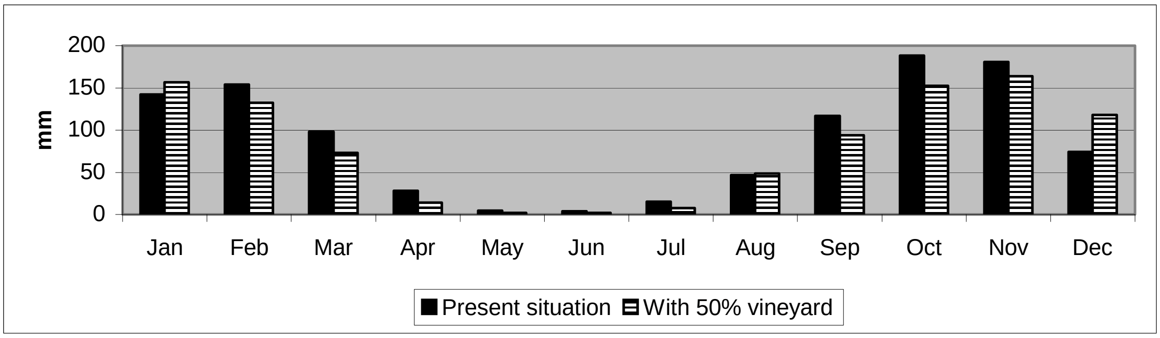

Figure 7.8.2 A comparison of the monthly irrigation requirements of the present crop rotation system of the Orange Vaal WUA, compared to a crop rotation system where vineyards will constitute 50% of the system.

Such changes in a cropping system can be used in cases where there are limitations in the amount of water that could be delivered for peak requirements, or even total volume of water, and thus compile cropping systems that would still give the best yields within the framework of limitations.

8 CONCLUSIONS AND RECOMMENDATIONS

This study showed that it is quite possible to do an irrigation requirement planning for an area by making use of semi-structured small group interviews and by using SAPWAT. Such planning would quantify the monthly and yearly irrigation requirements in such a way that the values could be used with confidence as inputs for the planning and management of water of bigger areas, as is required by the National Water Act (Act 36 of 1998) with the establishment of WUAs.

It is obvious that, as far as possible, relevant information of the target area should be collected to ensure a reliable result. This information includes:

- Historic background, mainly because preferences and rejections, farming and marketing patterns, the management of water and general farm management is the result of the historical development of an area, and because it gives a good background against which planning can be done

- Relevant information about climate and natural resources that could have an influence on farming patterns and water management

- Present crop patterns, possible alternatives, cultivation practices and farming patterns linked to crop production

- Profitability and marketing possibilities

- Human aspects, although not necessarily by way of formal survey, that could influence irrigation planning and management. Of specific interest is the level of development, as well as social, cultural and economic aspects that could determine crop preferences, farming patterns and management, specifically that of water.

An example of a questionnaire is attached as Appendix 8.1.

In this case, where the WUAs are making use of a method for the calculation of water requirements, and backed by an irrigation service supplied by the cooperative, it is not surprising that there is good agreement between the results obtained through the application of SAPWAT, and that which is calculated by the WUAs. This is an indication that the WUAs accept the responsibility of water management with the necessary earnestness.

One would have liked to see more water measuring being applied. However, the farmers have rain gauges under their centre pivots and at the end of the season they can say how much water was applied. Unfortunately, there is no monitoring of water flow through pumps and sluices, and this aspect worries one. It is said that the gauges on the market are too expensive, too complicated, not reliable, and a host of other reasons. The authors suspect that the reason for non-acceptance of water measuring lies elsewhere, and recommend that an extension study in this regard be done in the near future.

Presently the RSA has only one database that link agricultural production to the natural resource base, and that database is 10 years old. The possibility must be considered that all information that is collected for planning of this nature, be marshalled at a central point so that a new database about irrigation in the country can be compiled. This facet could be linked to the irrigation database that is presently being planned by the Institute for Soil, Climate and Water.

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APPENDIX 2.1

Size ranges of scheduled areas in the different irrigation areas and sub areas

WUA	Sub area	Size ranges of scheduled area								Total
		0 - 5	6 - 10	11 - 25	26 - 50	51 - 100	101 - 250	251 - 500	501 - 1000	
Orange-Riet WUA	Sub area 1	7	0	6	6	4	1	0	0	24
	Sub area 2	0	0	0	2	16	1	0	0	19
	Sub area 3	1	0	0	8	13	1	1	0	24
	Total	**8**	**0**	**6**	**16**	**33**	**3**	**1**	**0**	**67**
Orange-Vaal WUA	Sub area 1 (Olierivier)	0	0	1	4	7	8	4	0	24
	Sub area 2 (Vaallus)	0	0	0	1	6	3	4	1	15
	Sub area 3 (Atherton)	2	1	3	3	2	0	0	0	11
	Sub area 4 (Bucklands)	69	14	25	10	1	1	0	0	120
	Sub area 5 (New Bucklands)	0	0	0	2	4	1	0	0	7
	Total	**71**	**15**	**29**	**20**	**20**	**13**	**8**	**1**	**177**
Grand total		**79**	**15**	**35**	**36**	**53**	**16**	**9**	**1**	**244**

APPENDIX 3.1.1

Weather data for the Orange-Vaal- and Orange-Riet WUA areas as provided by AGROMET (undated)

Climate Info for: **DOUGLAS: JAIL.**
AM# 256/424L0 Comp# 19843 Lat: 2904S Long: 2345E Alt: 1030 YS: 1976 YE: 1991

Month	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	ANNUAL	YEARS
MaxT	20.2	22.7	26	28.7	31.6	33.5	34.8	32.9	30.7	26.5	23.3	19.8	27.6	16
AveX	26.3	29.5	33.8	35.6	37.2	39	39.6	37.9	35.6	32.8	29.5	25.5	33.5	16
MinT	0.9	3.5	7.8	11.3	14	16.5	17.9	17.6	15	10.5	5.3	1.4	10.1	16
AveN	-5.1	-3.7	-0.1	3.6	6.9	10.4	11.7	11.5	8.3	2.8	-1.2	-4.7	3.4	16
AveT	10.5	13.1	16.9	20	22.8	25	26.3	25.2	22.8	18.5	14.4	10.6	18.8	16
HU	50.4	106.4	208.4	309.8	384	464.4	506.8	426.7	397.8	254.5	141	47.2	3 297.4	16
Rain	1.8	7.5	12.3	28.4	29.6	42.3	29.4	76	70.5	27.9	5.7	3.6	335	16
Evap	3.6	4.6	6.6	8.4	9.9	11	11	8.9	6.8	4.9	3.9	3.2	2 517.3	14
ET_0	2.4	3.3	4.5	5.8	6.9	7.3	7.8	6.0	4.9	3.5	2.7	2.1	1 737.0	
Suns	9	9.3	9.4	10	10.7	11.1	10.7	9.2	9.1	8.4	8.9	8.6	9.5	14
Wind	108.5	119.3	140.8	154.1	156.4	153.4	147.3	130.3	109.5	97.3	96.1	102.4	126.3	14

Highest maximum temperature:............ .....42.2
Heat Units (October to March):......…………2489.5

Lowest minimum temperature:.......…… -6.5
Heat Units (April to September):……….. 807.9

Earliest date of frost (DD/MM):....…………30/ 4
Mean first date of frost (DD/MM):...…………18/ 5
Mean frost season length:.............. ………..105 days
Percentage of years with a moderate frost:..92.9%

Last date of frost:.............…………….11/ 9
Mean last date of frost:........... …………31/ 8
Mean numbers of days with frost:...……41 days

Climate Info for: **RIET RIVER,SANDPERSEL**
AM# 0258/184L0 Comp# 19892 Lat: 2904S Lon: 2437E Alt: 1140 YS: 1982 YE: 1997

Month	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	ANNUAL	YEARS
MaxT	19	22	26.4	28	30.4	32.7	34	32.1	30	26.1	23	18.9	26.9	16
AveX	25.2	28.9	34	35	36.8	38.6	38.7	37.4	35.4	31.7	28.8	25.1	33	16
MinT	0	2.7	7.5	11.1	13.8	15.7	17.9	16.9	14.4	9.9	5	0.8	9.6	16
AveN	-5.7	-3.6	0.4	3.8	7.5	9.4	12	10.9	8.3	2.1	-1.5	-4.7	3.2	16
AveT	9.5	12.3	16.9	19.6	22.1	24.2	25.9	24.5	22.2	18	14	9.8	18.3	16
HU	29.4	89.8	209.3	296.3	363.2	440.3	493.8	406.7	378.1	239.8	131.6	30.3	3 108.6	16
Rain	6.4	6.5	15.3	40.1	41.7	52.7	40.2	60.7	61.1	26.1	5.4	5.3	361.5	16
Evap	3.3	4.8	6.6	7.4	9	10	9.7	8.1	5.6	4.4	3.6	3	2 292.1	16
ET_0	2.3	3.1	4.3	5.2	6.3	6.6	6.9	5.8	4.7	3.4	2.5	1.9	1 609.0	
Suns	8.7	9.2	9.3	9.5	10.2	10.4	10.1	9.1	9	8.5	8.7	8.4	9.3	15
Wind	95.5	111.9	128.7	144.1	152	147.5	143	129.6	107.1	94.3	87.5	91.6	119.4	15

Highest maximum temperature:........... 41.5
Heat Units (October to March):........2378.4

Lowest minimum temperature:......... -8.0
Heat Units (April to September):... 730.2

Moderate Frost: Grass minimum less than –2 degrees

Earliest date of frost (DD/MM):...... 25/ 4
Mean first date of frost (DD/MM):.... 21/ 5
Mean frost season length:.............. 103 days
Percentage of years with a moderate frost: 92.9%

Last date of frost:................ 14/ 9
Mean last date of frost:........... 1/ 9
Mean numbers of days with frost:.....44 days

KEY:
AM# - AgroMet Number (based on SAWB)
Comp# - Computer Number
Lat – Latitude DDMM D – degrees
Lon - Longitude DDMM M – minutes
Alt – Altitude above sea level (m)
YS – First year of data used
YE – Last year of data used
MaxT - Maximum Temperature (øC)
MinT - Minimum Temperature (øC)
AveT - Average Temperature (øC)
HU - Heat Units above 10øC
Rain – Total Rainfall (mm/month)
Evap - A-pan Evaporation (mm/day)
AveX - Average of the one highest MaxT per month (øC)
AveN - Average of the one lowest MinT per month (øC)
ET_0 – Penman-Monteith reference evapo-transpiration (mm/day)
(**Note**: These values were added to the original table for purposes of this report)

APPENDIX 3.3.1

IRRIGATION SYSTEMS

WUA	Sub areas	Micro- and drip irrigation	Sprinkler irrigation	Flood- and furrow irrigation	Total
Orange-Riet WUA	Sub area 1	7	557	159	724
	Sub area 2	14	1 102	262	1 377
	Sub area 3		919	919	1 838
	Total	21	2 578	1 340	3 939
	%	1	65	34	100
Orange-Vaal WUA	Sub area 1 (Olierivier)	31	2 969	125	3125
	Sub area 2 (Vaallus)	27	1 861	771	2 659
	Sub area 3 (Atherton)	59	175	115	349
	Sub area 4 (Bucklands)	40	54	1 247	1 341
	Sub area 5 (New Bucklands)	19	598	0	617
	Total	176	5 657	2 258	8 091
	%	2	70	28	100
Total		197	8 235	3 598	12 030
%		2	68	30	100

APPENDIX 3.4.1

Detail soil data of physically irrigable soils of the Orange-Vaal and Orange-Riet irrigation areas, based on land type-information (ISCW, undated and MacVicar et al., 1977)

Land type	**Ae15**							
WUA area	**Orange-Riet**							
Area[7]	322 010							
Estimated area irrigable	0							
Geology	Red to flesh-coloured eolic sands of Tertiary to Recent age, with dolerite outcrops							
Soil series	**Depth**	**MB**	**Ha**	**%**	**Clay in A**	**Clay in B21**	**Fineness of sand**	**Depth limiting material**
Rock		4	36 226	11.2				
Mispah Ms10, Mangano Hu33	100 – 250	3	3 671	1.1	4 - 10	6 - 15	fine	R
Glendale Sd21, Bakkleysdrift Ss13, Craven Va21	100 – 250	4	1 964	0.6	8 - 15	35 45	fine	vr;pr
Mangano Hu33, Zwartfontein Hu34	700 – 1200	0	203 317	63.1	4 - 10	6 - 15	fine/medium	R;ka
Kalkbank Ms22, Mangano Hu33	100 – 450	3	29 979	9.3	4 - 10	6 - 15	fine	Ka
Annandale Cv33, Makuya Cv34, Blinkklip Cv36	600 – 1200	0	13 202	4.1	4 - 12	6 - 20	fine/medium	R;ka
Lindley Va41, Nyoka Sw41	100 – 300	0	9 306	2.9	8 - 20	35 - 50	fine	vp
Craven Va21, Bakklysdrift Ss13, Broekspruit Sw21	100 – 300	0	7 921	2.5	8 - 15	35 - 45	fine	vr;vp
Mispah Ms10	100 – 450	3	7 921	2.5	4 - 10		fine	R
Shorrocks Hu36	600 – 1200	0	5 281	1.6	8 - 15	15 - 25	Fine	R;ka
Dundee Du10, Killarney Ka20	450 – 900	0	3 220	1.0	15 - 40		Fine	R
Land type	**Ae277**							
WUA area	**Orange-Vaal**							
Area	6 610							
Estimated area irrigable	20							
Geology	Alluvium, sand and calcrete deposits overlying andecite and also conglomerate and sandstone both belonging to the Ventersdorp Supergroup							
Soil series	**Depth**	**MB**	**Ha**	**%**	**Clay in A**	**Clay in B21**	**Fineness of sand**	**Depth limiting material**
Rock		4	201	3.0				
Mangano Hu33, Zwartfontein Hu34, Shorrocks Hu36	>600	0	3 377	51.1	5 - 10	6 - 20	fine	R
Mangano Hu33, Zwartfontein Hu34, Shorrocks Hu36	100 – 300	3	1 589	24.0	5 - 10	6 - 20	fine	R
Mispah Ms10, Kalkbank Ms22	50 – 200	3	995	15.1	3 - 10		fine	R;ka
Annandale Cv33, Sunbury Cv30	>600	0	426	6.4	2 - 10	2 - 10	fine	R;ka
Rockford Oa14, Leeufontein Oa16	>1200	0	20	0.3	5- 10	10 - 20	medium	R;ka

[7] These areas are the total areas of the land type **within the boundaries of the map**. Except in cases where the boundary of a land type falls within the borders of the map, the actual area of the land types will be larger than shown in this table.

Land type	**Ah92**							
WUA area	**Orange-Vaal**							
Area	11 320							
Estimated area irrigable	226							
Geology	Sand, alluvium and calcrete overlying andecite, tillite and shale, sandstone and andecite; sand dunes occur sporadically							
Soil series	**Depth**	**MB**	**Ha**	**%**	**Clay in A**	**Clay in B21**	**Fineness of sand**	**Depth limiting material**
Rock		4	170	1.5				
Annandale Cv33, Vaalbank Cv43, Dudfield Cv46	>600	0	3 764	33.3	3 - 10	6 - 20	fine	ca;ka
Mangano Hu33, Lowlands Hu40, Roodepoort Hu30, Annandale Cv33	50 – 250	3	2 944	26.0	3 - 15	3 - 15	fine	R;ka
Mangano Hu33, Roodepoort Hu30, Lowlands Hu40	>600	0	2 320	20.5	2 - 10	3 - 15	fine	R;ka
Mispah Ms10, Kalkbank Ms22	50 – 250	3	1 697	15.0	3 - 15		fine	R;ka
Limpopo Oa46, Letaba Oa26	>1200	0	226	2.0	10 - 20	15 - 25	fine	
Valsrivier Va40, Zuiderzee Va20	700 – 1200	0	198	1.7	15 - 20	25 - 35	fine	ca;so

Land type	**Ia126**							
WUA area	**Orange-Riet**							
Area	23 990							
Estimated area irrigable	14 681	(Possible)						
Geology	Alluvium on shale of the Ecca Group, Karoo Sequence. Also dolerite							
Soil series	**Depth**	**MB**	**Ha**	**%**	**Clay in A**	**Clay in B21**	**Fineness of sand**	**Depth limiting material**
Rock		4	480	2.0				
Vaalrivier Oa33, Jozini Oa36	1000 – 1200	0	7 844	32.7	6 - 15	10 – 20	Fine	Ca
Limpopo Oa46, Mutale Oa47	1000 – 1200	0	6 837	28.5	10 - 20	25 - 45	Fine	Ca
Valsrivier Va40, Lindley Va41	>1200	0	3 599	15.0	10 - 20	30 - 45	Fine	
Annandale Cv33, Blinkklip Cv36	800 – 1200	0	2 543	10.6	6 - 15	10 - 20	Fine	R;ca
Mangano Hu33, Shorrocks Hu36	600 – 1200	0	1 008	4.2	6 - 15	10 - 20	Fine	R;ca
Mispah Ms10	10 – 100	3	480	2.0	10 - 20		Fine	R
Mangano Hu33, Shorrocks Hu36	100 – 300	0	360	1.5	6 - 15	10 - 20	fine	R;ca
Stream beds		4	840	3.5				

Land type	**Ia3**							
WUA area	**Orange-Vaal and Orange-Riet**							
Area	15 910							
Estimated area irrigable	10 341							
Geology	Alluvium of Tertiary to Recent age							
Soil series	**Depth**	**MB**	**Ha**	**%**	**Clay in A**	**Clay in B21**	**Fineness of sand**	**Depth limit-ing material**
Dundee Du10	>1200	0	7 477	47.0	8 - 30		fine	
Limpopo Oa46	>1200	0	1 830	11.5	6 - 15	15 - 35	fine	
Mutale Oa47	>1200	0	1 034	6.5	25 - 35	35 - 50	fine	
Jozini Oa36	>1200	0	1 034	6.5	6 - 15	15 - 35	fine	
Annandale Cv33, Makuya Cv34	900 – 1200	0	620	3.9	4 - 12	6 - 15	fine/medium	R;ka
Blinkklip Cv36	900 – 1200	0	525	3.3	8 - 15	15 - 35	fine	R;ka
Mangano Hu33, Zwartfontein Hu34	900 – 1200	0	414	2.6	4 - 12	6 - 15	fine/medium	R;ka
Shorrocks Hu36	900 – 1200	0	302	1.9	8 - 15	15 - 35	fine/medium	R;ka
Mispah Ms10, Loskop Ms12, Kalkbank Ms22, Muden Ms20	100 – 300	3	239	1.5	6 - 15		fine	R;ka
Summerhill Cv37	900 – 1200		206	1.3	25 - 35	35 - 45	fine	R;ka
Stream bed		4	2 227	14.0				
Land type	**Ia4**							
WUA area	**Orange-Riet**							
Area	11 420							
Estimated area irrigable	555							
Geology	Alluvium of Tertiary to Recent age							
Soil series	**Depth**	**MB**	**Ha**	**%**	**Clay in A**	**Clay in B21**	**Fineness of sand**	**Depth limit-ing material**
Rock, Mispah Ms10, Mangano Hu33		4	154	1.3				
Shorrocks Hu36	100 – 250	3	46	0.4	8 - 20	10 - 25	fine	R
Glendale Sd21, Rasheni Bo21, Glengazi Bo31, Skilderkrans Sw11	150 – 250	3	28	0.2	10 - 40	35 - 55	fine	R
Limpopo Oa46, Jozini Oa36, Mutale Oa47, Koedoesvlei Oa37	900 – 1200	0	3 774	33.0	10 - 20	15 - 40	fine	R
Lindley Va41, Sheppardvale Va42	200 – 300	0	1 759	15.4	10 - 25	40 - 60	fine	Vp
Leeufontein Oa16, Letaba Oa26	900 – 1200	0	1 222	10.7	10 - 20	15 - 30	fine	R
Swartland Sw31, Nyoka Sw41,								
Omdraai Sw42	100 – 250	0	731	6.4	10 - 25	40 - 60	fine	So
Arniston Va31	200 – 300	0	731	6.4	10 - 25	35 - 55	fine	Vp
Dundee Du10	>1200	0	555	4.9	15 - 50		fine	R
Valsrivier Va40, Herschel Va40	200 – 300	0	468	4.1	8 20	25 - 35	fine	Vp
Loskop Ms12, Kalkbank Ms22	150 – 300		457	4.0	10 - 25		fine	R;ka
Sterkspruit Ss26	150 – 250	0	274	2.4	15 - 20	40 - 55	fine	Vp
Craven Va21, Marienthal Va22	200 – 300	0	274	2.4	10 - 25	40 - 60	fine	Vr
Shorrocks Hu36, Shigalo Hu46	450 – 900	0	183	1.6	10 - 18	15 - 25	fine	R;ka
Mangano Hu33, Maitengwe Hu43	600 – 1200	0	183	1.6	6 - 12	8 - 15	fine	R;ka
Stanford Ss23	150 – 250	0	183	1.6	8 - 12	35 - 50	fine	Vp
Dudfield Cv46	600 – 1200	0	91	0.8	6 - 12	8 - 15	fine	R;ka
Stream beds		4	308	2.7				

Key:

ML: Mechanical limitation, prevalence of stones and of serious depth limitations

- 0: No limitation
- 1: Abundant stones, ploughable
- 2: Big stones and rocks, unploughable
- 3: Very shallow on rock
- 4: No soil

Depth limiting material:

- Ca: an accumulation of carbonates of alkali-earth metals, usually calcium.
- Ka: a hardened material cemented by calcium carbonate (calcrete).
- R: rock.
- Pr: a material that is not gleyed clay, with a strong prismatic developed columnar structure (usually coarse).
- So: weathered rock that, although unconsolidated, still has easily visible geogenic characteristics (saprolite).
- Vp: soil material which is not gleyed and the colour is not predominantly red, with structure of at least moderate developed blocks in the moist condition.
- Vr: soil material which is predominantly red with structure which is at least moderately developed blocks in the moist condition.

Note: Irrigable soil

Irrigable soil, as indicated, is based on broad soil surveys and general physical irrigability norms. Detail surveys, survey-specific irrigation classification and judgement which includes chemical norms, can indicate other areas than the above.

General physical irrigability norms on profile depth of 1200 mm:

1. No depth limiting layers.
2. Clay-content >6 and <35.
3. Structural development weaker than moderately developed blocks in the moist condition.
4. No mechanical limitation within ploughing depth.

APPENDIX 3.4.2

IRRIGATION POTENTIAL OF IRRIGABLE SOIL AS PERCEIVED BY THE RESPONDENTS

WUA	Sub area	High	Medium	Low	Total
Orange-Riet WUA	Sub area 1	94	5	1	100
	Sub area 2	68	32	0	100
	Sub area 3	48	51	1	100
	Total	**64**	**36**	**1**	**100**
Orange-Vaal WUA	Sub area 1 (Olierivier)	73	14	13	100
	Sub area 2 (Vaallus)	41	59	0	100
	Sub area 3 (Atherton)	76	24	0	100
	Sub area 4 (Bucklands)	0	50	50	100
	Sub area 5 (New Bucklands)	83	16	1	100
	Total	**51**	**36**	**13**	**100**
Grand total		**55**	**36**	**9**	**100**

APPENDIX 3.4.3

WATER LOGGING AND SALINISATION

Area and sub area	**Degree of water logging and salinisation**	
	Moderate[8] (%)	**Serious[9] (%)**
Orange-Riet WUA		
Sub area 1	7	0
Sub area 2	0	0
Sub area 3	30	10
Average for sub area	**15**	**5**
Orange-Vaal WUA		
Sub area 1 (Olierivier)	16	4
Sub area 2 (Vaallus)	40	40
Sub area 3 (Atherton)	5	0
Sub area 4 (Bucklands)	5	3
Sub area 5 (New Bucklands	0	2
Average for sub area	**15**	**20**
Average for study area	**12**	**19**

8 Moderate water logging and salinisation: Agricultural production can still take place, but that production potential is suppressed and/or crop choice is limited.

9 Serious water logging and salinisation: Agricultural production can no longer take place without special corrective measures, such as artificial drainage and/or the application of gypsum.

APPENDIX 4.1

THE INFLUENCE OF SOIL POTENTIAL ON CHOICE OF CROP TYPE

WUA	Sub area	High			Medium			Low			Total
		Pastures	Field crops, Vineyards, Fruit, Horti-culture, Hay, Silage	Total	Pastures	Field crops, Vineyards, Fruit, Horti-culture, Hay, Silage	Total	Pastures	Field crops, Vineyards, Fruit, Horti-culture, Hay, Silage	Total	Grand Total
Orange-Riet WUA	Sub area 1	0	682	682	0	36	36	6	0	6	**724**
	Sub area 2	0	937	937	40	400	440	0	0	0	**1 377**
	Sub area 3	0	884	884	50	884	934	20	0	20	**1 838**
	Total	**0**	**2 503**	**2 503**	**90**	**1 320**	**1 410**	**26**	**0**	**26**	**3 939**
Orange-Vaal WUA	Sub area 1 (Olierivier)	20	2 256	2 276	0	447	447	20	382	402	**3 125**
	Sub area 2 (Vaallus)	80	1 000	1 080	48	1 531	1 579	0	0	0	**2 659**
	Sub area 3 (Atherton)	0	266	266	16	67	83	0	0	0	**349**
	Sub area 4 (Bucklands)	0	0	0	13	664	677	0	664	664	**1 341**
	Sub area 5 (New Bucklands	0	510	510	0	100	100	7	0	7	**617**
	Total	**100**	**4 032**	**4 132**	**77**	**2 809**	**2 886**	**27**	**1 046**	**1 073**	**8 091**
Total		**100**	**6 535**	**6 635**	**167**	**4 129**	**4 296**	**53**	**1 046**	**1 099**	**12 030**

APPENDIX 4.2

SUMMARY OF PRESENT CROP PRODUCTION IN THE STUDY AREA

Crop	**Orange-Riet WUA**		**Orange-Vaal WUA**		**Total**	
	Ha	%	Ha	%	Ha	%
Wheat	2 604	66.1	4 156	51.4	6 759	56.2
Maize	909	23.1	2 594	32.1	3 503	29.1
Lucerne	355	9.0	1 361	16.8	1 715	14.3
Potatoes	539	13.7	423	5.2	962	8.0
Sunflowers	434	11.0	367	4.5	801	6.7
Cotton	129	3.3	303	3.7	431	3.6
Ground nuts	271	6.9	150	1.8	421	3.5
Vineyards	29	0.7	271	3.3	300	2.5
Onions	122	3.1	159	2.0	281	2.3
Carrots	74	1.9	207	2.6	281	2.3
Pastures (perennial)	74	1.9	188	2.3	262	2.2
Pastures (annual)	43	1.1	133	1.6	176	1.5
Dry beans	96	2.4	31	0.4	128	1.1
Beetroot	0	0.0	87	1.1	87	0.7
Cucurbits	53	1.3	34	0.4	87	0.7
Pecan nuts	0	0.0	53	0.7	53	0.4
Sweet corn	51	1.3	0	0.0	51	0.4
Cabbage	32	0.8	0	0.0	32	0.3
Pumpkins	0	0.0	31	0.4	31	0.3
Scheduled	**3 939**	**147.6**	**8 091**	**130.4**	**12 030**	**136.0**

APPENDIX 4.3

PRESENT CROP PRODUCTION IN THE STUDY AREA

Crop	Product	Planting date	Growing season	%	Soil potential High	Medium	Low
Orange-Riet WUA							
Sub area 1							
Ha scheduled: 724							
Wheat	Wheat	07/15	140	45	95	5	0
Potatoes	Table potatoes	01/10	120	25	100	0	0
Lucerne	Hay	08/01	365	16	95	5	0
Maize	Maize	12/15	120	15	95	5	0
Sunflower	Sunflower seed	01/01	100	13	95	5	0
Onions	Onions (fresh market)	04/01	180	8	100	0	0
Pastures (annual)	Pasture	03/01	180	6	100	0	0
Potatoes	Table potatoes	09/15	120	5	100	0	0
Maize	Maize	11/01	150	4	95	5	0
Vineyards	Wine grapes	08/01	365	4	95	5	0
Cucurbits	Pumpkin, water melon, melon	09/15	90	1	100	0	0
				142			

APPENDIX 4.3 (Continued)

PRESENT CROP PRODUCTION IN THE STUDY AREA

Crop	Product	Planting date	Growing season	%	Soil potential High	Medium	Low
Orange-Riet WUA							
Sub area 2							
Ha scheduled: 1377							
Wheat	Wheat	07/15	140	88	70	30	0
Maize	Maize	12/10	130	24	70	30	0
Sunflower	Seed	01/10	90	18	70	30	0
Potatoes	Seed & Table	10/01	120	6	100	0	0
Cotton	Cotton	10/15	170	4	0	100	0
Lucerne	Hay	08/01	365	4	0	100	0
Dry beans	Seed	01/01	90	3	70	30	0
Ground nuts	Ground nuts	12/10	120	3	100	0	0
Ground nuts	Ground nuts	10/15	150	2	100	0	0
Onions	Onions (fresh market)	04/15	180	2	100	0	0
Cucurbits	Pumpkin, water melon, melon	08/30	150	2	100	0	0
Cabbage	Cabbage	07/01	90	1	70	30	0
Sweet corn	Green mealies (fresh market)	12/10	90	1	0	0	0
				158			

APPENDIX 4.3 (Continued)

PRESENT CROP PRODUCTION IN THE STUDY AREA

Crop	Product	Planting date	Growing season	%	Soil potential High	Medium	Low
Orange-Riet WUA							
Sub area 3							
Ha scheduled: 1838							
Wheat	Wheat	07/01	140	58	50	50	0
Maize	Maize	12/15	120	22	50	50	0
Potatoes	Potatoes	01/15	120	13	100	0	0
Ground nuts	Ground nuts	10/31	150	11	100	0	0
Lucerne	Hay	08/01	365	10	0	100	0
Sunflower	Seed	01/10	100	5	0	100	0
Carrots	Carrots (fresh market)	09/15	120	4	100	0	0
Pastures (perennial	Pasture	08/01	365	4	0	50	50
Cotton	Cotton	10/15	170	4	0	100	0
Dry beans	Dry beans	01/7	90	3	50	50	0
Sweet corn	Green mealies (fresh market)	12/31	90	2	50	50	0
Onions	Onions (fresh market)	04/15	180	2	100	0	0
Maize	Maize	10/31	150	2	50	50	0
Cabbage	Cabbage (fresh market)	03/15	150	1	0	100	0
Cucurbits	Pumpkin, water melon, melon	08/15	120	1	100	0	0
				142			

APPENDIX 4.3 (Continued)

PRESENT CROP PRODUCTION IN THE STUDY AREA

Crop	Product	Planting date	Growing season	%	Soil potential High	Medium	Low
Orange-Vaal WUA							
Sub area 1 (Olierivier)							
Ha scheduled: 3125							
Wheat	Wheat	07/15	140	60	73	15	12
Maize	Maize	12/15	130	44	73	15	12
Lucerne	Hay	08/01	365	21	73	15	12
Potatoes	Seed & Table	01/10	120	7	100	0	0
Cotton	Cotton	10/15	150	5	73	15	12
Ground nuts	Ground nuts	10/15	120	4	73	15	12
Carrots	Carrots (fresh market)	09/15	120	4	100	0	0
Onions	Onions (fresh market)	04/15	180	3	100	0	0
Beetroot	Beetroot	09/01	90	2	100	0	0
Pastures (perennial	Pasture	08/01	365	1	50	0	50
Dry beans	Bone	01/10	120	1	100	0	0
Vineyards	Wine grapes	08/01	365	1	100	0	0
				153			

APPENDIX 4.3 (Continued)

PRESENT CROP PRODUCTION IN THE STUDY AREA

Crop	Product	Planting date	Growing season	%	Soil potential High	Medium	Low
Orange-Vaal WUA							
Sub area 2 (Vaallus)							
Ha scheduled: 2659							
Wheat	Wheat	07/15	140	58	40	60	0
Maize	Maize	12/15	130	25	40	60	0
Sunflower	Sunflower seed	01/10	100	12	40	60	0
Potatoes	Seed & Table	01/10	120	7	100	0	0
Pastures (perennial	Pasture	08/01	365	5	40	60	0
Cotton	Cotton	10/15	150	5	40	60	0
Pastures (annual)	Pasture	03/15	150	5	0	100	0
Lucerne	Hay	08/01	365	5	40	60	0
Vineyards	Wine grapes	08/01	365	3	100	0	0
Pecan nuts	Pecan nuts	08/01	365	2	100	0	0
Onions	Onions (fresh market)	04/15	180	2	100	0	0
Carrots	Carrots (fresh market)	09/15	120	1	100	0	0
Cucurbits	Pumpkin, water melon, melon	10/15	100	1	100	0	0
				131			

APPENDIX 4.3 (Continued)

PRESENT CROP PRODUCTION IN THE STUDY AREA

Crop	Product	Planting date	Growing season	%	Soil potential High	Medium	Low
Orange-Vaal WUA							
<u>Sub area 3 (Atherton)</u>							
<u>Ha scheduled: 349</u>							
Lucerne	Hay	08/01	365	39	80	20	0
Wheat	Wheat	07/15	140	27	80	20	0
Vineyards	Wine grapes	08/01	365	23	100	0	0
Maize	Maize	12/15	130	15	80	20	0
Sunflower	Sunflower seed	01/10	100	10	80	20	0
Pastures (perennial	Pasture	08/01	365	3	0	100	0
Cucurbits	Pumpkin, watermelon, melon	10/15	100	2	100	0	0
				119			
<u>Sub area 4 (Bucklands)</u>							
<u>Ha scheduled: 1341</u>							
Lucerne	Hay	08/01	365	32	0	50	50
Wheat	Wheat	07/15	140	8	0	50	50
Maize	Maize	12/15	130	8	0	50	50
Vineyards	Wine grapes	08/01	365	5	0	100	0
Pastures (perennial	Pasture	08/01	365	1	0	100	0
Cotton	Cotton	10/15	150	1	0	50	50
Sunflower	Sunflower seed	01/15	100	1	0	50	50
				56			

APPENDIX 4.3 (Continued)

PRESENT CROP PRODUCTION IN THE STUDY AREA

Crop	Product	Planting date	Growing season	%	Soil potential High	Medium	Low
Orange-Vaal WUA							
Sub area 5 (New Bucklands							
Ha scheduled: 617							
Wheat	Wheat	07/15	140	87	84	16	0
Maize	Maize	12/15	130	64	84	16	0
Carrots	Carrots (fresh market)	08/15	120	9	84	16	0
Pumpkins	Pumpkins	10/15	100	5	84	16	0
Beetroot	Beetroot	08/01	60	4	84	16	0
Ground nuts	Ground nuts	12/15	130	4	84	16	0
Potatoes	Seed & Table	01/10	120	3	84	16	0
Vineyards	Wine grapes	08/01	365	2	84	16	0
Onions	Onions (fresh market)	04/15	180	2	84	16	0
Lucerne	Hay	08/01	365	1	84	16	0
				181			

APPENDIX 4.4

COMPARISON OF PRESENT CROP PRODUCTION AND THAT OF 1990 IN THE STUDY AREA

Crop	**Orange-Riet WUA**		**Orange-Vaal WUA**	
Year	1990 %	1999 %	1990 %	1999 %
Wheat	59.6	66.1	76.0	51.4
Maize	14.0	23.1	38.0	32.1
Lucerne	11.5	9.0	5.0	16.8
Potatoes	14.0	13.7	19.0	5.2
Sunflower		11.0		4.5
Cotton	6.3	3.3	38.0	3.7
Ground nuts		6.9		1.8
Vineyards	5.7	0.7		3.3
Onions		3.1		2.0
Carrots	0.4	1.9		2.6
Pastures (perennial	3.8	1.9		2.3
Pastures (annual)		1.1		1.6
Dry beans		2.4		0.4
Beetroot		0.0		1.1
Cucurbits	0.4	1.3		0.4
Pecan nuts		0.0		0.7
Sweet corn		1.3		0.0
Cabbage		0.8		0.0
Pumpkins		0.0		0.4
Soy beans	1.6	0.0		0.0
Total	**115.7**	**147.6**	**176.0**	**130.4**

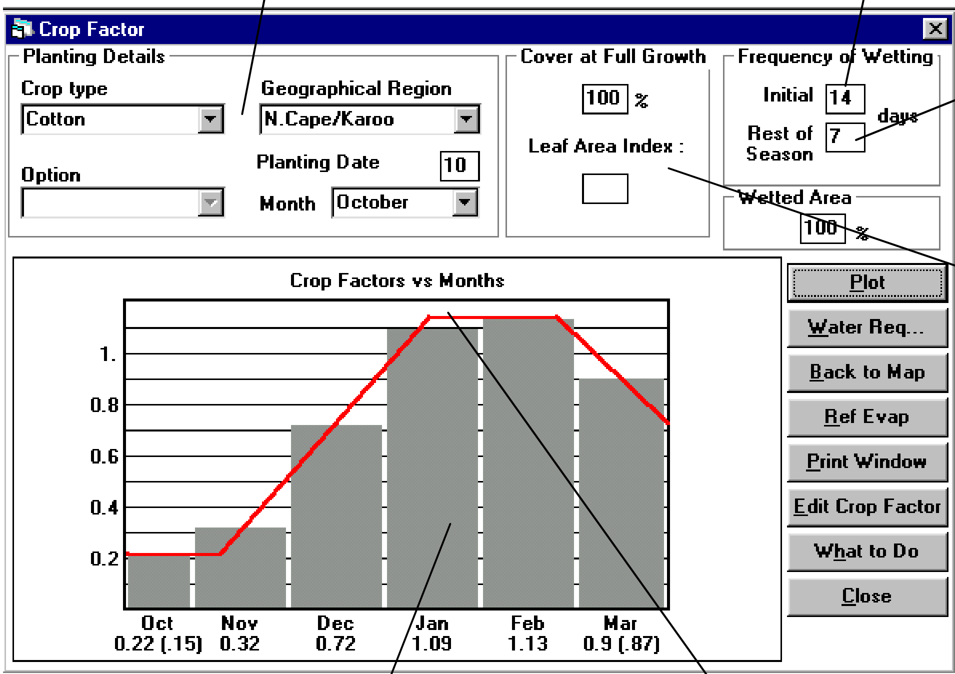
APPENDIX 5.6.6.1

EXAMPLE: CROP FACTOR SCREEN

The menus define the crop, the area and production practices. The windows in the left top corner is for selection of the crop, a cultivar, the geographic position and the planting date.

In the case of some crops, the frequency of wetting at the beginning is important because of evaporation losses. It is expected that there will be a limited requirement of water because the crop is planted in wet soil.

The "rest of season" frequency is determined by crop-characteristics and system-configuration



The elements "cover at full growth" and "wetted area" can be ignored for most row crops under centre pivot irrigation.

The 4-stage FAO crop factor curve helps with judgement. One can look at the screen and compare it against the growing pattern of the crop. For example, how fast does the foliage develop, or how long is the growing season? Here we have a growing season of 90 days. The curve is developed in accordance with practical experience. It must be discussed and edited.

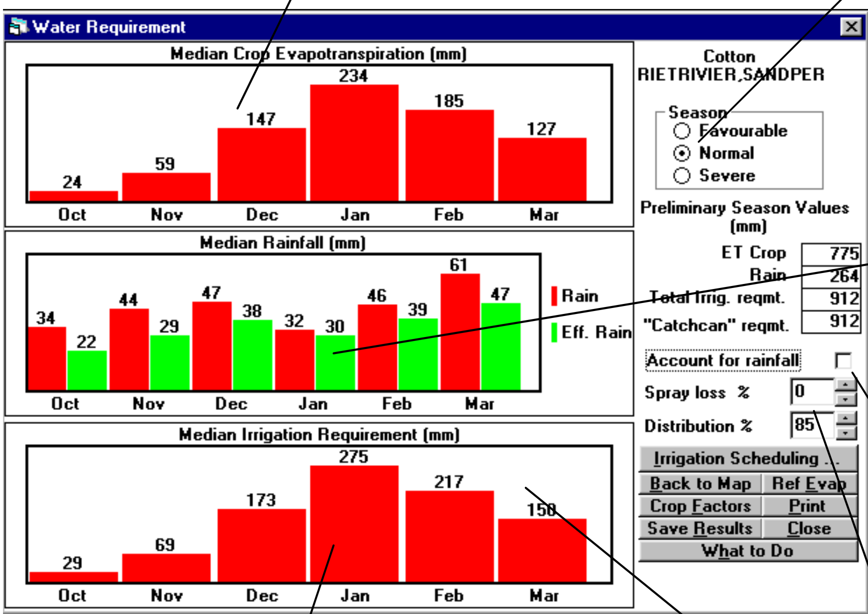
In conjunction with present approaches, the crop factors are developed for calendar months. The red line is the curve of daily values that is built into all calculations and outputs.

APPENDIX 5.6.6.2

EXAMPLE: WATER REQUIREMENT-SCREEN

SAPWAT calculates evapotranspiration (ET_{crop}) by making use of weather data in the countrywide database and crop-characteristics, which are stored in the crop files. This value is usually not applied unedited by practitioners.

There is an option to select a "normal" season, but to evaluate the effect of climate, a one-in-five year "favorable" or "severe" season can also be selected.



It is general practice in the study area to ignore rain and thus to build in a safety factor. It makes sense to see what rain can contribute. By not considering rainfall, automatic compensation for spray and other losses take place. Rainfall is counted as irrigation

Rainfall can be included in or excluded from the calculation of irrigation requirement. In this example, rainfall is excluded from the calculation, even though a rainfall figure shown in the table of values

Most of the information required for planning is available on this screen. The monthly irrigation requirements for each crop in the study area can be read off this screen and can be filled in on a planning spreadsheet for further processing. If optional planting dates must be considered, the date in the crop factor-screen can be changed. The graphs and data on this screen will be updated automatically.

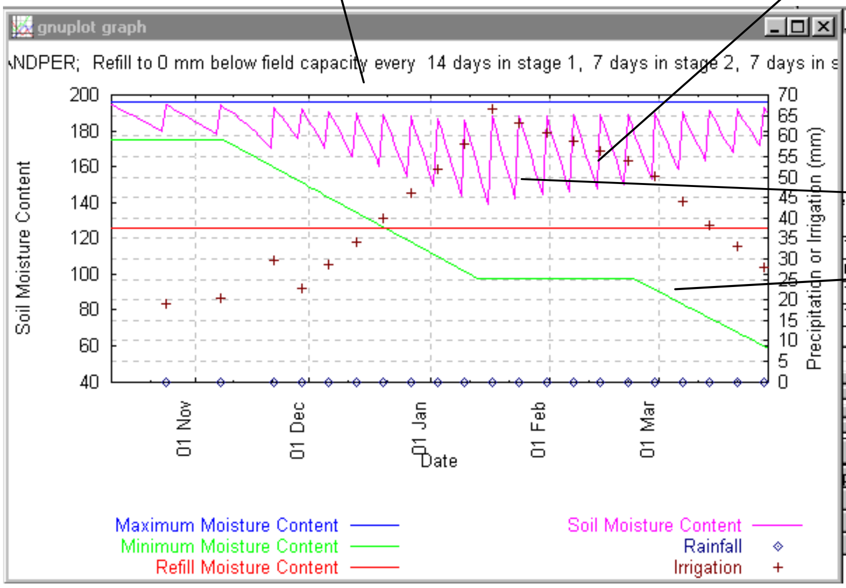
Spray losses are set as "zero" when working with "water in the rain gauge". The distribution efficiency is set at 85% to convert ET_{crop} to irrigation requirement.

APPENDIX 5.6.6.3

EXAMPLE: WEEKLY WATER REQUIREMENT SCREEN

In an arid area where rain does not have a big impact, it is possible to develop a weekly crop water requirement plan. Such plans can guide both the farmers and water mangers when water must be ordered. The values are obtained by asking SAPWAT in scheduling mode to fill the soil profile weekly to field capacity. Set distribution efficiency at 85% and spray losses at 0% to reflect an ideal situation out of a scheduling point of view. If re-quired, allowance can be made for spray losses.

The red crosses show the weekly requirement. The pattern of the crosses helps to form an image of water requirement over the season. Each crop has its own pattern.



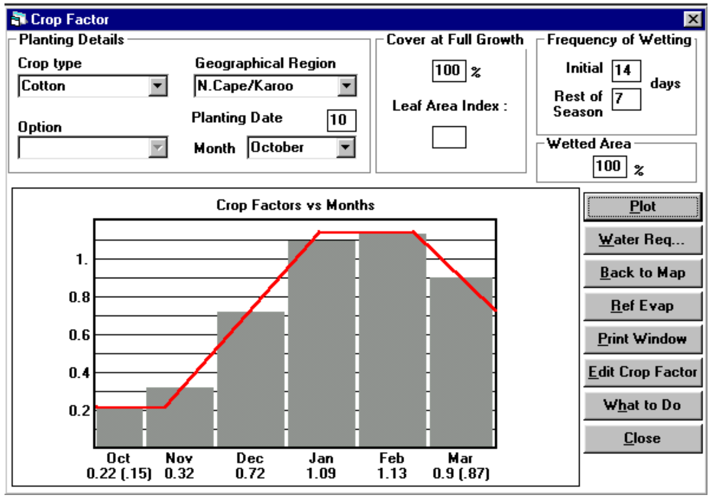
The aim in the study area is to keep the soil water content as close to field capacity as possi-ble. The allowable dep-letion is usually about 60 mm. In this example it represents the weekly requirement during the peak period in January. Under centre pivots in the study area one irri-gation of 60 mm is not possible. In practice a number of 12 to 20 mm irrigations are applied per week.

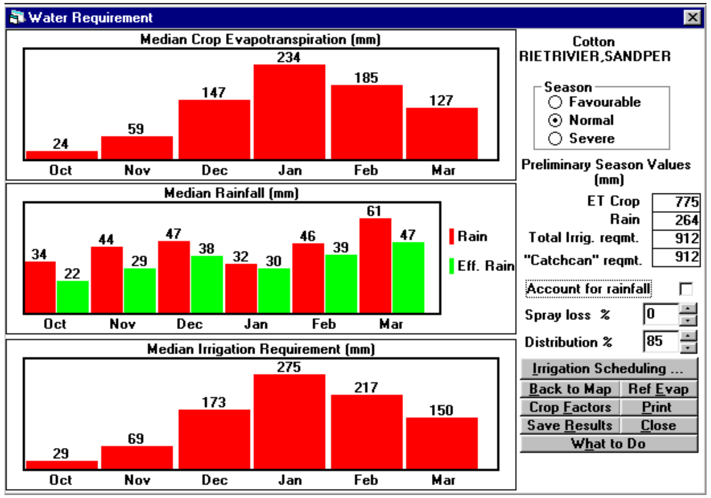
Weeks after plant	Date	Irrigation (mm/week)
2	25-Oct-00	10
4	8-Nov-00	11
6	22-Nov-00	15
7	29-Nov-00	23
8	6-Dec-00	29
9	13-Dec-00	34
10	20-Dec-00	40
11	27-Dec-00	46
12	3-Jan-01	52
13	10-Jan-01	58
14	17-Jan-01	67
15	24-Jan-01	63
16	31-Jan-01	61
17	7-Feb-01	59
18	14-Feb-01	56
19	21-Feb-01	54
20	28-Feb-01	50
21	7-Mar-01	44
22	14-Mar-01	38
23	21-Mar-01	33
24	28-Mar-01	28

The same information is also available in table format.

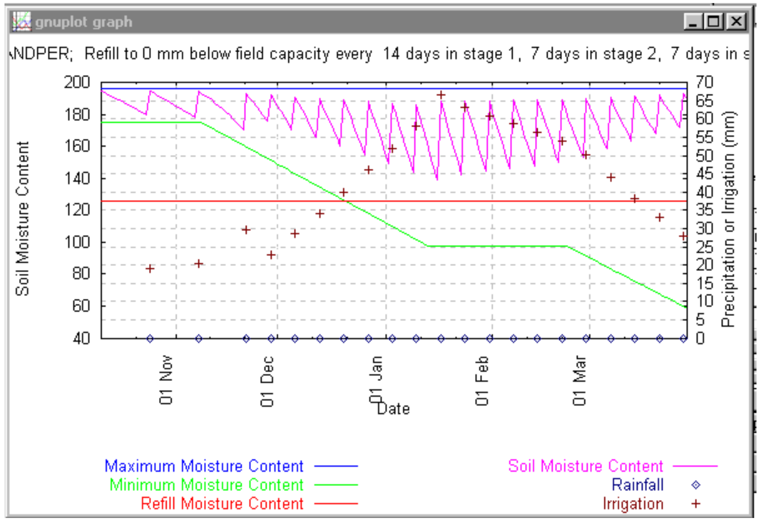
APPENDIX 5.6.6.4

EXAMPLE: MONTHLY AND WEEKLY WATER REQUIREMENT OF COTTON
Planting date 10 October, rainfall not considered, water in rain gauge





Weeks after plant	Date	Irrigation (mm/week)
2	25-Oct-00	10
4	8-Nov-00	11
6	22-Nov-00	15
7	29-Nov-00	23
8	6-Dec-00	29
9	13-Dec-00	34
10	20-Dec-00	40
11	27-Dec-00	46
12	3-Jan-01	52
13	10-Jan-01	58
14	17-Jan-01	67
15	24-Jan-01	63
16	31-Jan-01	61
17	7-Feb-01	59
18	14-Feb-01	56
19	21-Feb-01	54
20	28-Feb-01	50
21	7-Mar-01	44
22	14-Mar-01	38
23	21-Mar-01	33
24	28-Mar-01	28



APPENDIX 7.2.1.1 & 7.2.1.2

WATER REQUIREMENTS OF THE MOST IMPORTANT CROPS

The figures that follow, show how the estimated water requirement for the most important crops in the study area were determined with the aid of SAPWAT. The calculations are based on the following assumptions, which are a reflection of management practices applied in the area:

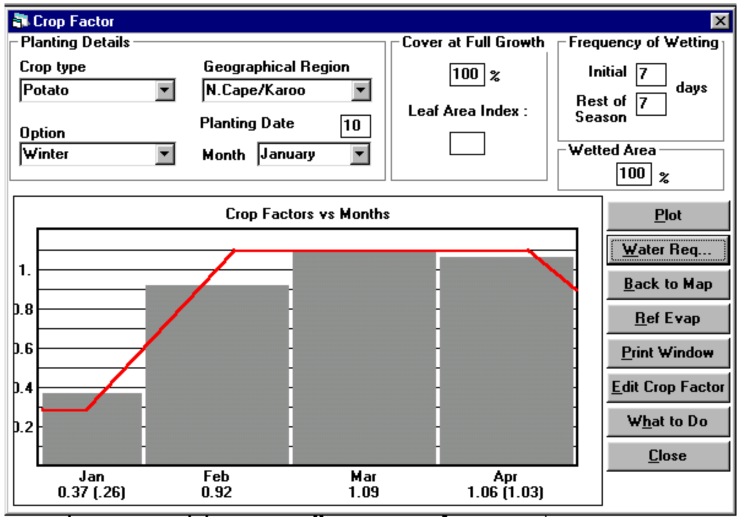
- a normal climatic year is used
- rainfall is not taken into account
- a distribution efficiency of 85% and spray losses of 10% are used as defaults for the area because centre pivot systems are the most important irrigation method and because it does seem as if the results obtained agree to a large extent, with the overall values used by the WUAs, which include efficiency factors
- where planting dates differ within reasonable bounds, the planting dates were reduced to a single date in order to reduce the number of calculations to a manageable level
- weekly irrigation cycles were used because it is the general pattern found in the study area in relation to scheduling services and water ordering.

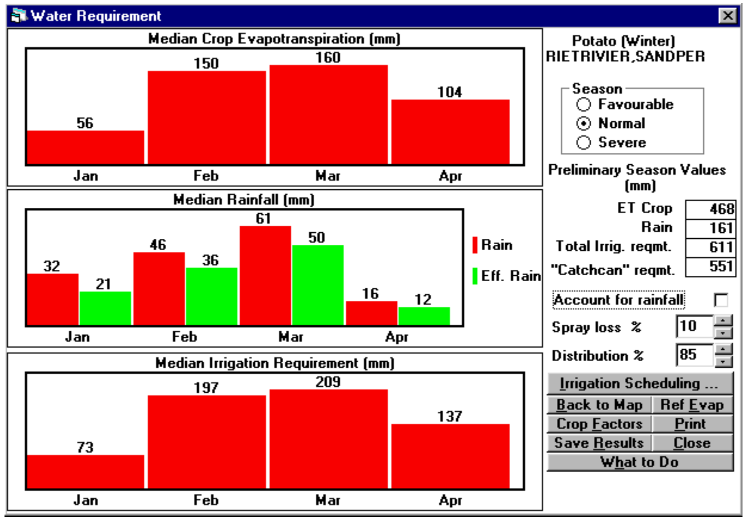
It must be kept in mind that calculations done by the WUAs and water delivered to the irrigators represent only one season, while the SAPWAT calculations are based on long term average data. Therefore differences can be expected and such differences do not necessarily represent faulty calculations.

The resultant estimated irrigation requirements show the quantity water that must be delivered to a farmer at his farm boundary to ensure that the crop receives the required water.

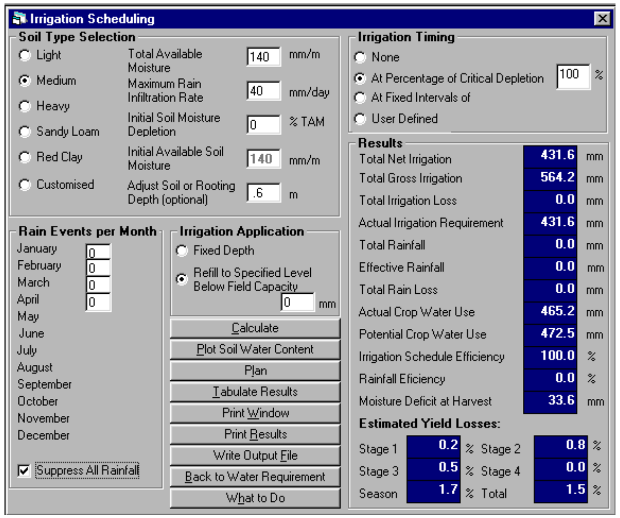
APPENDIX 7.2.1.1

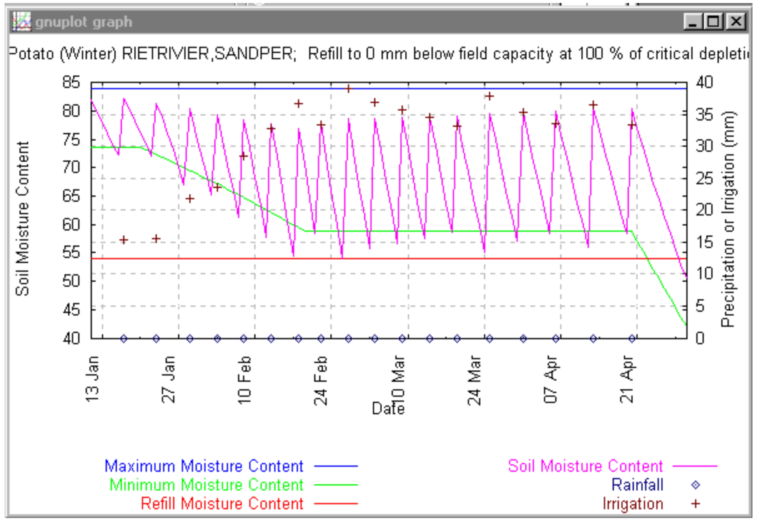
Orange-Riet WUA : Potatoes : 10 January : Without rain



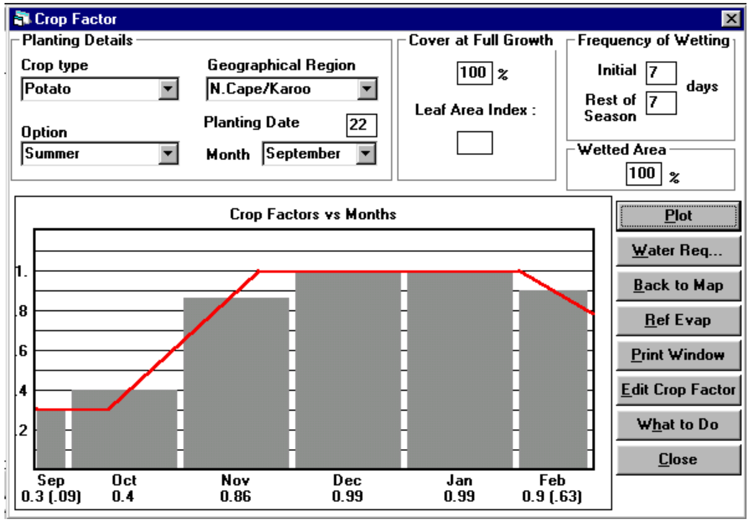


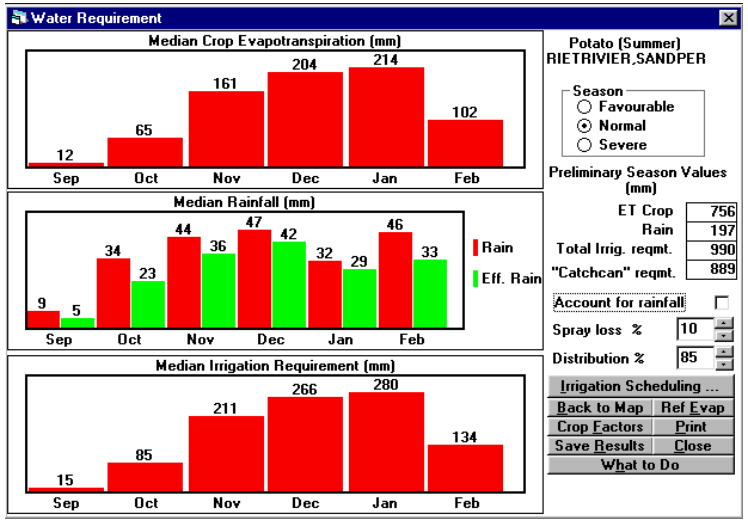
Date	Irrigation
17-Jan-00	16
23-Jan-00	16
29-Jan-00	22
03-Feb-00	24
08-Feb-00	29
13-Feb-00	33
18-Feb-00	37
22-Feb-00	34
27-Feb-00	39
04-Mar-00	37
09-Mar-00	36
14-Mar-00	35
19-Mar-00	33
25-Mar-00	38
31-Mar-00	35
06-Apr-00	34
13-Apr-00	37
20-Apr-00	33



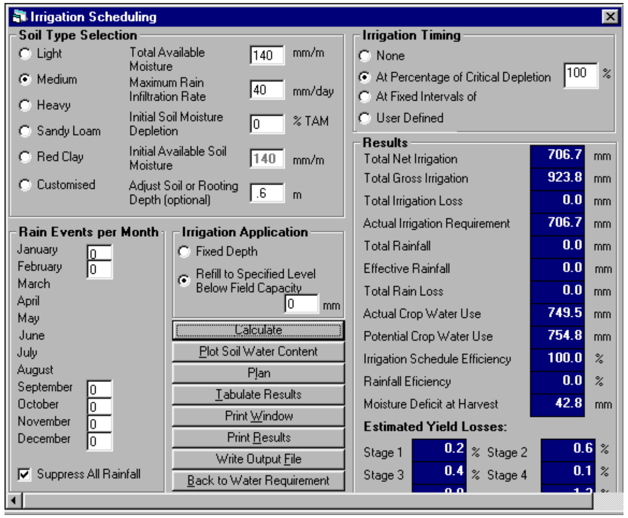


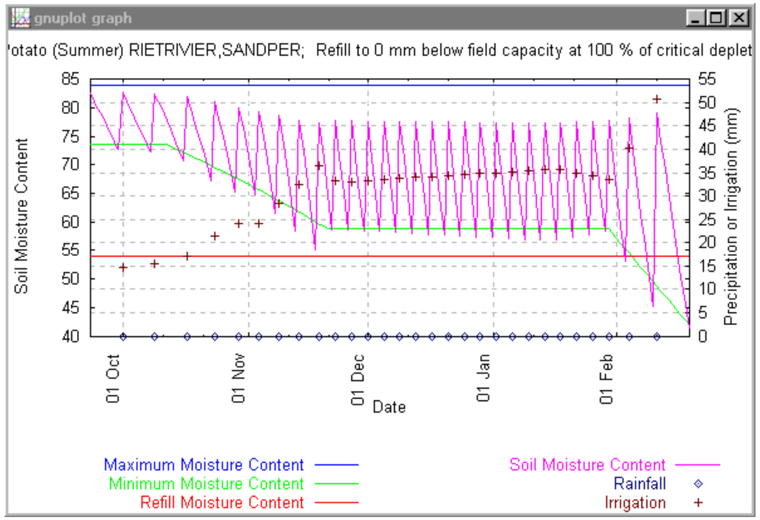
Orange-Riet WUA : Potatoes : 22 September : Without rain



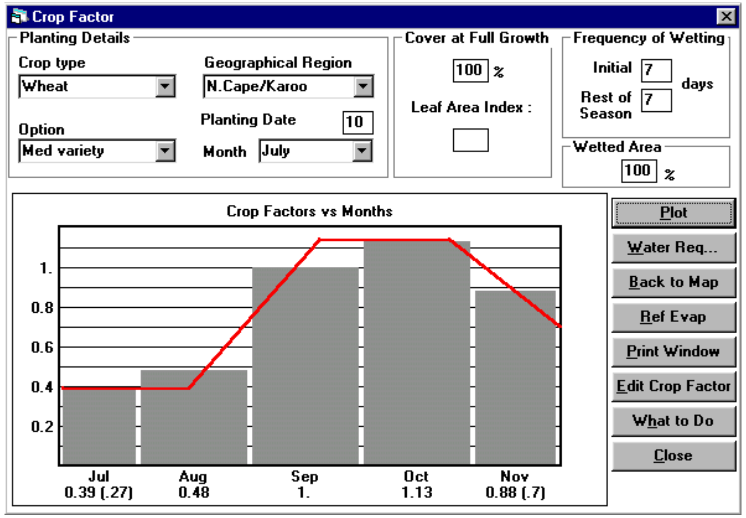


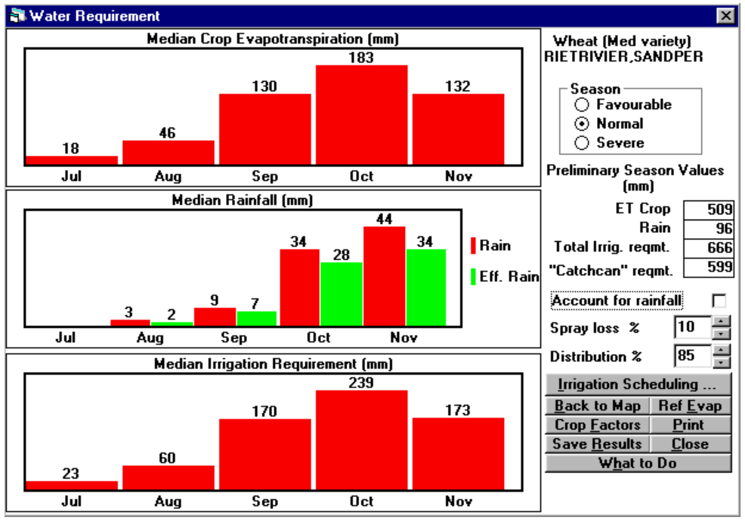
Date	Irrigation
01-Oct-00	15
09-Oct-00	16
17-Oct-00	17
24-Oct-00	22
30-Oct-00	24
04-Nov-00	24
09-Nov-00	28
14-Nov-00	33
19-Nov-00	37
23-Nov-00	33
27-Nov-00	33
01-Dec-00	33
05-Dec-00	34
09-Dec-00	34
13-Dec-00	34
17-Dec-00	34
21-Dec-00	34
25-Dec-00	35
29-Dec-00	35
02-Jan-01	35
06-Jan-01	35
10-Jan-01	35
14-Jan-01	36
18-Jan-01	36
22-Jan-01	35
26-Jan-01	34
30-Jan-01	34
04-Feb-01	40
11-Feb-01	51



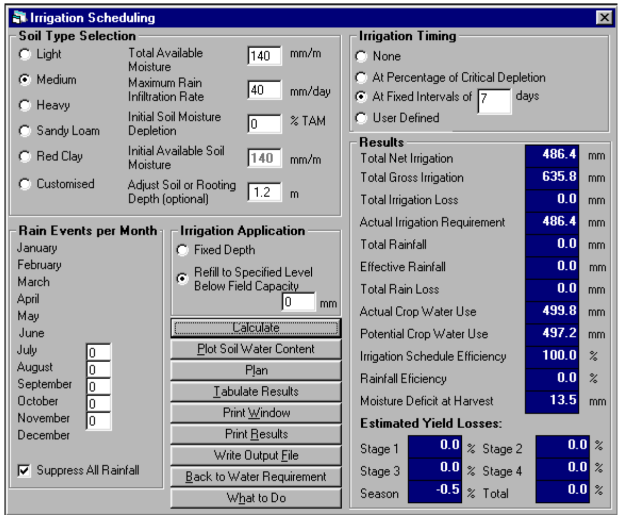


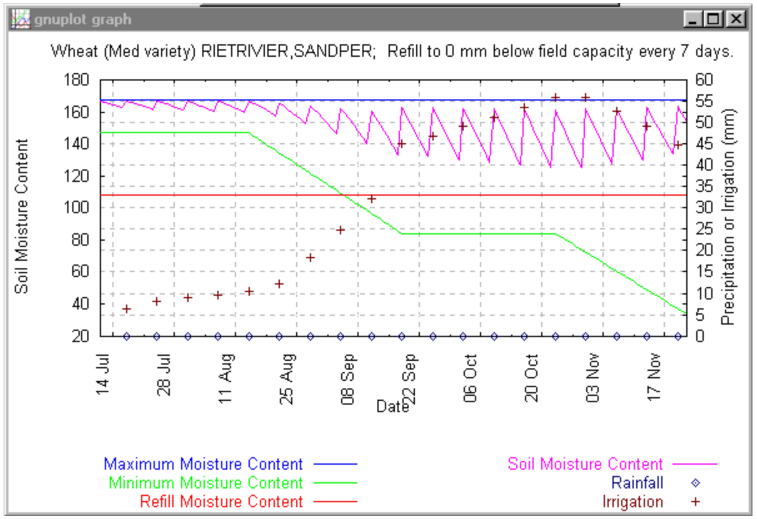
Orange-Riet WUA : Wheat : 10 July : Without rain



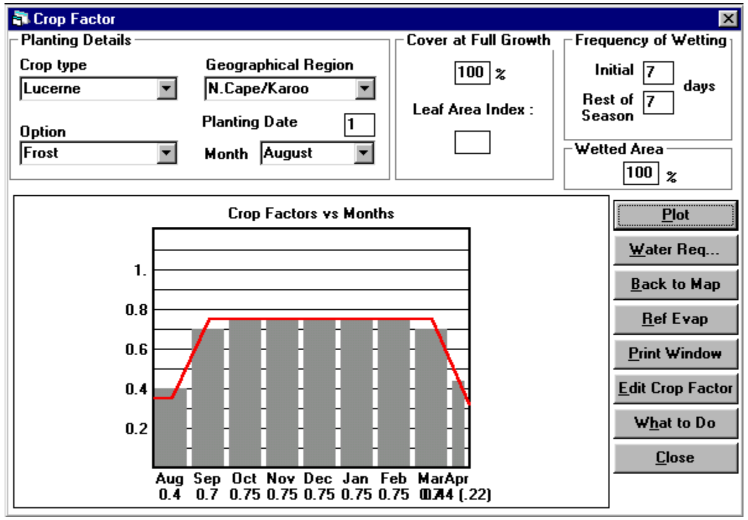


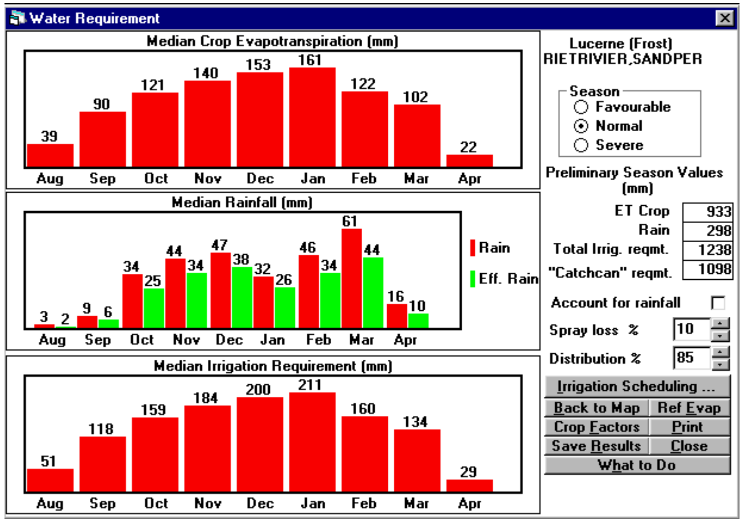
Date	Irrigation
17-Jul-00	6
24-Jul-00	8
31-Jul-00	9
7-Aug-00	10
14-Aug-00	11
21-Aug-00	12
28-Aug-00	18
4-Sep-00	25
11-Sep-00	32
18-Sep-00	45
25-Sep-00	47
2-Oct-00	49
9-Oct-00	51
16-Oct-00	54
23-Oct-00	56
30-Oct-00	56
6-Nov-00	53
13-Nov-00	49
20-Nov-00	45

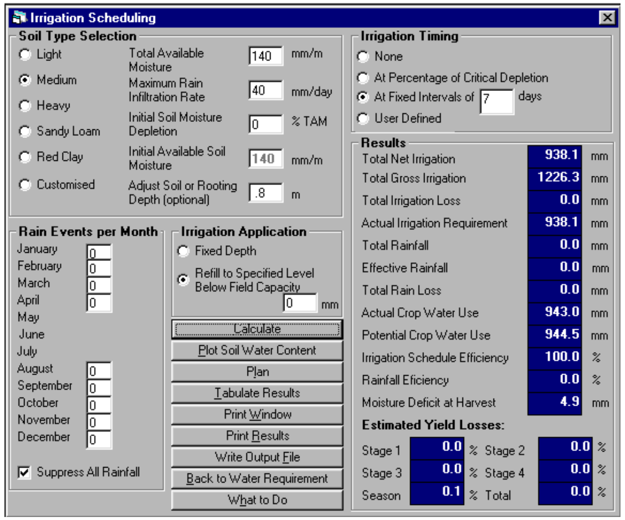


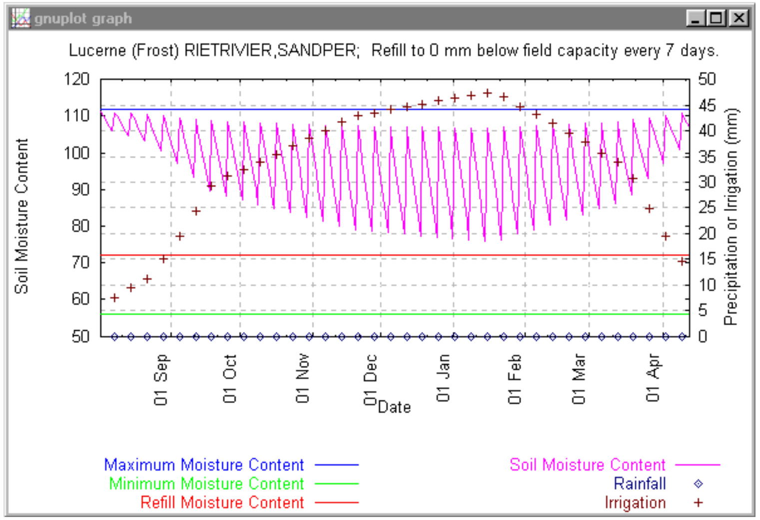


Orange-Riet WUA : Lucerne : 1 August : Without rain



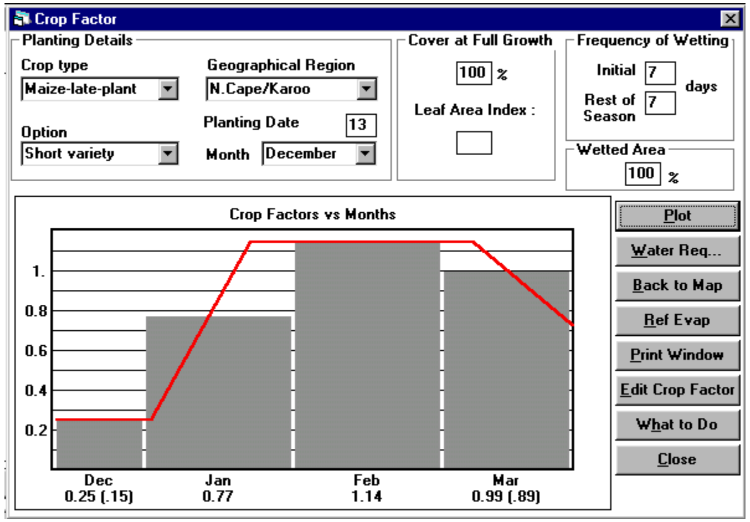


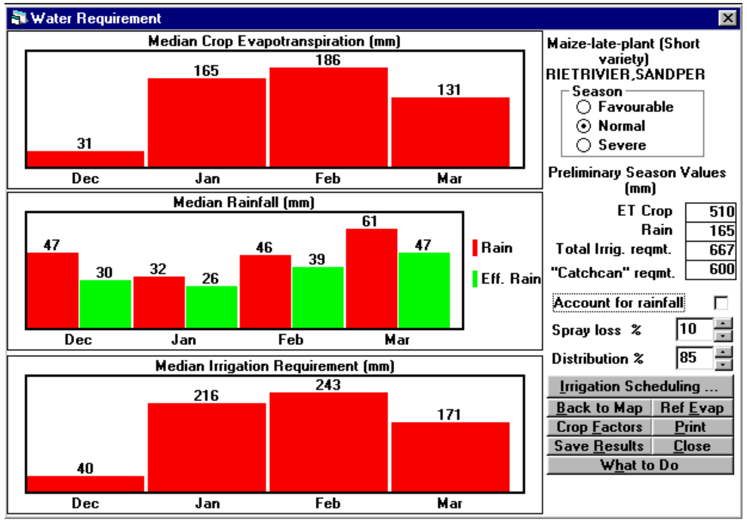




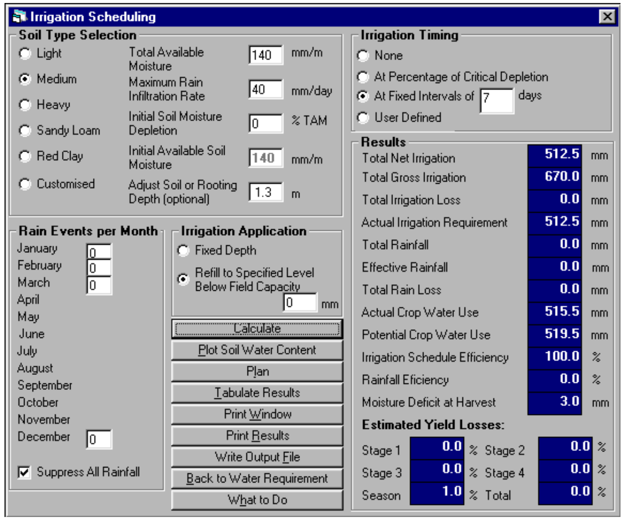
Date	Irrigation
08-Aug-00	8
15-Aug-00	10
22-Aug-00	11
29-Aug-00	15
05-Sep-00	20
12-Sep-00	24
19-Sep-00	29
26-Sep-00	31
03-Oct-00	33
10-Oct-00	34
17-Oct-00	35
24-Oct-00	37
31-Oct-00	39
07-Nov-00	40
14-Nov-00	42
21-Nov-00	43
28-Nov-00	44
05-Dec-00	44
12-Dec-00	45
19-Dec-00	45
26-Dec-00	46
02-Jan-01	46
09-Jan-01	47
16-Jan-01	47
23-Jan-01	47
30-Jan-01	45
06-Feb-01	43
13-Feb-01	41
20-Feb-01	40
27-Feb-01	38
06-Mar-01	36
13-Mar-01	34
20-Mar-01	31
27-Mar-01	25
03-Apr-01	19
10-Apr-01	15

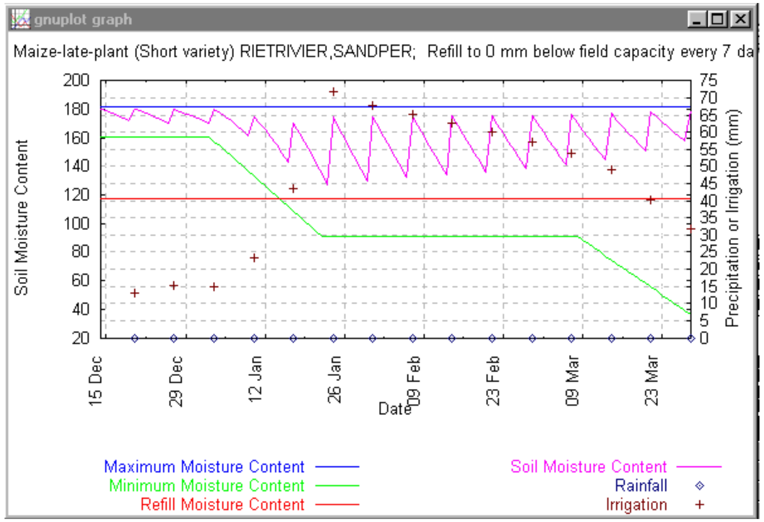
Orange-Riet WUA : Maize : 13 December : Without rain



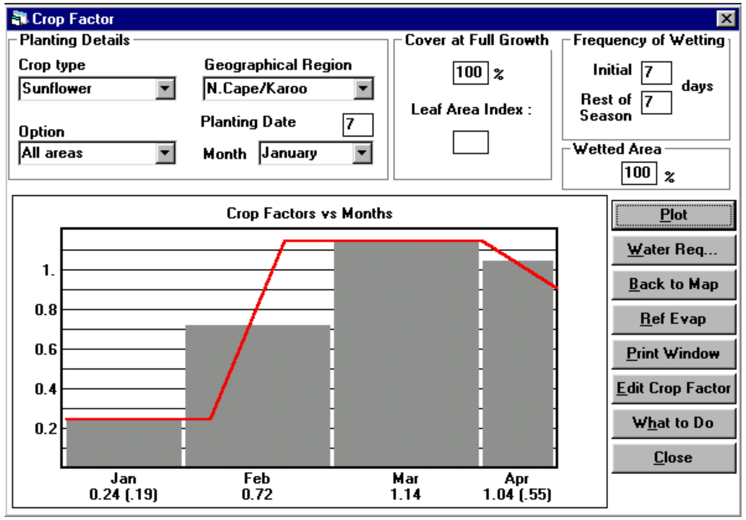


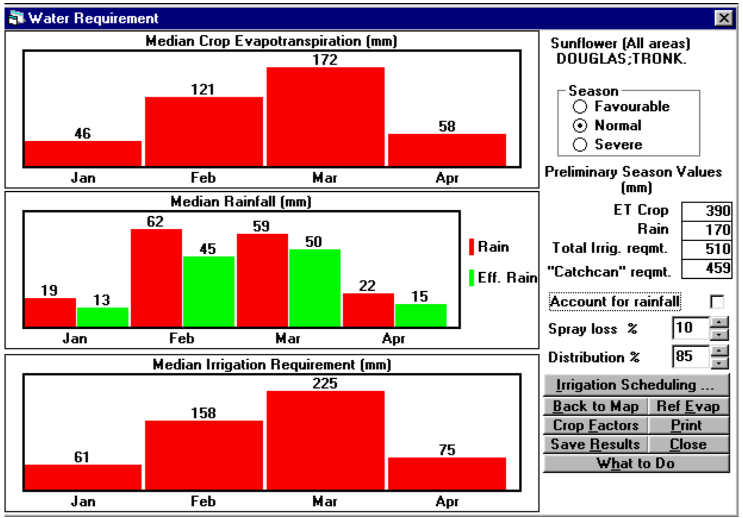
Date	Irrigation
20-Dec-00	13
27-Dec-00	15
03-Jan-01	15
10-Jan-01	24
17-Jan-01	43
24-Jan-01	72
31-Jan-01	68
07-Feb-01	65
14-Feb-01	63
21-Feb-01	60
28-Feb-01	57
07-Mar-01	54
14-Mar-01	49
21-Mar-01	40
28-Mar-01	32



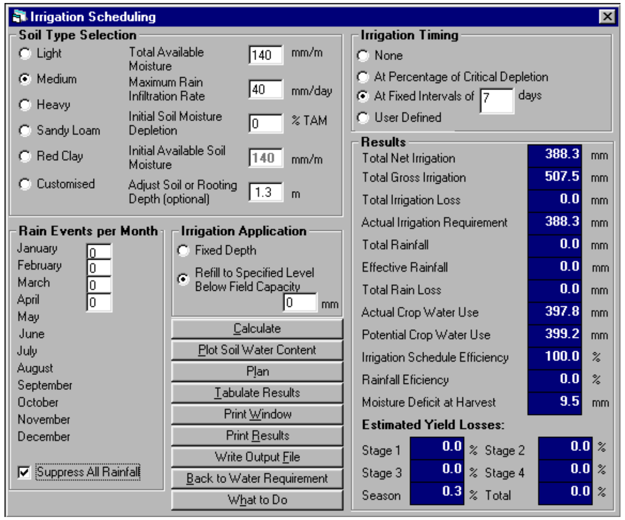


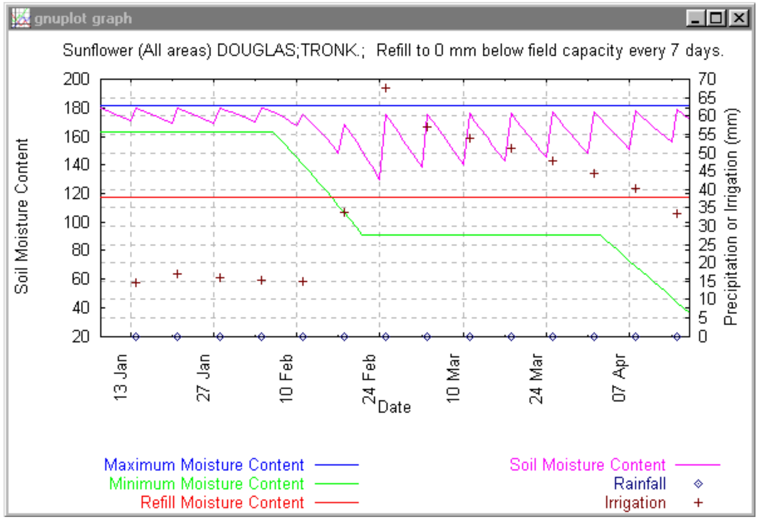
Orange-Riet WUA : Sunflower : 7 January : Without rain





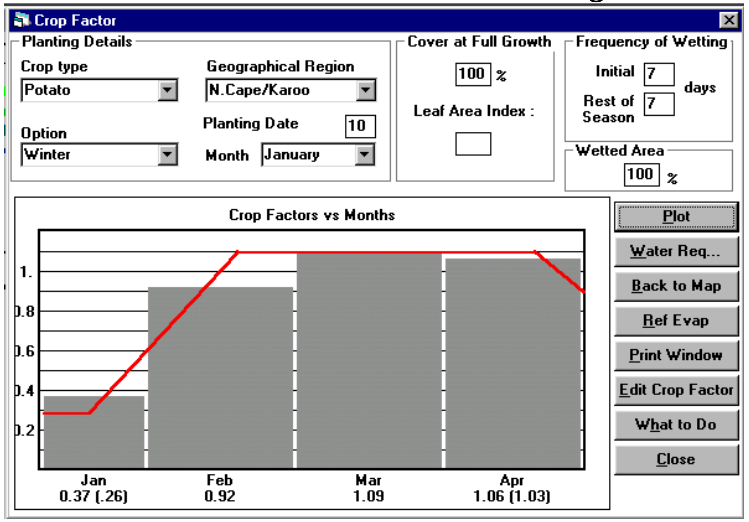
Date	Irrigation
14-Jan-00	15
21-Jan-00	17
28-Jan-00	16
04-Feb-00	15
11-Feb-00	15
18-Feb-00	34
25-Feb-00	68
04-Mar-00	57
11-Mar-00	54
18-Mar-00	51
25-Mar-00	48
01-Apr-00	45
08-Apr-00	40
15-Apr-00	34

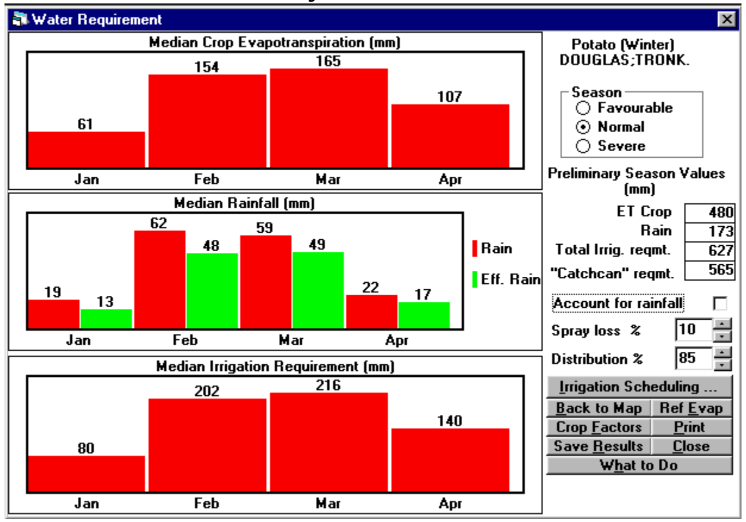




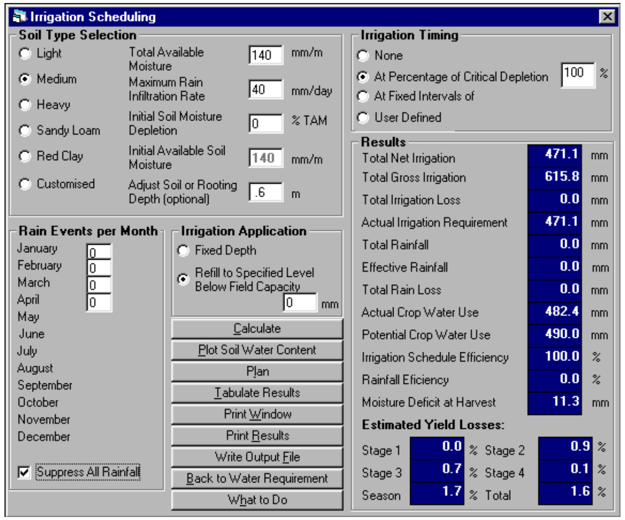
APPENDIX 7.2.1.2

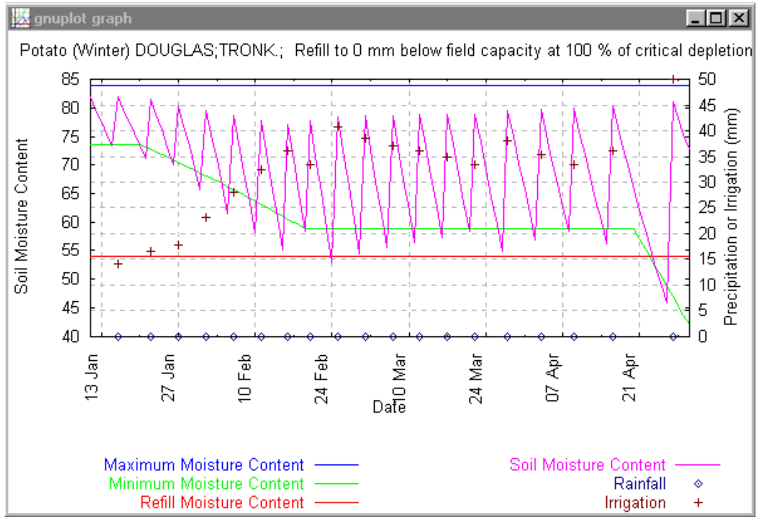
Orange-Vaal WUA : Potatoes : 10 January : Without rain



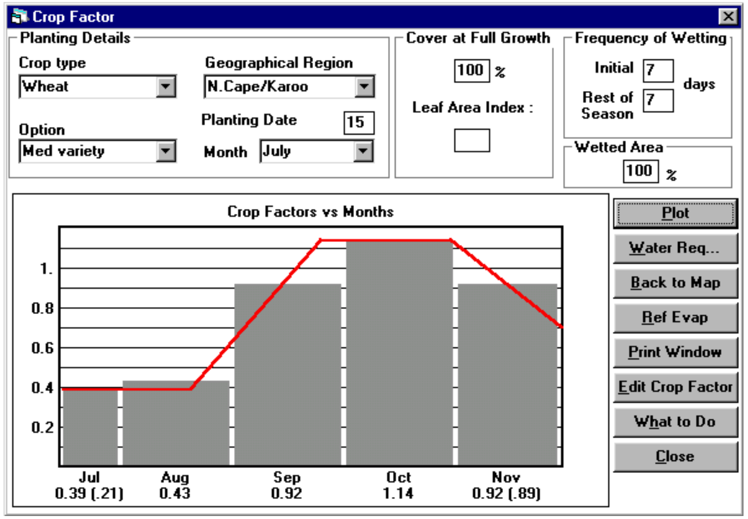


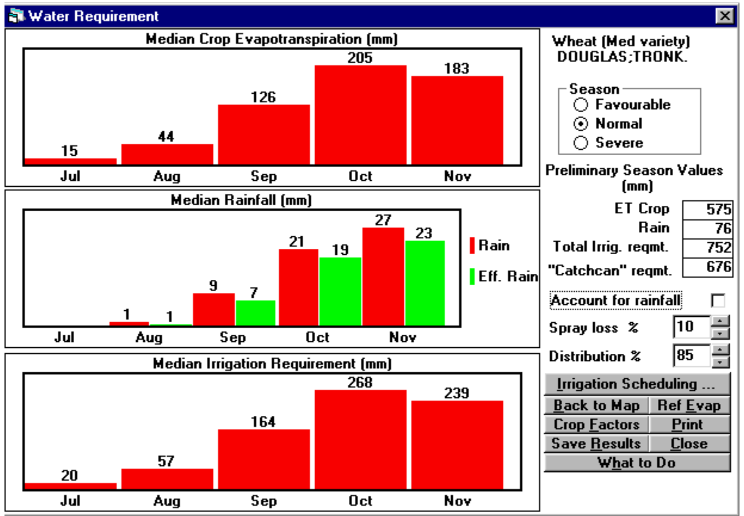
Date	Irrigation
16-Jan-00	14
22-Jan-00	17
27-Jan-00	18
01-Feb-00	23
06-Feb-00	28
11-Feb-00	32
16-Feb-00	36
20-Feb-00	34
25-Feb-00	41
02-Mar-00	39
07-Mar-00	37
12-Mar-00	36
17-Mar-00	35
22-Mar-00	33
28-Mar-00	38
03-Apr-00	35
09-Apr-00	34
16-Apr-00	36
27-Apr-00	50



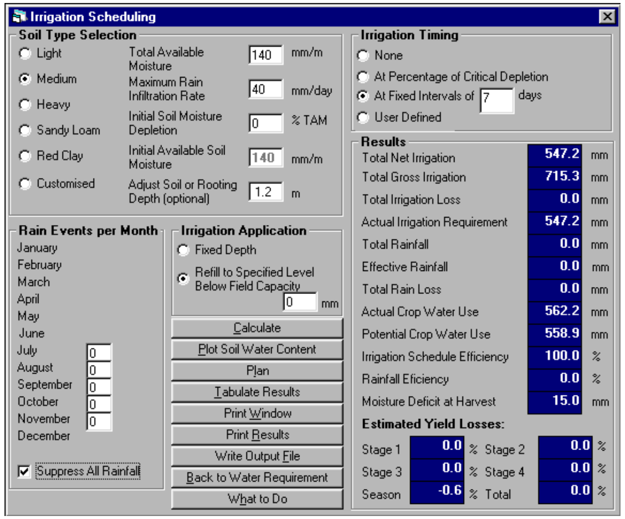


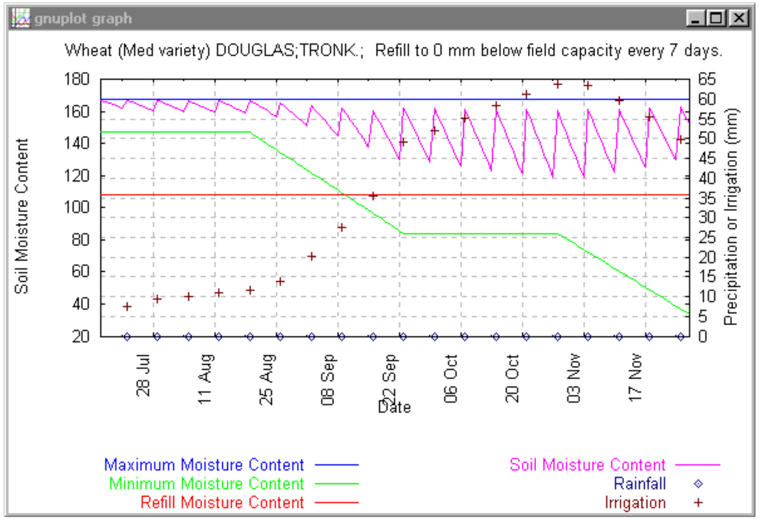
Orange-Vaal WUA : Wheat : 15 July : Without rain



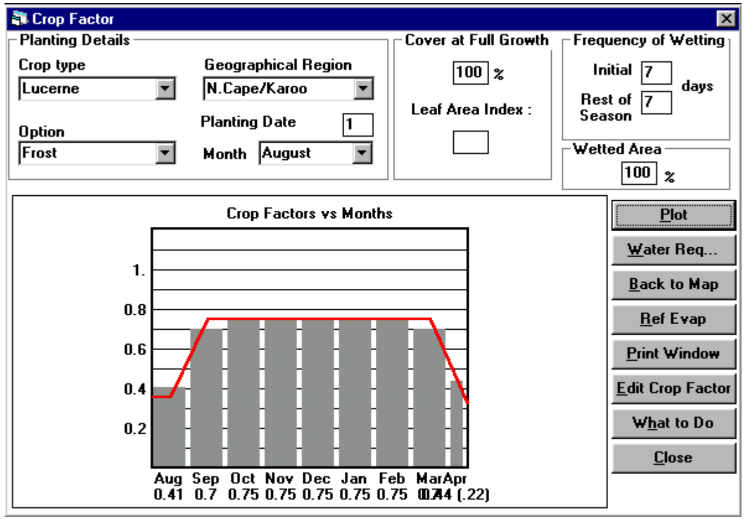


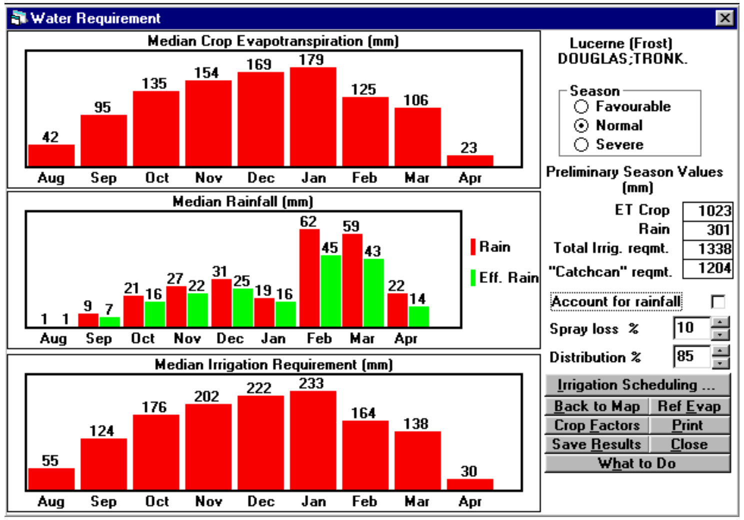
Date	Irrigation
22-Jul-00	8
29-Jul-00	9
05-Aug-00	10
12-Aug-00	11
19-Aug-00	12
26-Aug-00	14
02-Sep-00	20
09-Sep-00	27
16-Sep-00	36
23-Sep-00	49
30-Sep-00	52
07-Oct-00	55
14-Oct-00	58
21-Oct-00	61
28-Oct-00	64
04-Nov-00	64
11-Nov-00	60
18-Nov-00	55
25-Nov-00	50



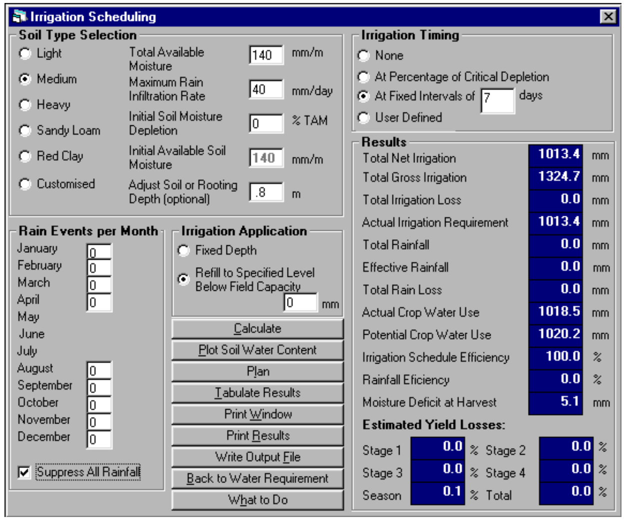


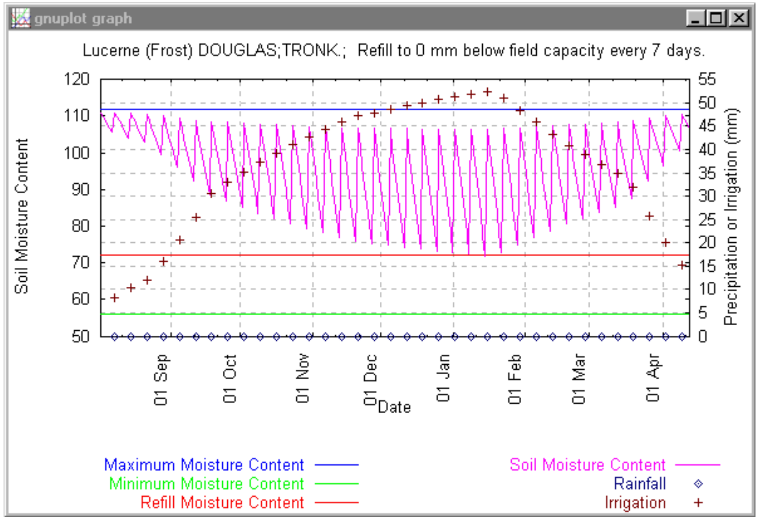
Orange-Vaal WUA : Lucerne : 1 August : Without rain



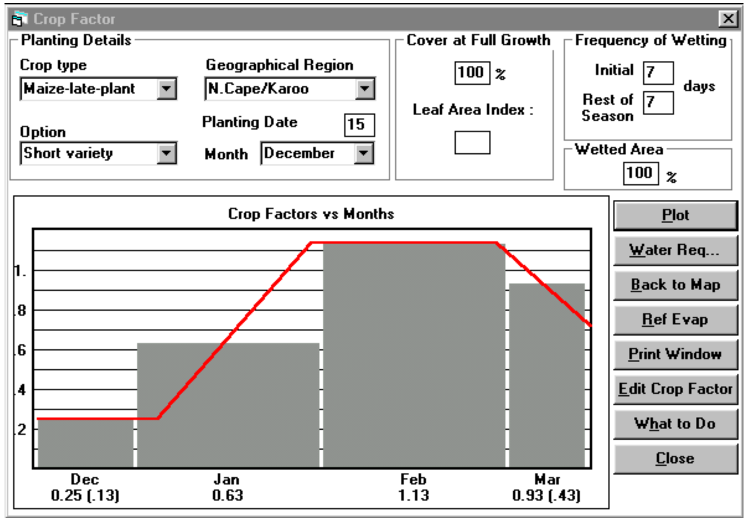


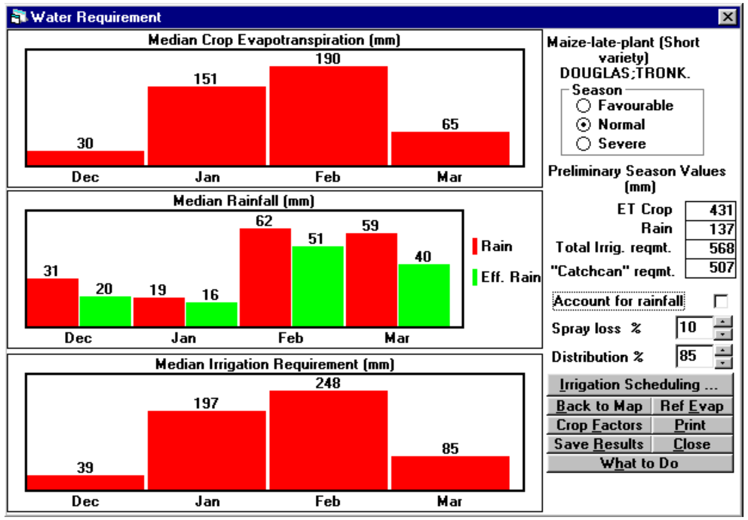
Date	Irrigation
08-Aug-00	8
15-Aug-00	10
22-Aug-00	12
29-Aug-00	16
05-Sep-00	21
12-Sep-00	26
19-Sep-00	31
26-Sep-00	33
03-Oct-00	35
10-Oct-00	37
17-Oct-00	39
24-Oct-00	41
31-Oct-00	43
07-Nov-00	44
14-Nov-00	46
21-Nov-00	47
28-Nov-00	48
05-Dec-00	49
12-Dec-00	49
19-Dec-00	50
26-Dec-00	51
02-Jan-01	51
09-Jan-01	52
16-Jan-01	52
23-Jan-01	51
30-Jan-01	48
06-Feb-01	46
13-Feb-01	43
20-Feb-01	41
27-Feb-01	39
06-Mar-01	37
13-Mar-01	35
20-Mar-01	32
27-Mar-01	26
03-Apr-01	20
10-Apr-01	15





Orange-Vaal WUA : Maize : 15 December : Without rain





Date	Irrigation
08-Dec-00	14
15-Dec-00	17
22-Dec-00	17
29-Dec-00	26
05-Jan-01	48
12-Jan-01	80
19-Jan-01	80
26-Jan-01	76
02-Feb-01	72
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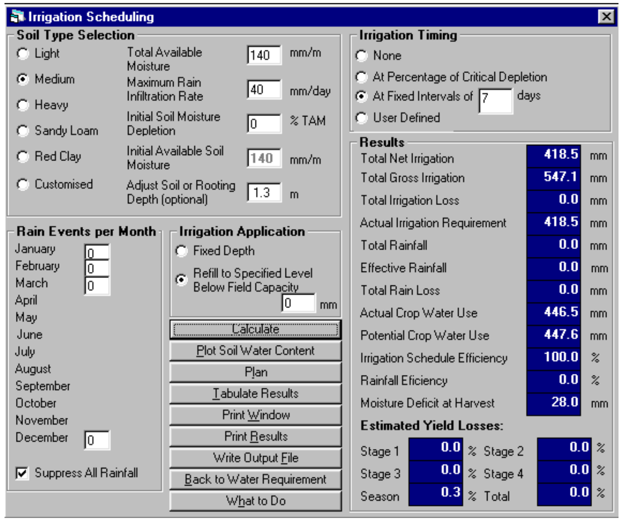
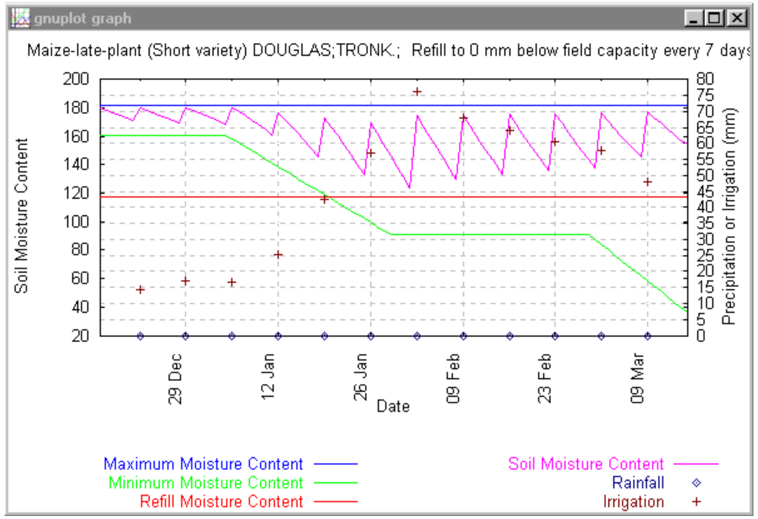
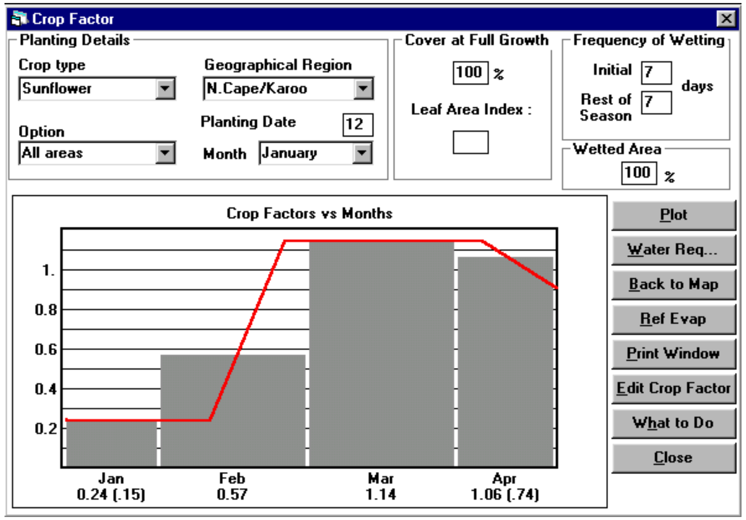
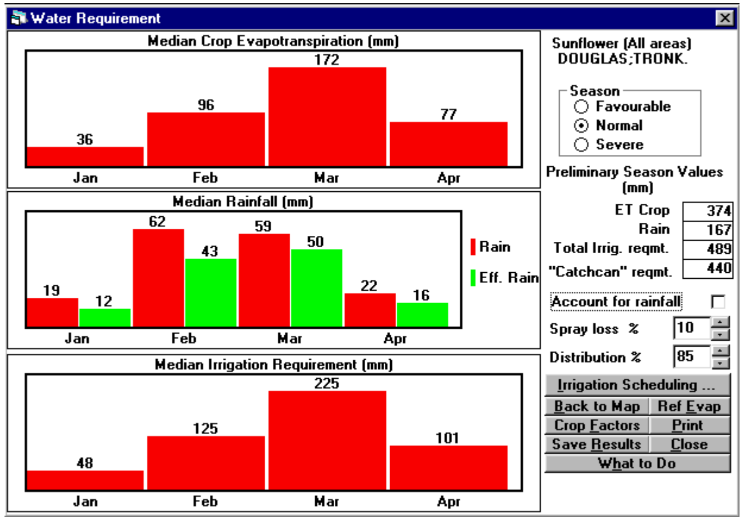
02-Mar-01	56
09-Mar-01	46
16-Mar-01	37



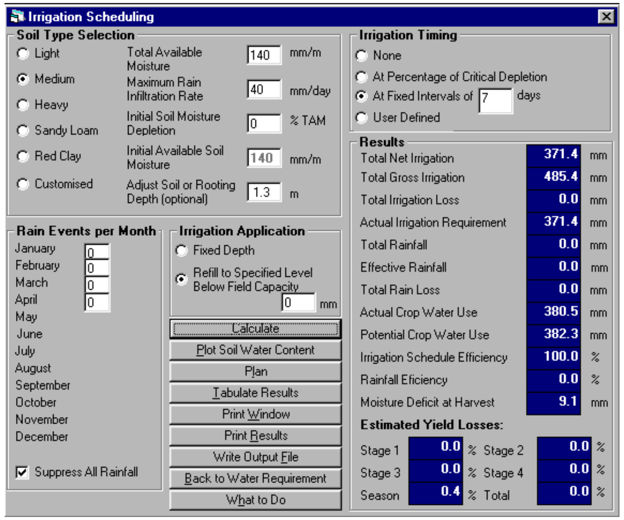


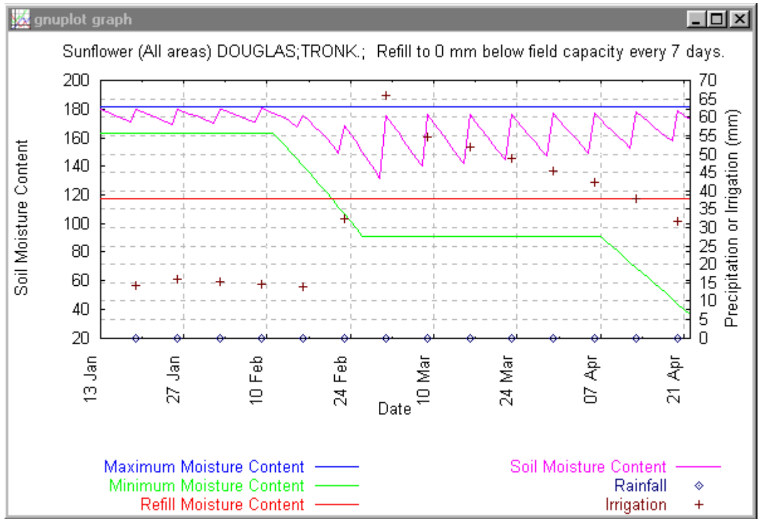
Orange-Vaal WUA : Sunflower : 12 January : Without rain





Date	Irrigation
19-Jan-00	14
26-Jan-00	16
02-Feb-00	15
09-Feb-00	15
16-Feb-00	14
23-Feb-00	32
02-Mar-00	66
09-Mar-00	55
16-Mar-00	52
23-Mar-00	49
30-Mar-00	46
06-Apr-00	42
13-Apr-00	38
20-Apr-00	32





APPENDIX 7.2.1.1.1

ORANGE-RIET WUA : IRRIGATION REQUIREMENT OF CROPS[10]

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	01 Mar	1.1			63	78	85	67	75	81					449
Pastures, perennial	01 Aug	1.9	170	129	116	81	60	45	51	76	102	127	147	161	1 265
Potatoes	10 Jan	10.7	73	197	209	137									616
Potatoes	22 Sep	3.0	280	134							15	85	211	266	991
Dry beans	02 Jan	2.4	73	198	192	8									471
Ground nuts	22 Oct	5.8	316	238	101							16	68	191	930
Ground nuts	10 Dec	1.0	126	233	215	49								44	667
Cotton	15 Oct	3.3	296	243	182	13						29	76	179	1 018
Cabbage	15 Mar	0.5			37	75	88	74	25						299
Cabbage	01 Jul	0.4							44	99	167	181			491
Wheat	10 Jul	66.1							23	60	170	239	173		665
Lucerne	01 Aug	9.0	211	160	134	29				51	118	159	184	200	1 246
Maize	01 Nov	1.7	307	243	195	60							60	150	1 015
Maize	13 Dec	21.4	216	243	171									40	670
Cucurbits	30 Aug	1.3									87	175	206	63	531
Sunflower	07 Jan	11.0	61	158	225	75									519
Sweet corn	20 Dec	1.3	161	204	57									29	451
Onions	10 Apr	3.1				32	43	60	84	126	164	113			622
Vineyards	01 Aug	0.7	154	108	46					47	67	105	134	147	808
Carrots	15 Sep	1.9									31	142	217	90	480

[10] Rainfall was not taken into consideration.

APPENDIX 7.2.1.2.1

ORANGE-VAAL WUA : IRRIGATION REQUIREMENT OF CROPS[11]

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	15 Mar	1.6			65	80	91	73	84	86					479
Pastures, perennial	01 Aug	2.3	189	133	120	83	64	49	57	80	107	141	162	178	1 363
Potatoes	10 Jan	9.6	80	202	216	140									638
Beetroot	01 Sep	1.1									75	232	184		491
Dry beans	10 Jan	0.4	73	198	192	8									471
Ground nuts	15 Oct	1.5	355	232	63							33	91	253	1 027
Ground nuts	15 Dec	0.3	112	227	226	75								38	678
Cotton	15 Oct	3.7	296	243	182	13						29	76	179	1 018
Wheat	15 Jul	51.4							20	57	164	268	239		748
Lucerne	01 Aug	16.8	233	164	138	30				55	124	176	202	222	1 344
Maize	15 Dec	32.1	197	248	85									39	569
Pecan nuts	01-May	0.7	237	167	151	104	81	62	74	105	136	179	205	225	1 726
Cucurbits	15 Oct	0.8	188									51	182	262	683
Sunflower	12 Jan	4.5	48	125	249	101									523
Onions	15 Apr	2.0				26	44	61	95	134	174	162			696
Vineyards	01 Aug	3.3	171	111	48					50	71	117	148	162	878
Carrots	05 Sep	2.6									63	190	231	29	513

[11] Rainfall was not taken into consideration.

APPENDIX 7.4.1.1.1

ORANGE-RIET WUA : SUB AREA 1 : IRRIGATION REQUIREMENT OF CROP ROTATION SYSTEM

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	01 Mar	6.0			63	78	85	67	75	81					449
Pastures, perennial	01 Aug	0.0	170	129	116	81	60	45	51	76	102	127	147	161	1 265
Potatoes	10 Jan	25.0	73	197	209	137									616
Potatoes	22 Sep	5.0	280	134							15	85	211	266	991
Dry beans	02 Jan	0.0	73	198	192	8									471
Ground nuts	22 Oct	0.0	316	238	101							16	68	191	930
Ground nuts	10 Dec	0.0	126	233	215	49								44	667
Cotton	15 Oct	0.0	296	243	182	13						29	76	179	1 018
Cabbage	15 Mar	0.0			37	75	88	74	25						491
Cabbage	01 Jul	0.0							44	99	167	181			665
Wheat	10 Jul	45.0							23	60	170	239	173		665
Lucerne	01 Aug	16.0	211	160	134	29				51	118	159	184	200	1 246
Maize	01 Nov	4.0	307	243	195	60							60	150	1 015
Maize	13 Dec	15.0	216	243	171									40	670
Cucurbits	30 Aug	1.0									87	175	206	63	531
Sunflower	07 Jan	13.0	61	158	225	75									519
Sweet corn	20 Dec	0.0	161	204	57									29	451
Onions	10 Apr	8.0				32	43	60	84	126	164	113			622
Vineyards	01 Aug	4.0	154	108	46					47	67	105	134	147	808
Carrots	15 Sep	0.0									31	142	217	90	480
SAPWAT-irrigation require-ment			**125**	**153**	**142**	**58**	**9**	**9**	**22**	**52**	**113**	**152**	**128**	**64**	**1 025**
Scheduled	723.7														
WUA			138	140	144	14	5	9	14	37	111	166	169	91	1 036

APPENDIX 7.4.1.2.1

ORANGE-RIET WUA : SUB AREA 2 : IRRIGATION REQUIREMENT OF CROP ROTATION SYSTEM

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	01 Mar	0.0			63	78	85	67	75	81					449
Pastures, perennial	01 Aug	0.0	170	129	116	81	60	45	51	76	102	127	147	161	1 265
Potatoes	10 Jan	6.0	73	197	209	137									616
Potatoes	22 Sep	0.0	280	134							15	85	211	266	991
Dry beans	02 Jan	3.0	73	198	192	8									471
Ground nuts	22 Oct	2.0	316	238	101							16	68	191	930
Ground nuts	10 Dec	3.0	126	233	215	49								44	667
Cotton	15 Oct	4.0	296	243	182	13						29	76	179	1 018
Cabbage	15 Mar	0.0			37	75	88	74	25						491
Cabbage	01 Jul	1.0							44	99	167	181			665
Wheat	10 Jul	88.0							23	60	170	239	173		665
Lucerne	01 Aug	4.0	211	160	134	29				51	118	159	184	200	1 246
Maize	01 Nov	0.0	307	243	195	60							60	150	1 015
Maize	13 Dec	24.0	216	243	171									40	670
Cucurbits	30 Aug	2.0									87	175	206	63	531
Sunflower	07 Jan	18.0	61	158	225	75									519
Sweet corn	20 Dec	1.0	161	204	57									29	451
Onions	10 Apr	2.0				32	43	60	84	126	164	113			622
Vineyards	01 Aug	0.0	154	108	46					47	67	105	134	147	808
Carrots	15 Sep	0.0									31	142	217	90	480
SAPWAT-irrigation requirement			**101**	**134**	**122**	**26**	**1**	**1**	**22**	**58**	**161**	**226**	**168**	**31**	**1 054**
Scheduled	1376.7														
WUA			105	121	109	80	0	0	25	60	158	223	197	58	1 136

APPENDIX 7.4.1.3.1

ORANGE-RIET WUA : SUB AREA 3 : IRRIGATION REQUIREMENT OF CROP ROTATION SYSTEM

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	01 Mar	0.0			63	78	85	67	75	81					449
Pastures, perennial	01 Aug	4.0	170	129	116	81	60	45	51	76	102	127	147	161	1 265
Potatoes	10 Jan	13.0	73	197	209	137									616
Potatoes	22 Sep	0.0	280	134							15	85	211	266	991
Dry beans	02 Jan	3.0	73	198	192	8									471
Ground nuts	22 Oct	11.0	316	238	101							16	68	191	930
Ground nuts	10 Dec	0.0	126	233	215	49								44	667
Cotton	15 Oct	4.0	296	243	182	13						29	76	179	1 018
Cabbage	15 Mar	0.0			37	75	88	74	25						491
Cabbage	01 Jul	1.0							44	99	167	181			665
Wheat	10 Jul	58.0							23	60	170	239	173		665
Lucerne	01 Aug	10.0	211	160	134	29				51	118	159	184	200	1 246
Maize	01 Nov	2.0	307	243	195	60							60	150	1 015
Maize	13 Dec	22.0	216	243	171									40	670
Cucurbits	30 Aug	1.0									87	175	206	63	531
Sunflower	07 Jan	5.0	61	158	225	75									519
Sweet corn	20 Dec	2.0	161	204	57									29	451
Onions	10 Apr	2.0				32	43	60	84	126	164	113			622
Vineyards	01 Aug	0.0	154	108	46					47	67	105	134	147	808
Carrots	15 Sep	4.0									31	142	217	90	480
SAPWAT-irrigation require-ment			**146**	**159**	**123**	**30**	**3**	**3**	**18**	**46**	**122**	**174**	**147**	**71**	**1 044**
Scheduled	1837.5														
WUA			138	141	109	60	0	0	16	40	114	170	163	87	1 038

APPENDIX 7.4.2.1.1

ORANGE-VAAL WUA : SUB AREA 1 : IRRIGATION REQUIREMENT OF CROP ROTATION SYSTEM

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	15 Mar	0.0			65	80	91	73	84	86					479
Pastures, perennial	01 Aug	1.0	189	133	120	83	64	49	57	80	107	141	162	178	1 363
Potatoes	10 Jan	7.0	80	202	216	140									638
Beetroot	01 Sep	2.0									75	232	184		491
Dry beans	10 Jan	1.0	73	198	192	8									471
Ground nuts	15 Oct	4.0	355	232	63							33	91	253	1 027
Ground nuts	15 Dec	0.0	112	227	226	75								38	678
Cotton	15 Oct	5.0	296	243	182	13						29	76	179	1 018
Wheat	15 Jul	60.0							20	57	164	268	239		748
Lucerne	01 Aug	21.0	233	164	138	30				55	124	176	202	222	1 344
Maize	15 Dec	44.0	197	248	85									39	569
Pecan nuts	01-May	0.0	237	167	151	104	81	62	74	105	136	179	205	225	1 726
Cucurbits	15 Oct	0.0	188									51	182	262	683
Sunflower	12 Jan	0.0	48	125	249	101									523
Onions	15 Apr	3.0				26	44	61	95	134	174	162			696
Vineyards	01 Aug	1.0	171	111	48					50	71	117	148	162	878
Carrots	05 Sep	4.0									63	190	231	29	513
SAPWAT-irrigation requirement			**175**	**184**	**97**	**18**	**2**	**2**	**15**	**51**	**135**	**220**	**209**	**87**	**1 196**
Scheduled	3124.7														
WUA			211	172	58	14	2	1	18	41	124	184	181	179	1 185

APPENDIX 7.4.2.2.1

ORANGE-VAAL WUA : SUB AREA 2 : IRRIGATION REQUIREMENT OF CROP ROTATION SYSTEM

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	15 Mar	5.0			65	80	91	73	84	86					479
Pastures, perennial	01 Aug	5.0	189	133	120	83	64	49	57	80	107	141	162	178	1 363
Potatoes	10 Jan	7.0	80	202	216	140									638
Beetroot	01 Sep	0.0									75	232	184		491
Dry beans	10 Jan	0.0	73	198	192	8									471
Ground nuts	15 Oct	0.0	355	232	63							33	91	253	1 027
Ground nuts	15 Dec	0.0	112	227	226	75								38	678
Cotton	15 Oct	5.0	296	243	182	13						29	76	179	1 018
Wheat	15 Jul	58.0							20	57	164	268	239		748
Lucerne	01 Aug	5.0	197	248	85									39	569
Maize	15 Dec	25.0	237	167	151	104	81	62	74	105	136	179	205	225	1 726
Pecan nuts	01-May	2.0	284	161	110	52	42	32	30	62	163	235	268	295	1 734
Cucurbits	15 Oct	1.0	188									51	182	262	683
Sunflower	12 Jan	12.0	48	125	249	101									523
Onions	15 Apr	2.0				26	44	61	95	134	174	162			696
Vineyards	01 Aug	3.0	171	111	48					50	71	117	148	162	878
Carrots	05 Sep	1.0									63	190	231	29	513
SAPWAT-irrigation requirement			**108**	**125**	**96**	**35**	**10**	**9**	**22**	**50**	**116**	**185**	**173**	**51**	**980**
Scheduled	2659.1														
WUA			135	123	61	15	2	1	18	42	115	166	147	111	937

APPENDIX 7.4.2.3.1

ORANGE-VAAL WUA : SUB AREA 3 : IRRIGATION REQUIREMENT OF CROP ROTATION SYSTEM

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	15 Mar	0.0			65	80	91	73	84	86					479
Pastures, perennial	01 Aug	3.0	189	133	120	83	64	49	57	80	107	141	162	178	1 363
Potatoes	10 Jan	0.0	80	202	216	140									638
Beetroot	01 Sep	0.0									75	232	184		491
Dry beans	10 Jan	0.0	73	198	192	8									471
Ground nuts	15 Oct	0.0	355	232	63							33	91	253	1 027
Ground nuts	15 Dec	0.0	112	227	226	75								38	678
Cotton	15 Oct	0.0	296	243	182	13						29	76	179	1 018
Wheat	15 Jul	27.0							20	57	164	268	239		748
Lucerne	01 Aug	39.0	233	164	138	30				55	124	176	202	222	1 344
Maize	15 Dec	15.0	197	248	85									39	569
Pecan nuts	01-May	0.0	237	167	151	104	81	62	74	105	136	179	205	225	1 726
Cucurbits	15 Oct	2.0	188									51	182	262	683
Sunflower	12 Jan	10.0	48	125	249	101									523
Onions	15 Apr	0.0				26	44	61	95	134	174	162			696
Vineyards	01 Aug	23.0	171	111	48					50	71	117	148	162	878
Carrots	05 Sep	0.0									63	190	231	29	513
SAPWAT-irrigation requirement			**174**	**143**	**106**	**24**	**2**	**1**	**7**	**51**	**112**	**173**	**186**	**149**	**1 120**
Scheduled	349.4														
WUA			157	132	82	8	4	3	9	20	80	125	145	144	909

APPENDIX 7.4.2.4.1

ORANGE-VAAL WUA : SUB AREA 4 : IRRIGATION REQUIREMENT OF CROP ROTATION SYSTEM

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	15 Mar	0.0			65	80	91	73	84	86					479
Pastures, perennial	01 Aug	1.0	189	133	120	83	64	49	57	80	107	141	162	178	1 363
Potatoes	10 Jan	0.0	80	202	216	140									638
Beetroot	01 Sep	0.0									75	232	184		491
Dry beans	10 Jan	0.0	73	198	192	8									471
Ground nuts	15 Oct	0.0	355	232	63							33	91	253	1 027
Ground nuts	15 Dec	0.0	112	227	226	75								38	678
Cotton	15 Oct	1.0	296	243	182	13						29	76	179	1 018
Wheat	15 Jul	8.0							20	57	164	268	239		748
Lucerne	01 Aug	32.0	233	164	138	30				55	124	176	202	222	1 344
Maize	15 Dec	8.0	197	248	85									39	569
Pecan nuts	01-May	0.0	237	167	151	104	81	62	74	105	136	179	205	225	1 726
Cucurbits	15 Oct	0.0	188									51	182	262	683
Sunflower	12 Jan	1.0	48	125	249	101									523
Onions	15 Apr	0.0				26	44	61	95	134	174	162			696
Vineyards	01 Aug	5.0	171	111	48					50	71	117	148	162	878
Carrots	05 Sep	0.0									63	190	231	29	513
SAPWAT-Irrigation requirement			**104**	**83**	**59**	**12**	**1**	**0**	**2**	**25**	**57**	**85**	**94**	**86**	**608**
Scheduled	1341.5														
WUA			102	81	48	1	1	1	3	7	46	75	91	92	547

APPENDIX 7.4.2.5.1

ORANGE-VAAL WUA : SUB AREA 5 : IRRIGATION REQUIREMENT OF CROP ROTATION SYSTEM

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	15 Mar	0.0			65	80	91	73	84	86					479
Pastures, perennial	01 Aug	0.0	189	133	120	83	64	49	57	80	107	141	162	178	1 363
Potatoes	10 Jan	3.0	80	202	216	140									638
Beetroot	01 Sep	4.0									75	232	184		491
Dry beans	10 Jan	0.0	73	198	192	8									471
Ground nuts	15 Oct	0.0	355	232	63							33	91	253	1 027
Ground nuts	15 Dec	4.0	112	227	226	75								38	678
Cotton	15 Oct	0.0	296	243	182	13						29	76	179	1 018
Wheat	15 Jul	87.0							20	57	164	268	239		748
Lucerne	01 Aug	1.0	233	164	138	30				55	124	176	202	222	1 344
Maize	15 Dec	64.0	197	248	85									39	569
Pecan nuts	01-May	0.0	237	167	151	104	81	62	74	105	136	179	205	225	1 726
Cucurbits	15 Oct	5.0	188									51	182	262	683
Sunflower	12 Jan	0.0	48	125	249	101									523
Onions	15 Apr	2.0				26	44	61	95	134	174	162			696
Vineyards	01 Aug	2.0	171	111	48					50	71	117	148	162	878
Carrots	05 Sep	9.0									63	190	231	29	513
SAPWAT-irrigation requirement			**148**	**178**	**72**	**8**	**1**	**1**	**19**	**54**	**157**	**269**	**250**	**48**	**1 206**
Scheduled	617.4														
WUA			301	243	40	13	2	1	37	83	217	308	272	251	1 767

APPENDIX 7.5.1.1

ORANGE-RIET WUA : IRRIGATION REQUIREMENT OF CROP ROTATION SYSTEM[12]

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	01 Mar	1.1			63	78	85	67	75	81					449
Pastures, perennial	01 Aug	1.9	170	129	116	81	60	45	51	76	102	127	147	161	1 265
Potatoes	10 Jan	10.7	73	197	209	137									616
Potatoes	22 Sep	3.0	280	134							15	85	211	266	991
Dry beans	02 Jan	2.4	73	198	192	8									471
Ground nuts	22 Oct	5.8	316	238	101							16	68	191	930
Ground nuts	10 Dec	1.0	126	233	215	49								44	667
Cotton	15 Oct	3.3	296	243	182	13						29	76	179	1 018
Cabbage	15 Mar	0.5			37	75	88	74	25						491
Cabbage	01 Jul	0.4							44	99	167	181			665
Wheat	10 Jul	66.1							23	60	170	239	173		665
Lucerne	01 Aug	9.0	211	160	134	29				51	118	159	184	200	1 246
Maize	01 Nov	1.7	307	243	195	60							60	150	1 015
Maize	13 Dec	21.4	216	243	171									40	670
Cucurbits	30 Aug	1.3									87	175	206	63	531
Sunflower	07 Jan	11.0	61	158	225	75									519
Sweet corn	20 Dec	1.3	161	204	57									29	451
Onions	10 Apr	3.1				32	43	60	84	126	164	113			622
Vineyards	01 Aug	0.7	154	108	46					47	67	105	134	147	808
Carrots	15 Sep	1.9									31	142	217	90	480
Irrigation requirement			**131**	**148**	**122**	**31**	**4**	**4**	**20**	**51**	**133**	**189**	**155**	**62**	**1 051**

[12] Rainfall was not taken into consideration.

APPENDIX 7.5.2.1

ORANGE-VAAL WUA : IRRIGATION REQUIREMENT OF CROP ROTATION SYSTEM[13]

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Pastures, annual	15 Mar	1.6			65	80	91	73	84	86					479
Pastures, perennial	01 Aug	2.3	189	133	120	83	64	49	57	80	107	141	162	178	1 363
Potatoes	10 Jan	9.6	80	202	216	140									638
Beetroot	01 Sep	1.1									75	232	184		491
Dry beans	10 Jan	0.4	73	198	192	8									471
Ground nuts	15 Oct	1.5	355	232	63							33	91	253	1 027
Ground nuts	15 Dec	0.3	112	227	226	75								38	678
Cotton	15 Oct	3.7	296	243	182	13						29	76	179	1 018
Wheat	15 Jul	51.4							20	57	164	268	239		748
Lucerne	01 Aug	16.8	233	164	138	30				55	124	176	202	222	1 344
Maize	15 Dec	32.1	330	248	88									99	765
Pecan nuts	01-May	0.7	284	161	110	52	42	32	30	62	163	235	268	295	1 734
Cucurbits	15 Oct	0.8	188									51	182	262	683
Sunflower	12 Jan	4.5	48	125	249	101									523
Onions	15 Apr	2.0				26	44	61	95	134	174	162			696
Vineyards	01 Aug	3.3	171	111	48					50	71	117	148	162	878
Carrots	05 Sep	2.6									63	190	231	29	513
Irrigation requirement			**185**	**154**	**99**	**28**	**4**	**4**	**15**	**47**	**117**	**189**	**181**	**94**	**1 116**

[13] Rainfall was not taken into consideration.

APPENDIX 7.6.1.1

IRRIGATION REQUIREMENT OF THE FIVE MOST IMPORTANT CROPS WITH INCLUSION OF RAIN AND LEACHING REQUIREMENT COMPARED TO THE ORANGE-RIET WUA'S PLANNING APPROACH WITHOUT RAIN AND LEACHING REQUIREMENT

With inclusion of rain and leaching requirement

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Leaching requirement	
																10%	20%
Potatoes	10 Jan	10.7	54	157	159	129									499	554	624
Potatoes	22 Sep	3.0	246	110							15	59	174	223	827	919	1 034
Wheat	10 Jul	66.1							22	55	167	207	144		595	661	744
Lucerne	01 Aug	9.0	179	122	88	25				46	116	130	148	160	1 014	1 127	1 268
Maize	01 Nov	1.7	273	203	146	55							29	112	818	909	1 023
Maize	13 Dec	21.4	185	202	129									20	536	596	670
Sunflower	07 Jan	11.0	48	95	174	73									390	433	488
Irrigation requirement of system			**79**	**88**	**74**	**25**	**0**	**0**	**15**	**40**	**121**	**150**	**114**	**27**	**734**	**816**	**918**
Irrigation requirement of system with 10% leaching			**88**	**98**	**82**	**28**	**0**	**0**	**16**	**45**	**135**	**167**	**127**	**30**	**816**		
Irrigation requirement of system with 20% leaching			**98**	**110**	**93**	**31**	**0**	**0**	**18**	**51**	**152**	**188**	**143**	**34**	**918**		

Without inclusion of rain and leaching requirement

Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total		
Potatoes	10 Jan	10.7	73	197	209	137									616		
Potatoes	22 Sep	3.0	280	134							15	85	211	266	991		
Wheat	10 Jul	66.1							23	60	170	239	173		665		
Lucerne	01 Aug	9.0	211	160	134	29				51	118	159	184	200	1 246		
Maize	01 Nov	1.7	307	243	195	60							60	150	1 015		
Maize	13 Dec	21.4	216	243	171									40	670		
Sunflower	07 Jan	11.0	61	158	225	75									519		
Irrigation requirement of system			**93**	**113**	**99**	**27**	**0**	**0**	**15**	**44**	**123**	**175**	**138**	**37**	**865**		

APPENDIX 7.6.2.1

IRRIGATION REQUIREMENT OF THE FIVE MOST IMPORTANT CROPS WITH INCLUSION OF RAIN AND LEACHING REQUIREMENT COMPARED TO THE ORANGE-VAAL WUA'S PLANNING APPROACH WITHOUT RAIN AND LEACHING REQUIREMENT

With inclusion of rain and leaching requirement																	
Crop	**Planting or starting date**	**%**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**	**Leaching requirement**	
																10%	**20%**
Potatoes	10 Jan	9.6	68	135	165	135									503	559	629
Wheat	15 Jul	51.4							20	53	150	227	204		654	727	818
Lucerne	01 Aug	16.8	213	101	95	26				51	111	141	168	168	1 074	1 193	1 343
Maize	15 Dec	32.1	307	177	67									64	615	683	769
Sunflower	12 Jan	4.5	38	65	174	98									375	417	469
Irrigation requirement of system			**143**	**90**	**61**	**22**	**0**	**0**	**10**	**36**	**96**	**140**	**133**	**49**	**779**	**866**	**974**
Irrigation requirement of system with 10% leaching			**158**	**100**	**68**	**24**	**0**	**0**	**11**	**40**	**106**	**156**	**148**	**54**	**866**		
Irrigation requirement of system with 20% leaching			**178**	**112**	**76**	**27**	**0**	**0**	**13**	**45**	**120**	**175**	**166**	**61**	**974**		

Without inclusion of rain																	
Crop	**Planting or starting date**	**%**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**		
Potatoes	10 Jan	9.6	80	202	216	140									638		
Wheat	15 Jul	51.4							20	57	164	268	239		748		
Lucerne	01 Aug	16.8	233	164	138	30				55	124	176	202	222	1 344		
Maize	15 Dec	32.1	330	248	88									99	765		
Sunflower	12 Jan	4.5	48	125	249	101									523		
Irrigation requirement of system			**155**	**132**	**83**	**23**	**0**	**0**	**10**	**39**	**105**	**167**	**157**	**69**	**941**		

APPENDIX 7.7.1.1

COMPARISON OF THE IRRIGATION REQUIREMENT FOR THE CROP ROTATION SYSTEM OF THE ORANGE-RIET WUA AS ESTIMATED WITH AID OF SAPWAT AND AS ESTIMATED BY THE WUA

Estimation	Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	Pastures, annual	01 Mar	1.1			63	78	85	67	75	81					449
	Pastures, perennial	01 Aug	1.9	170	129	116	81	60	45	51	76	102	127	147	161	1 265
	Potatoes	10 Jan	10.7	73	197	209	137									616
	Potatoes	22 Sep	3.0	280	134							15	85	211	266	991
	Dry beans	02 Jan	2.4	73	198	192	8									471
	Ground nuts	22 Oct	5.8	316	238	101							16	68	191	930
	Ground nuts	10 Dec	1.0	126	233	215	49								44	667
	Cotton	15 Oct	3.3	296	243	182	13						29	76	179	1 018
	Cabbage	15 Mar	0.5			37	75	88	74	25						491
	Cabbage	01 Jul	0.4							44	99	167	181			665
SAPWAT	Wheat	10 Jul	66.1							23	60	170	239	173		665
	Lucerne	01 Aug	9.0	211	160	134	29				51	118	159	184	200	1 246
	Maize	01 Nov	1.7	307	243	195	60							60	150	1 015
	Maize	13 Dec	21.4	216	243	171									40	670
	Cucurbits	30 Aug	1.3									87	175	206	63	531
	Sunflower	07 Jan	11.0	61	158	225	75									519
	Sweet corn	20 Dec	1.3	161	204	57									29	451
	Onions	10 Apr	3.1				32	43	60	84	126	164	113			622
	Vineyards	01 Aug	0.7	154	108	46					47	67	105	134	147	808
	Carrots	15 Sep	1.9									31	142	217	90	480
	Estimation for system			**131**	**148**	**122**	**31**	**4**	**4**	**20**	**51**	**133**	**189**	**155**	**62**	**1 051**
WUA	**Estimation for system**			**126**	**134**	**115**	**58**	**1**	**2**	**19**	**46**	**129**	**188**	**176**	**78**	**1 072**

APPENDIX 7.7.2.1

COMPARISON OF THE IRRIGATION REQUIREMENT FOR THE CROP ROTATION SYSTEM OF THE ORANGE-VAAL WUA AS ESTIMATED WITH AID OF SAPWAT AND AS ESTIMATED BY THE WUA

Estimation	Crop	Planting or starting date	%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
SAPWAT	Pastures, annual	15 Mar	1.6			65	80	91	73	84	86					479
	Pastures, perennial	01 Aug	2.3	189	133	120	83	64	49	57	80	107	141	162	178	1 363
	Potatoes	10 Jan	9.6	80	202	216	140									638
	Beetroot	01 Sep	1.1									75	232	184		491
	Dry beans	10 Jan	0.4	73	198	192	8									471
	Ground nuts	15 Oct	1.5	355	232	63							33	91	253	1 027
	Ground nuts	15 Dec	0.3	112	227	226	75								38	678
	Cotton	15 Oct	3.7	296	243	182	13						29	76	179	1 018
	Wheat	15 Jul	51.4							20	57	164	268	239		748
	Lucerne	01 Aug	16.8	233	164	138	30				55	124	176	202	222	1 344
	Maize	15 Dec	32.1	197	248	85									39	569
	Pecan nuts	01-May	0.7	237	167	151	104	81	62	74	105	136	179	205	225	1 726
	Cucurbits	15 Oct	0.8	188									51	182	262	683
	Sunflower	12 Jan	4.5	48	125	249	101									523
	Onions	15 Apr	2.0				26	44	61	95	134	174	162			696
	Vineyards	01 Aug	3.3	171	111	48					50	71	117	148	162	878
	Carrots	05 Sep	2.6									63	190	231	29	513
	Estimation for system			**142**	**154**	**98**	**28**	**4**	**4**	**15**	**47**	**117**	**188**	**180**	**74**	**1 053**
WUA	**Estimation for system**			**173**	**145**	**57**	**12**	**2**	**1**	**17**	**38**	**113**	**167**	**160**	**146**	**1 030**

APPENDIX 7.8.1

CHANGE IN IRRIGATION REQUIREMENTS OF THE ORANGE-RIET WUA IF VINEYARDS SHOULD INCREASE BY 50%

Crop		%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Crop combination		50	131	148	122	31	4	4	20	51	133	189	155	62	1 051
Vineyards		50	154	108	46					47	67	105	134	147	808
Irrigation requirement			**143**	**128**	**84**	**16**	**2**	**2**	**10**	**49**	**100**	**147**	**145**	**105**	**930**

CHANGE IN IRRIGATION REQUIREMENTS OF THE ORANGE-VAAL WUA IF VINEYARDS SHOULD INCREASE BY 50%

Crop		%	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Crop combination		50	142	154	98	28	4	4	15	47	117	188	180	74	1 053
Vineyards		50	171	111	48					50	71	117	148	162	878
Irrigation requirement			**178**	**133**	**74**	**14**	**2**	**2**	**8**	**49**	**94**	**153**	**165**	**128**	**997**

APPENDIX 8.1

RECOMMEND QUESTIONNAIRE FOR APPLICATION OF SAPWAT IN THE DETERMINATION OF IRRIGATION REQUIREMENTS

RESPONDENT

Name	
Organisation	
Address	
Telephone	
Fax	
E-mail	
Date	

AREA INFORMATION

Each combination of a sub-unit of a water user association and drainage area forms a unit. A complete questionnaire must be completed for each unit. If an administrative area is meaningfully subdivided, use that subdivision and complete a questionnaire for each subdivision.

Province	Northern, North West, Gauteng, Mpumalanga, Northern-Cape, Free State, Kwazulu-Natal, Western-Cape, Eastern-Cape
Magisterial district	
Drainage area (Quartenary)	
Land type	
Name of WUA, etc.	
Type of organisation	WUA, water board, etc.
Name of sub area	
Names of weather stations in area	

FARMERS, FARMS & SCHEDULED AREA (community farming excluded)

Area scheduled	Number of farms
0 – 5	
6 – 10	
11 – 25	
26 – 50	
51 – 100	
101 – 250	
251 – 500	
501 – 1 000	
1 000 +	

COMMUNITY FARMING

Number	
Total area (Ha)	
Number of participants	

PROVISION OF WATER

- Permanent irrigation is where soil is permanently cultivated and where the major source of water replenishment is irrigation.
- Supplementary irrigation is where rainfall is usually enough for rain-fed agriculture, but where irrigation is sometimes necessary, or is applied during critical growth periods to increase or stabilise production.
- Opportunistic irrigation is where irrigation only takes place when water is available, for example the "saaidam" system found in Namaqualand and Bushmanland.
- The source can be seen as permanent if it can supply an adequate amount of water for at least 70% of the time.
- Relative importance shows the relative importance of different water sources for different types of irrigation. The total must add up to 100.

Application	Relative importance (%)	Source			
		Surface water		Bore holes	
		Relative importance (%)	Permanent (Yes or No)	Relative importance (%)	Permanent (Yes or No)
Permanent irrigation					
Supplementary irrigation					
Opportunistic irrigation					
Total	100	XXXXXXXX	XXXXXXXX	XXXXXXXX	XXXXXXXX

SCHEDULED AREA AND WATER QUOTA

Annual quota (m^3/ha/jaar)	
Scheduled area (Ha)	
Area cultivated (Ha)	

Describe any deviations or adaptations on the water quota, e.g. buying of extra water, exchange or selling actions, seasonal distribution of water, etc.

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SOIL

- Non-ploughable refers to soil that, because of limited soil depth, rock, erosion, climate, watercourses, or other limitations, should not be cultivated within the framework of generally applicable techniques and/or by the average farmer.

- High-, medium- and low potential classes refer to the irrigation potential according to ISCW norms applicable to a specific area.

Usage	Ha	Potential class	Dominant texture class	Present usage (Ha)	Additional potential (Ha)	Total (Ha)
Field crops, Vineyards, Fruit, Horticulture, Hay, Silage		High				
		Medium				
		Low				
		Non-ploughable				
Pastures		High				
		Medium				
		Low				
		Non-ploughable				
Flowers and ornamentals		High				
		Medium				
		Low				
		Non-ploughable				
Forestry		High				
		Medium				
		Low				
		Not ploughable				
Non agriculture		High				
		Medium				
		Low				
		Non-ploughable				

WATER QUALITY
Mark only the blocks where water quality suppresses production, limits crop choice, or where the soil is in danger of becoming saline as a result of bad water quality.

Usage	Source	
	Surface water	Bore holes
Permanent irrigation		
Supplementary irrigation		
Opportunistic irrigation		

WATER LOGGING AND salinisation

- Serious water logging and salinisation is where agricultural production is no longer possible without special remedial actions, such as installation of artificial drainage.

- Less serious water logging and salinisation is where agricultural production is still possible, but where the production potential is suppressed and/or the crop choice is limited.

Degree of water logging and salinisation	% of irrigated area
Serious water logging and salinisation	
Less serious water logging and salinisation	

IRRIGATION SYSTEMS

Evaluate suitability in terms of applicability for the soil-crop-climate combination

Type	Relative importance (%)	Suitability (1 – 3, where 1 = Not suitable and 3 = Very suitable)
Flood- and furrow irrigation		
Sprinkler irrigation		
Micro- and drip irrigation		
Total	100	XXXXXXXXXXXXXXXXXX

WATER MANAGEMENT

- Work per water year

- Get the actual water usage of an area and fill in against the months

- Calculate the area system water requirement and fill in against the months

Survey		Office calculations		
Months	Water extracted (m^3)	Water require-ment (m^3)	Difference (Abso-lute) (m^3)	Deviation (%)

PROFILE AVAILABLE WATER (MANAGEMENT) AT THE BEGINNINGOF SEASON

Wet	
Semi wet	
Dry	

CROP PRODUCTION

- `all crops grown must be shown.
- If "fallow" is of essence in the system, it must be indicated.
- The sum of the percentages total crop composition need not be 100.
- The sum of the potentials per potential class must be 100.
- Production is expressed in the following terms:
  - All crops sold by weight, **ton/ha**
  - Pastures: **LSU/ha** daily average for the production period of the crop
  - Flowers: **Pedicles/m^2**
  - Ornamentals: **Number/ha**
  - Wood: **m^3/ha**

(i) Crop (ii) Planting date (iii) Growing season	Product	Relative importance				Suitability (1 – 5), where 1 = Very poor and 5 = Very good)	Level of production	Production per land class		
		Per total crop composition (%)	Per land potential class					High	Average	Low
			High (%)	Med (%)	Low (%)					
Lucerne 1 August 365 days	Hay						Average farmer			
							Top farmer			
							Experimental			
Lucerne 1 August 365 days	Pasture						Average farmer			
							Top farmer			
							Experimental			
							Average farmer			
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							Average farmer			
							Top farmer			
							Experimental			

ALTERNATIVE CROPS

- Show potential alternative crops for the area

- Production is expressed in the following terms:
  - All crops sold by weight, **ton/ha**
  - Pastures: **LSU/ha** daily average for the production period of the crop
  - Flowers: **Pedicles/m^2**
  - Ornamentals: **Number/ha**
  - Wood: **m^3/ha**

(i) Crop (ii) Planting date (iii) Growing season	Product	Potential relative importance				Suitability (1 – 5), where 1 = Very poor and 5 = Very good)	Potential production
		Per total crop combination (%)	Per land potential class				
			High (%)	Med (%)	Low (%)		

HISTORIC DEVELOPMENT

What is the development history of the scheme. Describe specifically:

- Reasons for development (Original objectives)
- Development phases, specifically relating to infrastructure
- Development phases of water supply and reasons
- Farm sizes and reasons
- Development of changes in farming patterns and reasons
- Development of changes in management practices of the scheme and reasons

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FARM MANAGEMENT

Say your son or son-in-law wants to start farming in the area and you must advise him. What are you going to tell him? Accentuate the following:

- How do the farmers irrigate, specifically with the eye on water management (for example, how many times, how much per irrigation, problems, bottlenecks, deviations from normal and reasons)
- What are the problems and/or bottlenecks pertaining to irrigation in the area
- What is planted and why
- How are the crops managed
- Fertilisation
- Plant and pest control

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