DEPARTMENT OF WATER AFFAIRS
Directorate of Project Planning

ORANGE RIVER SYSTEM ANALYSIS

Historical and future water demands and return flows

Report no 4564/02

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EXECUTIVE SUMMARY

The Orange River System Analysis is being undertaken to determine the yield characteristics of the system in order to ensure the economic utilisation of its water resources. The analysis includes a hydrological investigation using climatic and physiological information for the period from 1920 to 1988. The likely future behaviour of the system is then modelled based on the historical hydrological assessment and potential problems concerning supply and demand imbalances can be isolated. To ensure satisfactory results, the system analysis depends upon details of all the water consumed, returned to or transferred from the system, and this report outlines all of these findings. The demands and return flows for the Riet and Modder Rivers are also included as these rivers form an integral part of the system. However, the demands and return flows for the Vaal River were assessed under the Vaal River System Analysis.

Irrigation is the major consumer of water from the Orange River System and an area of some 1 120 km^2 is irrigated directly with Orange River water. Table 1 gives a summary of all the irrigated areas along the various river sections of the Orange River System. The estimated crop water requirements for these river sections are outlined in table 2, from which an average requirement of 10 750 m^3/ha/a is estimated. Thus, the total annual crop water requirement from the Orange River is believed to be in the order of 1 $200.10^6 m^3$/a, although the full requirement is probably not supplied.

The volumes of water consumed by the urban and industrial sectors are not of the same magnitude as that consumed by agriculture. A number of point abstractions for urban and industrial uses occur along the river and a few distribution networks are in operation. The Bloemfontein area in particular is supplied by an extensive distribution system which is made up of a large number of consumers. An inter-basin transfer also exists from the Hendrik Verwoerd Dam to the Great Fish and Sundays Rivers.

Table 1 : Summary of the estimated areas under irrigation at present along the various river sections of the Orange River System

River Section	Area (ha)
Modder River upstream of Krugersdrift Dam	4 400
Riet River upstream of Kalkfontein Dam	7 700
Modder River downstream of Krugersdrift Dam	3 400
Riet River downstream of Kalkfontein Dam	7 750
Lower Riet River	2 640
Caledon River upstream of Welbedacht Dam	3 680
Caledon tributaries	3 850
Kraai River	2 500
Stormberg River	1 500
Orange River upstream of Hendrik Verwoerd Dam	4 100
Caledon River downstream of Welbedacht Dam	4 840
Orange River upstream of P.K. le Roux Dam	1 400
Orange River downstream of P.K. le Roux Dam	11 000
Orange-Riet Canal	6 350
Orange-Vaal Canal	4 500
Brak and Ongers River	3 000
Middle Orange River	8 000
Boegoeberg Scheme	8 780
Upington Islands Scheme	12 930
Kakamas Scheme	5 440
Namaqualand	4 250
Total	112 010

Table 2 : Summary of the estimated crop water requirements along the various river sections of the Orange River System

River Section	Requirement (m^3/ha/a)
Riet and Modder Rivers	11 000
Caledon River upstream of Welbedacht Dam	7 500
Caledon River downstream of Welbedacht Dam	9 000
Orange River upstream of Hendrik Verwoerd Dam	8 000
Kraai River	8 000
Stormberg River	8 000
Orange River upstream of P.K. le Roux Dam	11 000
Orange River downstream of P.K. le Roux Dam	11 000
Orange-Riet canal	11 000
Orange-Vaal canal	10 000
Brak and Ongers Rivers	13 000
Middle Orange River	13 000
Lower Orange River	15 000
Namaqualand	15 000

The main objective of this report is to establish the principle consumers of Orange River water and the volumes consumed and returned to the system. The determination of the historical growth in water demands and an assumption of the future demand trends are also considered.

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HISTORICAL AND FUTURE WATER DEMANDS AND RETURN FLOWS

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1 PURPOSE OF THE PROJECT

The Orange River System Analysis is being undertaken to determine the yield characteristics of the system in order to ensure the economic utilisation of its water resources. The analysis involves a hydrological investigation using recorded data from the past 60 years, based upon which the likely future operation of the system is to be modelled. The evaluation of the water consumed, returned to or transferred from this system is of the utmost importance for the analysis. Thus, a comprehensive study of the demands and return flows in the Orange River System is required.

This report outlines all the water demands, abstractions and return flows of the Orange River and its tributaries (excluding the Vaal River). The demands and return flows for the Riet and Modder Rivers are also included as these rivers form an integral part of the system. Irrigation is the major consumer of water from the Orange River System, however, a number of point abstractions for domestic and industrial uses occur along the River and its tributaries. The Bloemfontein area in particular is supplied by an extensive distribution system and consists of a large number of consumers.

The main objective of this report is to establish the principal consumers of Orange River water and the volumes consumed and returned to the system. The determination of the historical growth in the water demands and an assumption of the future demand trends are also considered. Another fundamental aim is to identify all the areas under irrigation and give an account of the irrigation development. Thus, the areas of all the controlled, uncontrolled and proposed irrigation is ascertained, as well as the type of crops under irrigation in the particular areas. The crop water requirements can be calculated from this information and, along with the quotas for the controlled irrigation areas, the total water consumption may be determined.

The demand and return flows report summarises both the historical and expected future water consumption in the Orange River Catchment. It may be used as a working document from which information for the hydrological and stochastic analyses is obtained. It also forms a document on its own as a collation of an extensive amount of information from various sources, some of which may be subjective. Some of the material stated has been obtained from local agricultural personnel and is open to revision should more accurate or up-to-date information come to light.

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2 INTRODUCTION

2.1 GENERAL

The Orange River System Analysis will assess the water resources of the entire Orange River and tributaries, however, the Vaal River and the upper portion of the Orange River in Lesotho have been excluded. All the water from the Vaal River is required for use within its own catchment and this system has been analysed in another study. Likewise, a separate study is being made of the Senqu River (Upper Orange River in Lesotho) from which the Lesotho Highlands Water Project will augment the flow in the Vaal River. The Orange River System Analysis will include the Riet and Modder Rivers as the Riet River flows into the Vaal River just above the Orange-Vaal confluence. Thus, the Riet and Modder Rivers make a direct contribution to the flow in the Orange River. The Riet and Modder catchment is also an important part of the Orange System due to inter-basin transfers of Orange River water for both irrigation and urban uses.

The Orange River System virtually spans the whole subcontinent of Africa and drains almost the entire interior plateau. The River arises in the Natal Drakensberg on the eastern border of Lesotho, and flows westwards for some 2 250 km to the Atlantic Ocean. It has a catchment area of about one million square kilometers of which only 290 000 km^2 lies above the confluence of the Orange and Vaal Rivers. Nonetheless, this upper portion contributes a major portion of the stream flow. The catchment accounts for 47 % of the total area of the Republic of South Africa (RSA), however, the mean annual runoff (MAR) of about 11 400 million m^3 is only 14 % of the country's total MAR. This is due to the low rainfall over most of the catchment as well as the poor rainfall to runoff ratio caused by the extensive evaporation losses in the western interior.

Three large rivers contribute to the flow in the Orange River apart from the Senqu River in the Lesotho Highlands. The Orange River System location map in Appendix A shows the whereabouts of the river's making up the system. The first major tributary joining the Orange River outside Lesotho is the Kraai River, the confluence of which is just upstream of Aliwal North in the north eastern Cape Province. The next major tributary is the Caledon River which meets the Orange further downstream near Bethulie in the southern Orange Free State. These rivers along with the Senqu River form the headwaters of the Orange River. Finally, the Orange and Vaal Rivers converge in the vicinity of Douglas in the northern Cape Province.

Rainfall within the Orange catchment is low with virtually no rain falling on the west Coast. The mean annual precipitation (MAP) gradually increases in an easterly direction to about 600 mm at the Lesotho border. The rainfall gradient then rises sharply to well above 1 000 mm on the Natal Drakensberg. Evaporation losses from the catchment are high with much of the river along its course through Namaqualand being subject to annual evaporation losses from an open water surface of greater than 2 700 mm. The mean annual evaporation at the source of the Orange River is in the region of 1 200 mm which is below the MAP in some places.

The Orange River catchment consists of many topographic features with a variety of natural vegetations. It also experiences a wide range of climatic conditions. The source of the Orange and area of major runoff production is in the Lesotho Highlands. The river flows from Lesotho through the undulating grasslands of the southern Orange Free State and north eastern Cape Province. From there the river follows a course along most of the northern part of the Karoo, then forms the international border between the RSA and South West Africa (SWA). This region is virtual desert with the valley bottom well below the general elevation of the surrounding rugged terrain. The topography within the immediate vicinity of the river has influenced the development of irrigation from the Orange.

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2.2 CATCHMENT DEVELOPMENT

Irrigation is the major consumer of water from the Orange River, however, urban consumers must be conidered and the rapidly growing peri-urban areas in and around Bloemfontein require substantial amounts of water. Industrial growth in the Orange River Catchment has been minimal and in most instances the industrial water requirements have been included along with the urban demands. Only a few mining centres are worthy of mention, namely, Koffiefontein where diamonds are mined, the Black Mountain Mineral Development Company (Pty) Limited which falls under the jurisdiction of the Pelladrift Water Board and Consolidated Diamond Mines at Oranjemund in SWA. Before continuing with the specific details of the irrigation and urban demands, abstractions and return flows, a brief overview of the development of irrigation in the Orange River catchment is given.

Two modes of irrigation exist in the Orange basin:

- controlled irrigation, and
- diffuse irrigation.

Controlled irrigation is that which is governed by a body such as a State Water Scheme or an Irrigation Board whereby some quota system ensures that demands are satisfied. Diffuse irrigation is not controlled in any way except by normal water laws. Irrigation in a diffuse mode is supplied from farm dams, springs, flowing streams and rivers, whereas controlled irrigation generally is on a much larger scale and is supplied by major rivers and dams. Most of the irrigation within the catchment is from the main perennial rivers, although a fair amount of uncontrolled irrigation does occur in the upper reaches of the catchment.

Irrigation using groundwater sources will not be considered in the context of the Orange River System Analysis. The assumption is that only relatively small areas are irrigated from the groundwater and this will have very little direct affect on the streamflow. Any increased runoff due to this irrigation will be insignificant and the fact that the groundwater reserves are being depleted to satisfy this demand implies that the stream flows should not be reduced.

Irrigation from the Orange River started as far back as the end of the last century. The irrigation developed in small patches along the Orange River and its tributuaries and has led to the establishment of both State Water Schemes and private Irrigation Boards. These bodies control various sections of the rivers, manage the development of the irrigation and ensure water supply and the fair allocation of rights.

Irrigation along the Orange River is controlled by State Water Schemes for a considerable portion of its length, especially in the lower reaches. From the Lesotho border to the P.K. le Roux Dam the river bed is well below the level of the surrounding land making the pumping of water expensive. This has prevented any large scale irrigation development in the area. The greater part of the irrigation occurs downstream of the P.K. le Roux Dam to the Augrabies Falls. Large sections of the Riet and Modder Rivers are also controlled by State Water Schemes whereby dams were built to control the flows downstream or to supply irrigation canals. Irrigation Boards exist within these schemes to manage matters at a local scale as well as to institute some limited development.

Field surveys of the early 1960's revealed that there was insufficient economically situated irrigable soil within the catchment of the Orange River to allow the water resources to be fully utilized. This brought about the idea of the Orange River Development Project whereby it would be possible to transfer Orange River water to other catchments where the resource can be fully developed (White Paper X-62).

A brief outline of the designation of the water resources of the Orange River System as established in the Development Project follows. Water from the Caledon River is reserved for supplementing the flow in the Modder River and for satisfying the urban demand of the greater Bloemfontein area. A proportion of the water from the Senqu River in the Lesotho Highlands is to be used to augment the flow in the Vaal River via the Lesotho Highlands Water Project. Finally, some of the Orange River water is now being transferred into the Great Fish and Sundays Rivers to relieve the water stress experienced by the irrigation farmers there.

The results of the field surveys given in White Paper X-62 are summarised in table 2.1. This table indicates the areas of existing and potential irrigable lands that may be supplied by water from the Orange River. Subsequent studies have revealed that much of this area would not be feasible to irrigate, and the eventual area to be served by Orange River water will be substantially less than that given in Table 2.1.

Much of the Orange River Development Project has been implemented since it was first envisaged in 1962. The Hendrik Verwoerd Dam was completed in 1971 for the purposes of flow regulation, power generation, silt control and water supply. The dam also feeds the Orange-Fish tunnel which supplements the water resources of the Great Fish and Sundays Rivers. This tunnel became operational in 1975. The P.K. le Roux Dam was built 130 km downstream of the Hendrik Verwoerd Dam, and its functions are to generate

Table 2.1: Existing and potential irrigable areas (ha) considered initially in the Orange River Development Project (White Paper X-62).

Irrigable Areas	Area (ha)	Total
LAND WITHIN THE ORANGE RIVER CATCHMENT:		
PK le Roux Dam area	30 000	
Riet River area	3 400	
Downstream Vaal/Orange to Prieska	23 000	
Beervlei-Brak River area	42 800	
Luckhoff, Kaffir River, Sak River and Witsand areas which can be served by P K le Roux Dam	80 500	
Boegoeberg Dam to Augrabies Falls	24 000	
Augrabies Falls to Alexandar Bay	7 700	211 400
LAND OUTSIDE THE ORANGE RIVER CATCHMENT:		
Great Fish River area	66 750	
Lower Sundays River area	2 550	
Upper Sundays River area	27 400	96 700
Total		308 100

power, regulate the river flow as well as to supply water for irrigation. The dam was completed in 1977 and its high wall has made possible the development of the high lying riparian land below the dam for irrigation purposes. This dam ultimately controls all the irrigation downstream to the mouth either by regulating the flows and levels of the river, or directly by canal systems.

The original proposal of the Orange River Development Project envisaged an extensive canal system below P.K. le Roux Dam, however, it has been found that pumping directly from the river is less expensive. Development has only occurred along the right bank with the Van der Kloof and Ramah Branch Canals serving downstream riparian farms. Irrigation from these canals only commenced in 1983. The Orange-Riet or Sarel Hayward Canal was completed in 1986 and is used to supply the Riet River State Water Scheme. The resources of this scheme have proved inadequate to meet the crop water requirements. A new addition to the Development Project is the takeover and improvement of the Orange-Vaal Canal which supplies the Orange-Douglas State Water Scheme. This scheme was faced with severe water restrictions and supplied with poor quality water until the construction of the canal. The Orange River Development Project has also provided for the supply of urban water.

The urban demands of Bloemfontein and the surrounding areas have outgrown the resources of the Modder River. To resolve this problem the Welbedacht Dam was constructed in 1973 along with the purification works and pipeline to supply potable water to the Bloemfontein area. The silting up of Welbedacht Dam resulted in the water supply being inadequate and the demands could not be met. Thus, the Knellpoort Dam on the Rietspruit was constructed as an off-channel storage dam which is supplied by water from the Caledon River. Water may be diverted in the future from the Knellpoort Dam into the Modder River by means of pumping. This water may then be used by the existing purification and distribution system on the Modder River. The Knellpoort Dam also augments the supply of water from the Welbedacht Dam when storage levels drop.

The future phases to be considered in the Orange River Development Project are not clear. One certainty is that irrigation will develop as far as possible but will be limited by the crop prices and development costs. The supply of Orange River water to some southern Orange Free State towns will also be assessed. The present economic climate, the escalation in construction costs and the poor crop prices, expecially maize, has curtailed a lot of the envisaged development. Bearing this in mind as well as the history of the Orange River Development Project, the historical and future water demands and return flows of the Orange River System are now evaluated. Due to the fact that irrigation is the largest consumer of Orange River water, the irrigation requirements are discussed separately from the urban and industrial requirements.

3 IRRIGATION REQUIREMENTS

3.1 RIET AND MODDER CATCHMENT

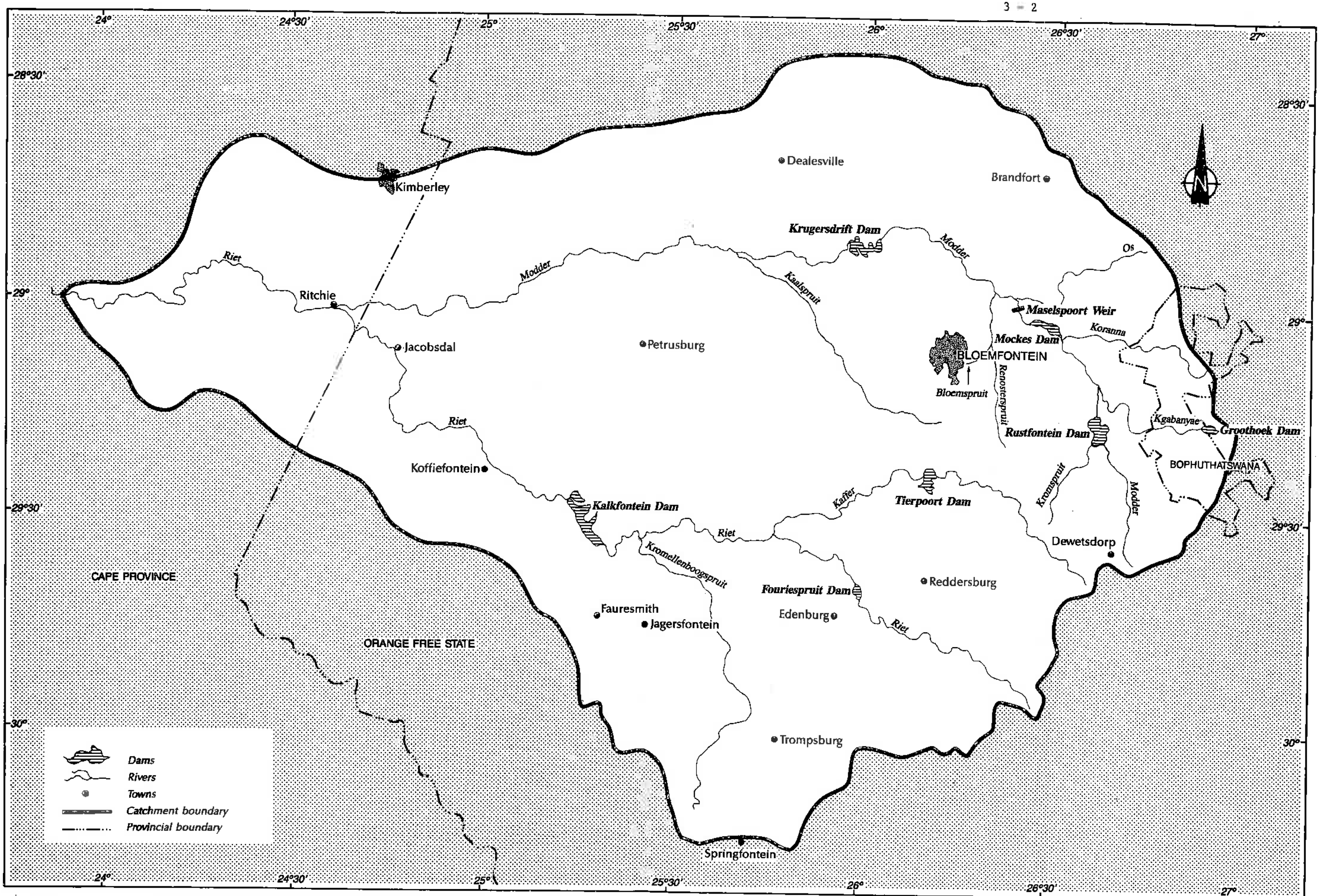
3.1.1 General

The Riet and Modder rivers do not form part of the Orange River basin, however, they do make a considerable contribution to the flow in the Vaal River which enters the Orange a short distance downstream at Douglas. Water from the Orange and Caledon Rivers is also consumed in the Riet and Modder Catchment via inter-basin transfers. Thus, it is important to assess this catchment along with the Orange basin as it forms an integral part of the Orange River System.

3.1.2 Catchment description

The Riet and Modder Rivers are the only major rivers in this catchment, however, some tributaries make contributions to the flow. Figure 3.1 shows the locations of all the major rivers and dams in the Riet and Modder Catchment. The Kaffer River is a right bank tributary of the Riet River, on which the Tierpoort Dam was constructed for irrigation purposes in the early 1920's. This Dam was washed away in the floods of 1988 but is being rebuilt to its original capacity. Just downstream of the confluence of the Kaffer and Riet Rivers is the Kalkfontein Dam which was built in 1938 to supply water to the Riet River State Water Scheme.

The Modder River is the main tributary of the Riet River the confluence of which is just upstream of Ritchie. Three dams are situated along the length of the Modder River the most upstream of which is the Rustfontein Dam. This dam came into operation in 1954 and is the major source of water for Bloemfontein, Botshabelo and the rapidly growing areas of Thaba 'Nchu in Bophuthatswana. Mockes Dam is situated

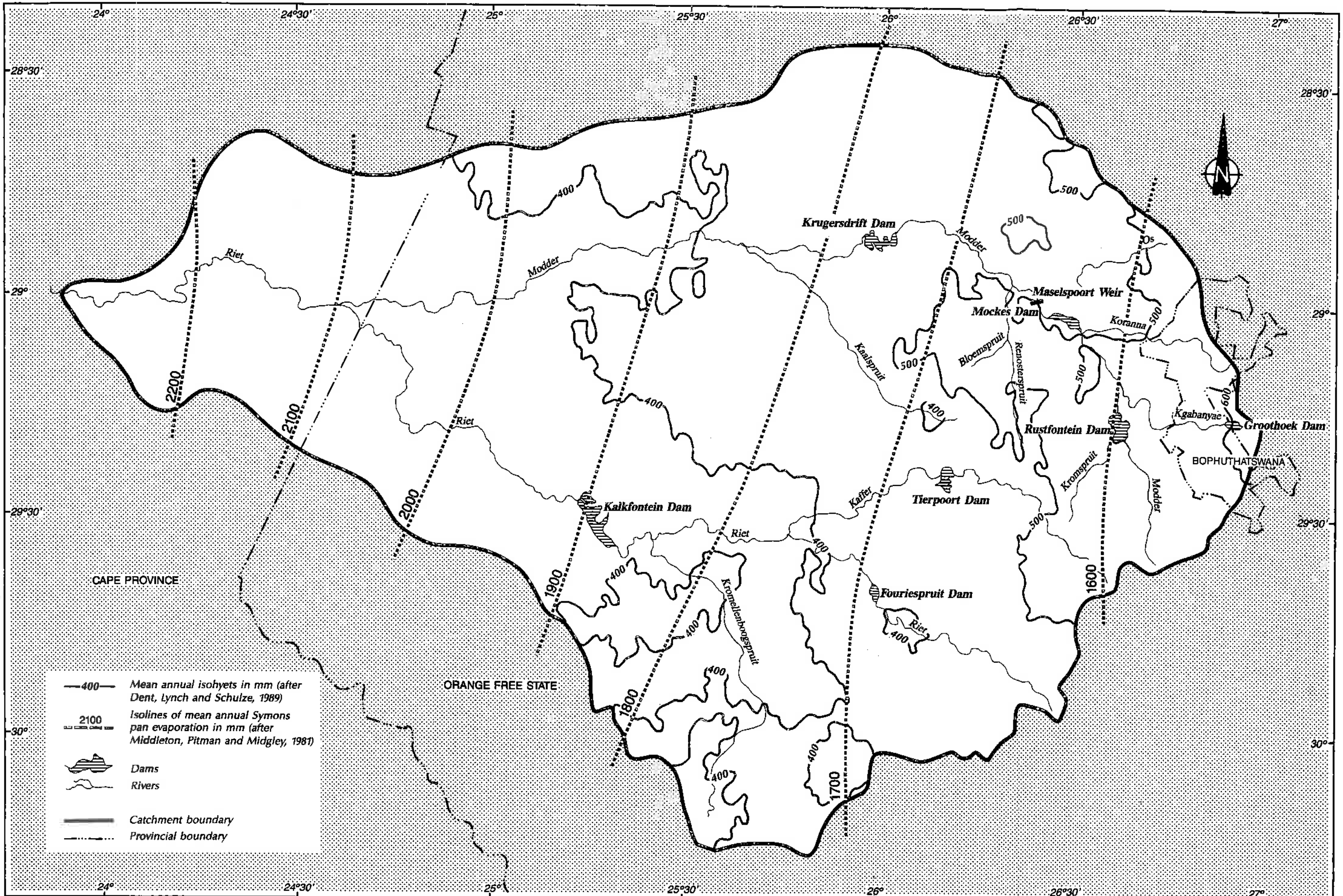


ORANGE RIVER SYSTEM ANALYSIS

Riet and Modder catchment : rivers and towns **3.1**

downstream of the Rustfontein Dam and is the source for the Bloemfontein purification works at Mazelspoort Weir. The Krugersdrift Dam is sited on the Modder River to the north west of Bloemfontein and has supplied the Modder River State Water Scheme by controlled releases since 1971. The Groothoek Dam near Thaba 'Nchu is on the Kgabanyae River in Bophuthatswana, the water from which eventually flows into the Modder River.

The area of the Riet and Modder catchment is 32 800 km^2 (Middleton, Pitman and Midgley, 1981) and is made up of flat or undulating terrain. Only 19 300 km^2 of the total area contributes to the streamflow, the rest is made up of pans or enclosed drainage basins. The catchment vegetation varies from a Kalahari thornveld invaded by Karoo in the west to grassland in the east. The rainfall over the area is low with the MAP ranging from 600 mm in the east to less than 400 mm in the west. The isohyetal map in figure 3.2 indicates the rainfall gradients over the catchment. It is a summer rainfall region with most rain falling in the first three months of the year. The average evaporation from an open water surface varies from 1 600 mm per annum to greater than 2 200 mm, the evaporation increasing in a westerly direction along the catchment. Figure 3.2 also shows the isolines of the annual evaporation losses as measured by a Symons pan evaporimeter. The climate is typical of the highveld with warm summers and cold winters. The mean daily maximum temperatures in summer reach about 30 °C and the minimum for winter almost drops to freezing when a fair amount of frost occurs. Although much dryland agriculture is practiced, substantial increases in yield are obtained by irrigation, consequently much of the potentially irrigable areas have been developed.



Riet and Modder catchment : rainfall and evaporation isolines **3.2**

3.1.3 Irrigation

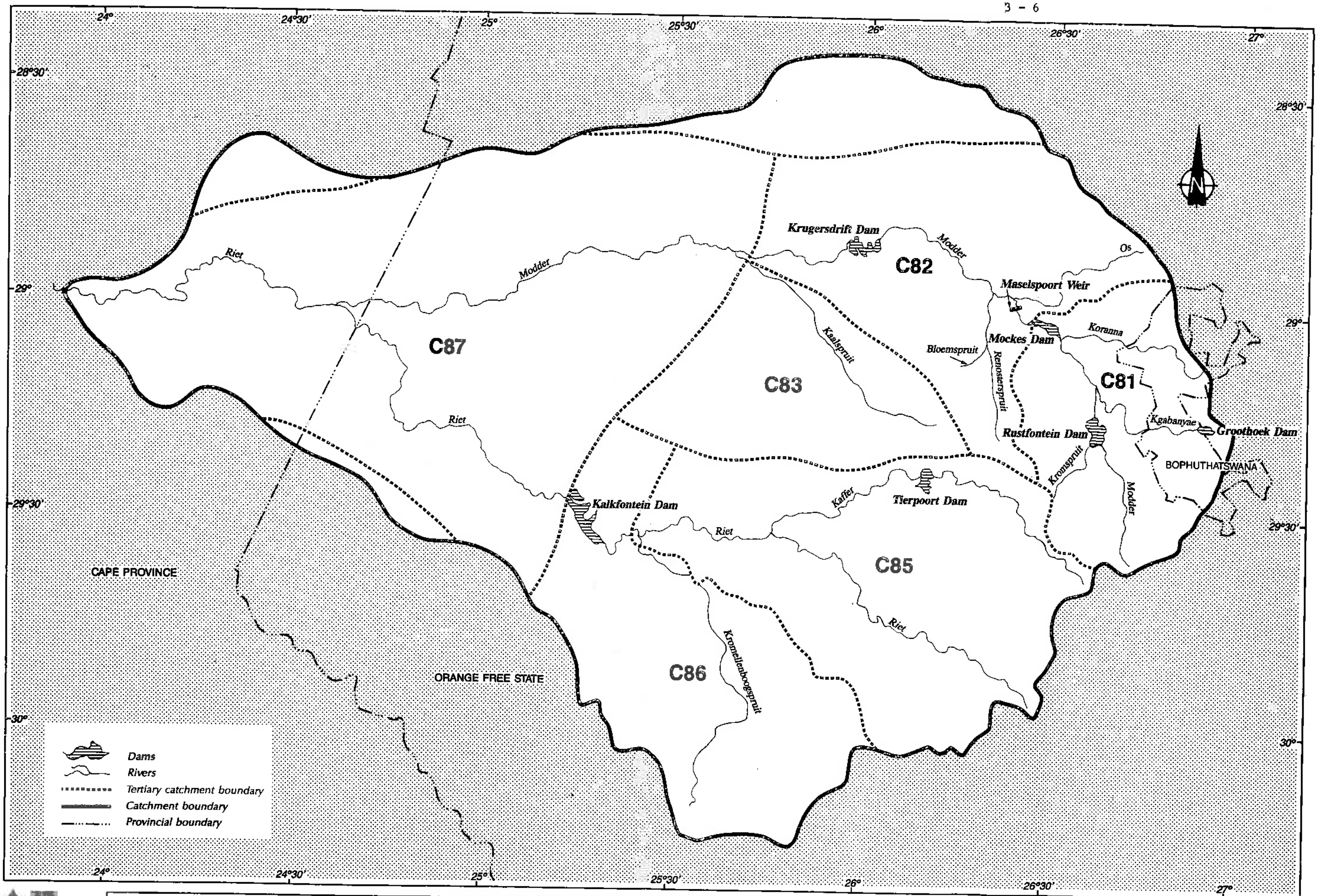
3.1.3.1 Overview of existing irrigation studies

The extensive development of irrigation in the Riet and Modder catchment has resulted in the formation of State Water Schemes and Irrigation Board Schemes. The Schemes that control and ensure the supply of water to irrigators on both the Riet and Modder Rivers and are listed below:

- Modder River,
- Riet River,
- Lower Riet River,
- Roodeheuwel Irrigation Board, and
- Kaffer River Irrigation Board.

Diffuse irrigation also occurs throughout the catchment on a large scale, the sources of the water being farm dams, rivers and streams.

A study of the Surface Water Resources of South Africa by Middleton et al. (1981) includes an assessment of the irrigation in the Riet and Modder Catchment. Table 3.1 summarises this information which was originally obtained from an Agricultural Census. Middleton et al. (1981) divided the area into tertiary catchments for which irrigation areas are given. The tertiary catchments of Middleton et al. (1981) have been superimposed on the catchment map at the Riet and Modder Rivers in figure 3.3. At places the tertiary catchment boundary has deviated from the main catchment boundary due to the difficulty in determining the watershed in the very flat areas at this catchment. Most of the controlled irrigation (Government Schemes and Irrigation Boards) occurs in the lower part of both rivers (tertiary catchment C87). The larger proportion of the diffuse irrigation (that uncontrolled irrigation from farm dams and streams) occurs further up the catchment, particularly on the Kaffer River and the upper Riet (tertiary catchment C85 and C86).



ORANGE RIVER SYSTEM ANALYSIS

Riet and Modder catchment : HRU tertiary subcatchments **3.3**

Table 3.1: Areas irrigated (ha) according to the source of water in the tertiary catchments of the Riet and Modder Rivers (Middleton et al., 1981).

HRU tertiary catchment	Source of water				Total
	State schemes	Irrigation boards	Springs & rivers	Farm dams	
C81	70	100	530	1 540	2 240
C82	170	40	810	1 130	2 150
C83	150	40	580	610	1 380
C85	80	490	2 510	1 990	5 070
C86	30	10	1 510	1 150	2 700
C87	8 280	1 560	3 320	180	13 340
Total	8 780	2 240	9 260	6 600	26 880
	11 020		15 860		

The Census for Agriculture (1981) also has information regarding irrigation in the Riet and Modder catchment and is given in table 3.2. The areas under irrigation have been tabulated according to the magisterial districts in which they lie, portions of which may fall outside the catchment However, this gives a good index of the irrigation within the catchment. The area under controlled irrigation (11 705 ha) ties in closely to the 11 020 ha obtained by Middleton et al. (1981), however, the area of 10 814 ha under diffuse irrigation is almost 5 000 ha less than the value obtained by Middleton et al. (1981). It is difficult to estimate the diffuse irrigation area and the results of the Census of Agriculture (1981) indicate that there is as much land under diffuse irrigation as under controlled irrigation in the catchment. A more detailed description of the controlled irrigation schemes is now given.

Table 3.2: Areas irrigated (ha) according to the source of water in the magisterial districts of the Riet and Modder catchment (Census of Agriculture, 1981).

Magisterial District	State water schemes	Irrigation board schemes	Springs, Rivers & streams	Farm dams	Total
Herbert	2 843	1 787	1 894	9	6 533
Fauresmith	1 381	-	114	13	1 508
Jacobsdal	3 214	302	375	11	3 902
Koffiefontein	697	26	73	3	799
Bloemfontein	90	727	1 351	261	2 429
Petrusburg	502	132	109	14	757
Dewetsdorp	4	-	300	1 227	1 531
Reddersburg	-	-	739	320	1 059
Edenburg	-	-	1 809	930	2 739
Trompsburg	-	-	484	554	1 038
Jagersfontein	-	-	210	14	224
Total	8 731	2 974	7 458	3 356	22 519
	11 705		10 814		

3.1.3.1 Controlled irrigation

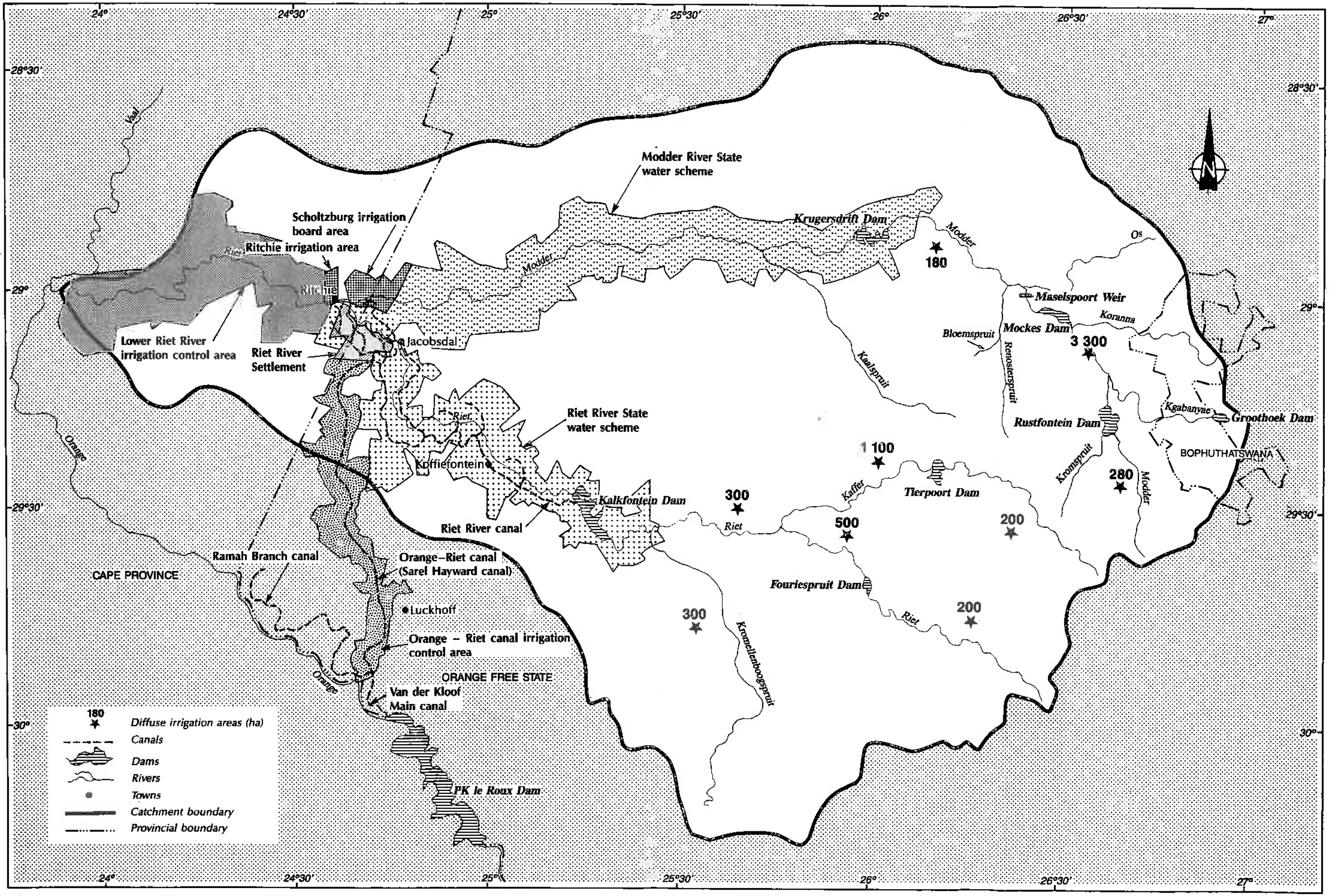
Five bodies monitor the irrigation within the Riet and Modder catchment. Figure 3.4 indicates the controlled irrigation areas as well as the canals which supply the water. Information from the Department of Water Affairs (1989) as to the areas irrigated under these bodies is given in table 3.3. It must be noted that from time to time the management of the Irrigation Boards change hands and the State may control some Boards, the areas of which will be included within the State Water Scheme. This is the case with the Scholtzburg Irrigation Area which has been included under the Modder River Scheme. The total area of the controlled irrigation given in table 3.3 (15 218 ha) is somewhat higher than the 11 020 ha given by Middleton <u>et al.</u> (1981). This discrepancy is probably due to substantial irrigation developments which have taken place during the past decade.

Table 3.3: Areas irrigated during 1984 on the controlled schemes of the Riet and Modder catchment (Department of Water Affairs, 1989).

Scheme name	River	Area (ha)	Total
STATE WATER SCHEMES:			
Modder River	Modder	3 400	
Riet River	Riet	7 752	11 152
IRRIGATION BOARDS:			
Lower Riet River	Riet	2 790	
Kaffer River	Kaffer	1 096	
Roodeheuwel	Modder	180	4 066
Total			15 218

The Modder River State Water Scheme extends along the Modder River from upstream of the Krugersdrift Dam to Ritchie, below the confluence of the Riet and Modder Rivers. Over the years various schemes and boards were established with the idea of developing irrigation along the Modder River, but the construction of Krugersdrift Dam was the first major step. The Krugersdrift Dam came into use in 1963 and its main purpose is to stabilise the flow in the Modder River and give riparian irrigators a more assured supply of water. Riparian farms in the lower Riet River area below Ritchie also benefit from the Dam.

The dam originally had a capacity which ensured sufficient water for the irrigation during the summer months of 240 mm (14400 m^3/ha/a) to the 3 425 ha under irrigation along the Modder and Lower Riet Rivers (White Paper 0-63). It was proposed to raise the dam wall in 1967 and provision has also been made to increase the storage capacity still



Riet and Modder catchment : irrigation areas **3.4** further. Over the years the area under irrigation in the Modder River State Water Scheme has remained fairly constant, and the Department of Water Affairs (1989) maintained that 3 400 ha was under irrigation in 1984.

Weirs have also been constructed on the Modder River upstream of Krugersdrift Dam at Eureka and Roodekop to supply the Roodeheuwel Irrigation District. These weirs were built in 1974 and supply water to riparian owners on both banks of the Modder River on which 347 ha of land was scheduled (White Paper C-74). The area scheduled in 1984 dropped to 180 ha according to the Department of Water Affairs (1989).

The lower Riet River irrigation area stretches from the town of Ritchie downstream of the Riet-Modder confluence, to just upstream of the Riet-Vaal confluence. By 1962 there were six storage weirs along this reach of the River (White Paper O-62). The dams further upstream the Riet and Modder rivers do not subsidise the storage in these weirs, however, the stabilised flow conditions do benefit the abstractors in this area. By 1962 some 1 322 ha was already under irrigation and 3 680 ha was estimated to be suitable for irrigation, however, there was insufficient water to develop this land. It was then proposed to build new weirs with sluices and reconstruct the old ones to improve the situation and enable further development. The Annual Report of the Department of Water Affairs (1983) indicated that some 2 790 ha was under irrigation at that time, and White Paper D-86 quoted that the area irrigated in 1986 was 2 640 ha.

The Riet River State Water Scheme consists of riparian farms along the Riet River downstream of Kalkfontein Dam to the Modder River and includes the Riet River Settlement near Jacobsdal. The scheme is supplied by a canal from the Kalkfontein Dam. The dam was completed in 1938 and the canal system became operational in 1942. The Scholtzburg and Ritchie Irrigation Districts are also supplied by the canal. In 1977 it was proposed that the dam wall be raised and a saddle dam be constructed to safegaurd the dam in heavy floods.

The first schedule appeared in 1943 which served 3 074 ha of land, and by 1951 a water quota of 11 200 m^3/ha/a was introduced (White Paper J-77). The scheduling amounted to 7 858 ha by 1977 of which 3 782 ha were situated at the Riet River Settlement. The water quota for the scheme was reduced and by 1977 was 9 100 m^3/ha/a, however, the rainfall generally supplemented this requirement and the demand was approximately 85 % of the quota (White Paper J-77). Subsequent investigations in 1984 revealed that the quota was not sufficient for satisfactory crop production and a supply of between 9 520 and 12 610 m^3/ha/a was required (White Paper H-84).

By 1986 the total scheduled area of irrigated lands had dropped slightly to 7 753 ha as the scheme had been developed to its maximum and the Kalkfontein dam was unable to satify all the demands at an acceptable level of assurance (White Paper D-86). The construction of the Orange-Riet Canal (Sarel Hayward Canal) from the P.K. le Roux Dam in 1987 made additional water supplies available to the scheme. This enabled the entire needs of the Riet River Settlement and the Ritchie and Scholtzburg Irrigation Districts to be satisfied (4 347 ha) while allowing for further development. The remaining area of the Riet River State Water Scheme (3 406 ha) is now supplied by Kalkfontein Dam. The quota for the scheme has been raised to 11 000 m^3/ha/a as the demand on the dam reduced (White Paper D-86). The estimated additional scheduled areas to be served by the Orange-Riet Canal was 3 087 ha which included some of the area presently supplied by the Modder River

State Water Scheme. An amount of 3 320 ha has been envisaged as the area to be developed to irrigation along the canal route (White Paper H-84). The possibility of supplementing supplies to the Lower Riet River area was also investigated.

3.1.3.3 Summary of the irrigated areas

The areas under irrigation in the various river sections of the Riet and Modder catchment have been summarised in table 3.4. These totals are somewhat subjective and include both the controlled and diffuse irrigation areas. The values were arrived at by considering the latest information from the White Papers as well as the results from Middleton et al. (1981) and the Agricultural Census (1981).

Table 3.4: Summary of the areas under irrigation at present in the various river sections of the Riet and Modder catchment.

No.	River section	Area (ha)
1	Modder River upstream of Krugersdrift Dam	4 400
2	Modder River downstream of Krugersdrift Dam	3 400
3	Lower Riet River	2 640
4	Riet River downstream of Kalkfontein Dam	7 750
5	Riet River upstream of Kalkfontein Dam	7 700
Total		25 890

Refering to table 3.4, the areas given for river sections 2, 3 and 4 are from the White Papers and represent the controlled irrigation in these sections. Little diffuse irrigation occurs along these sections of the Riet and Modder Rivers. The areas given for the river sections 1 and 5 are subjective estimates considering all the available information as well as the impressions from a field trip conducted in the area. The irrigation in these areas is for the most part diffuse, however, the areas under the jurisdiction of the Kaffer River and Roodeheuwel Irrigation Boards have been included.

The crop water requirements can be estimated from the quotas stated in the White Papers for the various State Water Schemes. The present quota for the Riet River State Water Scheme is 11 000 m^3/ha/a now that water is being subsidised from the Orange River. This value is probably representative of the crop water requirements throughout the catchment, however, the requirements may also be estimated by considering the climatic conditions and crop evapotranspiration.

3.1.4 Crop water requirements

In order to estimate the water requirements of the crops irrigated in the Riet and Modder catchment, details on the crop types and the area of each type is required. A representative value of the monthly A-pan evaporation along with the specific crop factors will enable the evapotranspiration to be estimated from which the crop water demands are determined.

The Census of Agriculture (1981) revealed information on the crop types under regular irrigation. The areas of the irrigated crops for the magisterial districts of the Riet and Modder catchment are summarised in table 3.5. These results indicate that approximately 40 % of the irrigated land is under pastures, whilst the rest is made up at annual plantings.

Table 3.5: Areas of the crop types under the regular irrigation (ha) in the magisterial districts of the Riet and Modder catchment (Census of Agriculture, 1981).

Magisterial district	Annual plantings under regular irrigation	Perennial plantings under regular irrigation		
		Vineyards/ orchards	Fodder/ pastures	Timber
Herbert	4 884	495	1 569	-
Fauresmith	1 598	45	388	2
Jacobsdal	2 447	182	1 732	6
Koffiefontein	481	76	706	-
Bloemfontein	1 745	86	1 869	-
Petrusburg	904	34	918	20
Dewetsdorp	554	27	1 096	-
Reddersburg	593	2	691	
Edenburg	1 618	22	1 623	-
Trompsburg	380	-	935	-
Jagersfontein	150	-	236	-
Total	15 354	969	11 763	28
		12 760		

Details on the crop types under irrigation in various river sections of the Riet and Modder catchment have also been outlined in various White Papers. The major crops irrigated in the Modder River State Water Scheme are lucerne, wheat, potatoes, fruit and vegetables (White Paper C-74). Further downstream in the Lower Riet River Irrigation Area, the main crop is lucerne, but vegetables and fruit are also produced on a small scale. The agricultural production in the Riet River settlement on the Riet River State Water Scheme has been monitored closely. The average areas of the crops under irrigation in the settlement during 1977 are given in table 3.6

Table 3.6: Average areas (ha) of irrigated crops on the Riet River Settlement (White Paper, J-77).

Crop			Area (ha)	Total
Summer	:	Groundnuts	500	
		Cotton	200	
		Vegetables	150	
		Maize	100	950
Winter	:	Wheat	2 000	
		Vegetables	50	2 050
Perennial	:	Lucerne	800	
		Vines	350	1 150

Other information on the areas of the individual crops under irrigation has been obtained from local agricultural personnel. This information along with the material from the White Papers has been summarised in table 3.7. This table gives the percentage of the total area that each crop represents for the same river sections numbered in table 3.4. More detailed information on the individual crop factors and the monthly A-pan evaporation figures is given in Appendix B. This information must be used with great care as it is subjective in many cases. Another point to bear in mind is that the crops that are irrigated are continually changing according to the market and crop prices. However, not many different varieties of crops may be grown in this region due to the condition of the soils and climate.

Table 3.7: Proportion of crops irrigated in the various river sections of the Riet and Modder catchment.

Crop	River section number *				
	1	2	3	4	5
Maize	0,10	-	0,25	0,30	0,10
Wheat	0,50	0,10	0,25	0,15	0,20
Lucerne	0,20	0,70	0,30	0,30	0,40
Annual pastures	0,15	-	-	-	0,20
Perennial pastures	-	0,10	-	-	-
Cotton	-	-	0,20	0,15	0,05
Potatoes	0,05	0,05	0,20	0,05	-
Cabbage	0,05	-	-	-	-
Vegetables	-	0,05	-	0,05	0,10
Fruit	0,05	0,05	-	0,05	-

* 1 : Modder River upstream of Krugersdrift Dam

2 : Modder River downstream of Krugersdrift Dam

3 : Lower Riet River

4 : Riet River downstream of Kalkfontein Dam

5 : Riet River upstream of Kalkfontein Dam

3.2 ORANGE CATCHMENT UPSTREAM OF THE ORANGE-VAAL CONFLUENCE

3.2.1 General

The Orange River Basin has been divided into four regions according to the following river sections:

- Upper Orange River,
- Middle Orange River,
- Lower Orange River, and
- Namaqualand.

The Upper Orange River is that part of the Orange upstream of the Orange-Vaal confluence including the Caledon and Senqu Rivers. The irrigation demands within the Senqu catchment in the Lesotho Highlands are small as little development has occurred. The construction of the Lesotho Highlands Water Project will completely dominate the flows in the Orange River downstream of Lesotho border with the result that the water demands for irrigation purposes will be insignificant. Thus, the Senqu Catchment has not been considered. However, the other major upstream tributuary, the Caledon River, is affected by some substantial irrigation development as has the rest of the Upper Orange catchment.

3.2.2 Caledon Catchment

3.2.2.1 General

The Caledon River is an important tributary of the Orange River making a substantial contribution to its flow. Much land has been developed for the purpose of irrigation along the banks of the Caledon River and there are indications of further development, especially in Lesotho. Some diffuse irrigation also occurs within the catchment making use of water from farm dams and streams. The Caledon catchment above Welbedacht Dam is assessed here, and the Orange catchment downstream of the Lesotho border will be included in the following section.

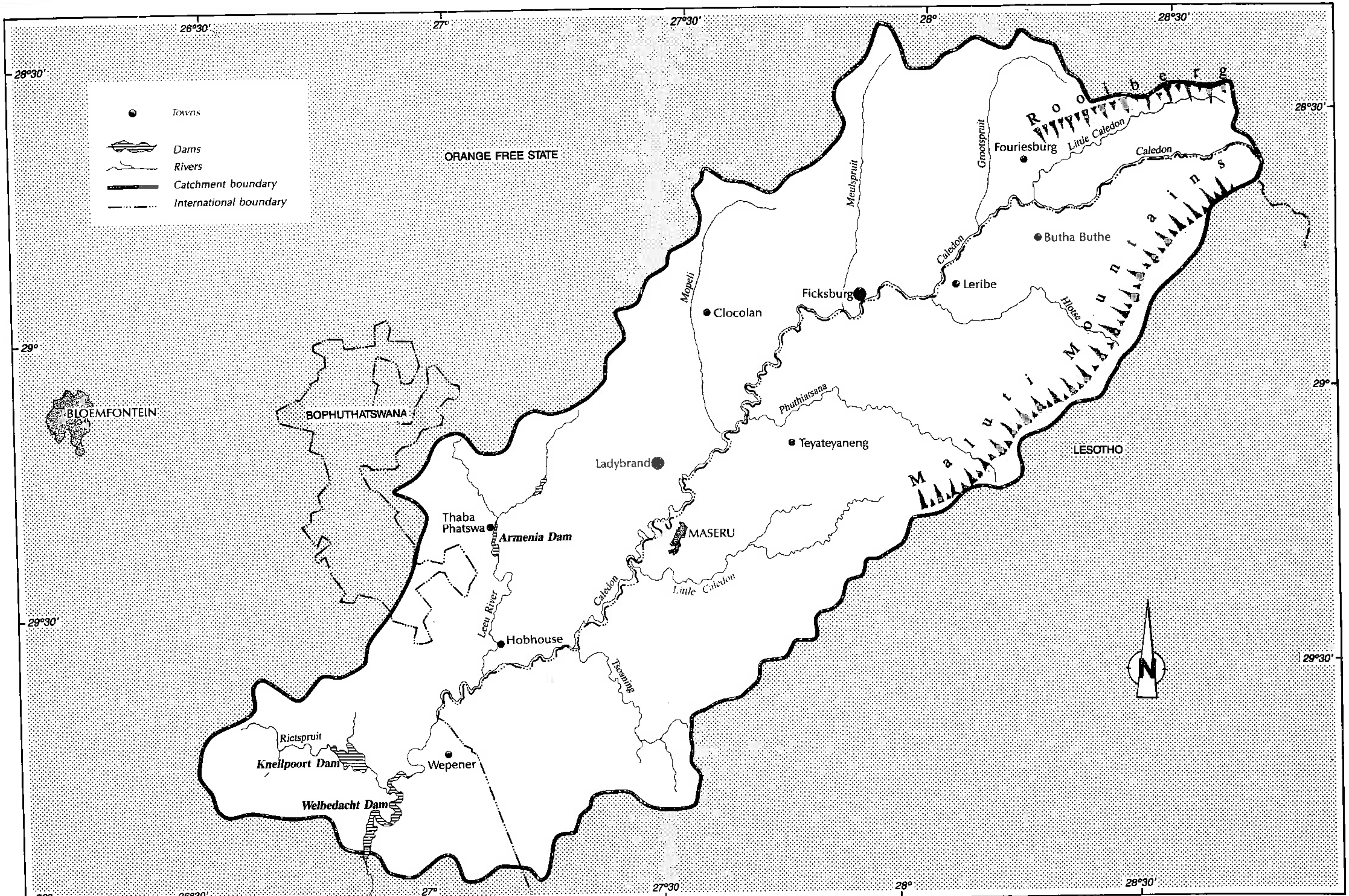
3.2.2.2 Catchment description

The source of the Caledon River is in the Natal Drakensberg and it flows in a south-westerly direction dropping some 1 650 m to Welbedacht Dam. Figure 3.5 depicts the layout of the river system in the Caledon catchment. The Caledon River forms the border between the RSA and Lesotho for most of its course to the dam. The area of the Caledon catchment above Welbedacht Dam is 15 245 km^2. The catchment consists of narrow valleys with steep slopes at the top end and gradually transforms into undulating terrain lower down. The vegetation varies from an alpine veld and highland sourveld in the higher lying regions to a pure grassveld lower down the catchment. There is a fairly steep rainfall gradient along the length of the catchment which is indicated by the isohyets in figure 3.6. The MAP ranges from well above 1 000 mm on the Drakensberg to below 600 mm at Welbedacht Dam, and approximately 80 % of the rainfall occurs in summer (October to March). The evaporation from an open water surface increases from around 1 300 mm per annum at the top of the catchment to about 1 600 mm at the lower end. The isolines of evaporation from an open water surface as measured by Symons pan evaporimeters are shown in figure 3.6.

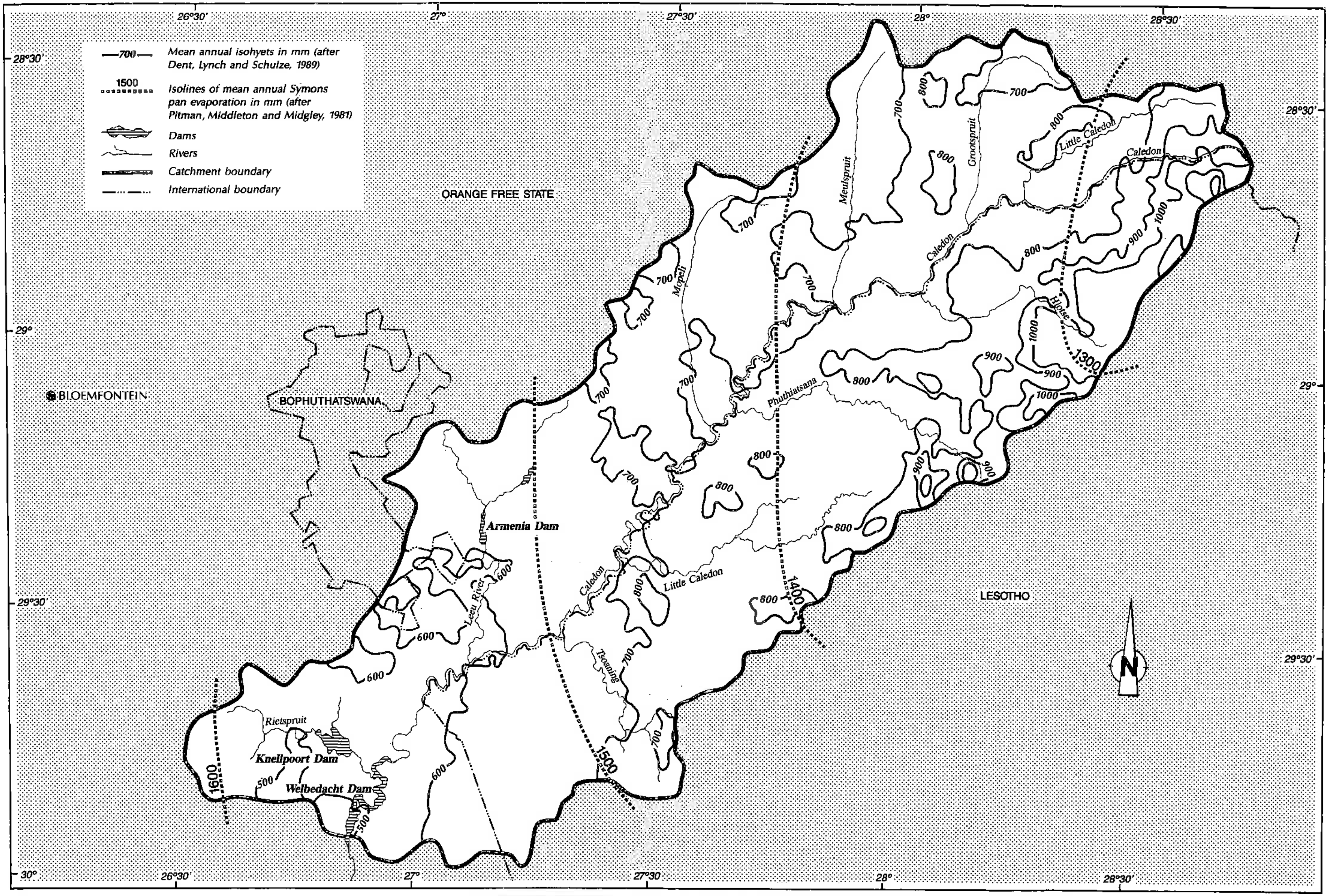
The climate is generally cool with moderate summers and winters which can be particularly severe with a fair amount of frost occurring. Therefore, the growing seasons of the crops are long and double cropping is not practiced. With the high rainfall and relatively low evaporation, agricultural production flourishes under dryland conditions, however, higher yields can be obtained by means of irrigation.

3.2.2.3 Overview of existing irrigation studies

Most of the irrigation in the Caledon catchment above Welbedacht Dam is uncontrolled and of a diffuse nature. The land riparian to the Armenia Dam on the Leeu River and the downstream areas have been gazetted as control areas as has



Caledon catchment : rivers and towns 3.5

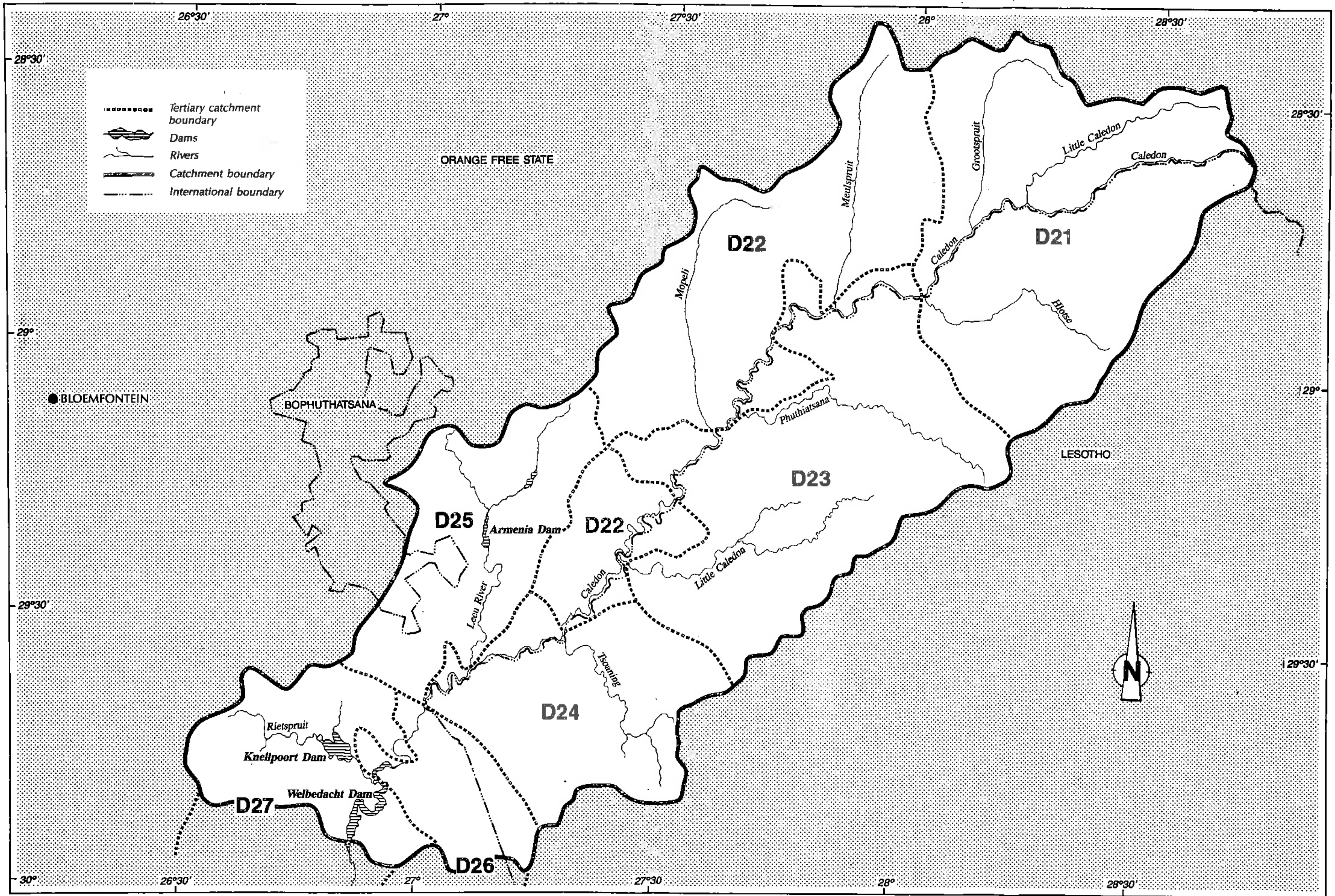


Caledon catchment : rainfall and evaporation isolines **3.6** the area around Welbedacht Dam. Information on the irrigation within the control areas is plentiful but not much is known with respect to the diffuse irrigation occurring in the rest of the catchment. Various studies and surveys have been carried out from time to time, the results of which are assessed.

Pitman, Middleton and Midgley (1981) summarised the areas under irrigation for specific tertiary catchments within the Caledon catchment. The results of this study are outlined in table 3.8 where the areas under irrigation in the tertiary subcatchments to just below the Welbedacht Dam are given. The tertiary catchments at Pitman et al. (1981) are depicted on the general catchment map in figure 3.7. The diffuse irrigation in tertiary catchment D26 (2 400 ha) and most of the controlled irrigation in D27 (450 ha) does not fall in the Caledon catchment above Welbedacht Dam. Thus, the total area under irrigation in the Caledon Catchment is of the order of 8 410 ha as estimated by Pitman et al. (1981).

Table 3.8: Areas irrigated (ha) according to the source of water in the tertiary catchments of the Caledon River (Pitman et al., 1981).

HRU tertiary catchment	Source of water				Total
	State schemes	Irrigation boards	Springs & rivers	Farm dams	
D21	-	-	450	430	880
D22	130	-	530	940	1 600
D23	60	-	60	80	200
D24	50	20	80	110	260
D25	340	70	510	940	1 860
D26	230	380	860	1 540	3 010
D27	130	320	1 070	1 930	3 450
Total	940	790	3 560	5 970	11 260
	1 730		9 530		



ORANGE RIVER SYSTEM ANALYSIS

Caledon catchment : HRU tertiary subcatchments 3.7

The Census for Agriculture (1981) depicts a slightly different situation as can be seen from the information in table 3.9. This table gives the areas under irrigation according to the magisterial districts in the Caledon catchment. Approximately half of the Wepener district falls outside the catchment, thus only 1 500 ha of irrigation from this district lies within the catchment. The total irrigated land will therefore be around 5 000 ha or 60 % of that estimated by Pitman *et al*. (1981).

Table 3.9: Areas irrigated (ha) according to the source of water in the magisterial districts of the Caledon catchment (Census of Agriculture, 1981).

Magisterial District	State water schemes	Irrigation board schemes	Springs, rivers & streams	Farm dams	Total
Fouriesburg	-	-	194	191	385
Ficksburg	-	-	210	462	672
Clocolan	-	-	52	427	479
Ladybrand	341	-	442	818	1 601
Wepener	141	615	1 342	832	2 930
Total	482	615	2 240	2 730	6 067
	1 097		4 970		

To emphasise the importance of an accurate estimate of the area under irrigation with respect to its effect on the streamflow, consider the following scenario:

MAR at Welbedacht Dam (D2R04) = $1\ 200.10^6 m^3$,

area irrigated as estimated by Pitman *et al*. (1981) = 8 410 ha, and

estimated annual irrigation requirement = $8\ 000\ m^3/ha$.

Now the estimated total annual irrigation requirement for this situation would be $67.10^6 m^3$, or 5,6 % of the MAR at Welbedacht Dam. This irrigation requirement represents a sizeable amount of water, yet, when considered in context with the annual streamflow it seems to be relatively small. The problem is that this demand may occur at times of low flows when the supply could be limiting, hence an accurate estimation of the irrigation requirement and when it is required is important. Thus a further study on the irrigation in the Caledon catchment was undertaken.

3.2.2.4 Determination of irrigated areas by satellite imagery

Irrigated areas alongside the Caledon River and its tributaries were determined using satellite imagery. The catchment was subdivided into zones consisting of river sections and a mask image of the river sections was created. Each river section incorporated the areas adjacent to the main rivers where irrigation is likely to be undertaken. Figure 3.5 shows the location of the main rivers. This mask image was overlaid onto image classifications in order to extract the irrigated areas.

LANDSAT multispectral scanner (MSS) data from January and September 1988 were analysed separately to try and obtain information on the seasonal variation of the irrigation. The January image was used to determine the area under irrigation during summer and the September image disclosed the areas of the winter crops that are irrigated. The classifications were overlain to obtain estimates of the perennial crops under irrigation or areas where double cropping occurs. The classifications were carried out using level-slicing and vegetation indices of specific LANDSAT bands lying in a particular range associated with irrigated vegetation. The output was a one band image from which the irrigated areas according to the mask image were determined.

The resulting areas as determined by the satellite imagery are given in table 3.10. The area of the perrenial crops under irrigation and double cropping areas were determined by adding the two classifications to indicate the same land irrigated both in January and September. The total areas under irrigation in both seasons and throughout the year are:

- Summer = 4 156 ha,
- Winter = 4 066 ha, and
- Perennial = 457 ha.

This yields a total area of 8 679 ha which is irrigated during the year.

Table 3.10: Areas irrigated (ha) in the Caledon catchment as determined by LANDSAT MSS imagery.

River Section	Irrigated Areas	
	9/1/88	5/9/88
Little Caledon (RSA)	824	448
Grootspruit	119	83
Hlotse	333	59
Meulspruit	144	202
Phuthiatsara	48	9
Mopeli	162	190
Little Caledon (Lesotho)	0	0
Tsoaning	4	46
Lower Leeu	29	174
Upper Leeu	185	755
Sandspruit	0	18
Rietspruit	0	12
Caledon	2 765	2 527
Total	4 613	4 523

In 1987 a survey was undertaken to determine the irrigation areas on the riparian farms on the RSA side of the Caledon River upstream of Welbedacht Dam. The survey reported that 2 747 ha was under irrigation, which is practically half of the area established using the Satellite imagery. Little irrigation has been developed on the Lesotho side of the River and the areas irrigated there are in the order at 500 ha to 1000 ha. The total area irrigated from the Caledon River still falls short of the 5300ha estimated by the satelite imagery. Information on the State controlled section of the Leeu River indicates that 148 ha are irrigated by pumping from Armenia Dam and 653 ha are scheduled downstream of the dam and supplied by canals (Department of Water Affairs, 1989). These figures also differ from those obtained by the satellite imagery.

A field survey was conducted to collect surface reference data and gather information on the crop types and irrigation development. This survey revealed that the preliminary results were a gross overestimation of the area irrigated. This was due to the extensive dryland cultivation alongside the rivers. The high MAP and the heavier-than-normal rains during the previous few seasons made the identification of the irrigated areas difficult. The final results shown in table 3.10 still indicate the irrigated areas to be higher than expected, particularly further up the catchment.

3.2.2.5 Summary of the irrigated areas

Due to the lack of good information and the conflicting data obtained from the various sources on the areas under irrigation in the Caledon catchment, a sound estimate of the area under irrigation at present is difficult. Table 3.11 summarises the estimated areas under irrigation in the Caledon catchment. The latest best estimate of the total area under irrigation in the Caledon catchment therefore is 7 530 ha. This is made up of the areas along the Caledon River as determined by the 1987 survey, the areas along the tributaries which were established from the satellite imagery, and the area alongside Welbedacht Dam as quoted by the Department of Water Affairs (1989). The Department of

Water Affairs also cited quotas for the two controlled areas in the catchment:

- Armenia Dam = 6 100 m^3/ha/a, and
- Welbedacht Dam = 7 620 m^3/ha/a.

Thus, an average crop water demand for the whole catchment is probably about 7500 m^3/ha/a.

Table 3.11: Summary of the areas under irrigation at present in the various river sections of the Caledon catchment.

No.	River section	Area (ha)
1	Caledon River	3 150
2	All tributaries of Caledon	3 850
3	Riparian land to Welbedacht Dam	530
Total		7 530

3.2.2.6 Crop water requirements

The water requirements for the crops irrigated in the Caledon catchment are determined from the proportion of the total area the particular crop covers, the crop factors and the A-pan evaporation information. Limited details are available on the types of crops irrigated in this area, however, the Census of Agriculture (1981) does contain particulars on the crops. Table 3.12 indicates the areas of the crop types under irrigation in the Caledon catchment as determined in the Census of Agriculture (1981). This summary shows that cultivated pastures is the major crop type under irrigation (57 %), whilst annual crops make up 35 % of the total irrigated area and fruit orchards the remaining 8 %.

Table 3.12: Areas of the crop types under regular irrigation (ha) in the magisterial districts of the Caledon catchment (Census of Agriculture, 1981).

Magisterial district	Annual plantings under regular irrigation	Perennial plantings under regular irrigation		
		Vineyards/ orchards	Fodder/ pastures	Timber
Fouriesburg	145	-	249	-
Ficksburg	289	184	249	-
Clocolan	16	75	410	-
Ladybrand	758	264	591	-
Wepener	979	-	2 039	-
Total	2 187	523	3 538	-
		4 061		

The field trip into the Caledon catchment also brought to light details on the crops irrigated. The main crops irrigated in the Ficksburg and Fouriesburg magisterial districts are pastures, fruit and vegetables. Most of the pastures cultivated in the catchment are under irrigation. Deciduous fruit (apples, peaches and cherries) is also irrigated in small quantities and vegetables such as cabbage are irrigated in growing amounts due to the ready market in Lesotho. Further down the catchment in the Ladybrand and Clocolan magisterial districts pastures, wheat and fruit are the main crop irrigated, and at the bottom of the catchment it is only wheat, pastures and some maize that are irrigated. The pastures in this catchment are normally lucerne, however, a big move is being made to annual grasses such as annual ryegrass (Midmar).

Table 3.13 gives the proportion of the crops that are irrigated in the Caledon catchment. This information has been determined from personal communication with numerous local Agricultural Offices and caution must be exercised in using it. The types of crops irrigated and the proportion of the total area a particular crop covers changes from season to season depending on numerous factors. This is by no means a static condition, but under the circumstances is the best possible estimate. A table in Appendix B indicates the details of the individual monthly crop factors and a representative monthly A-pan evaporation record for the Caledon catchment.

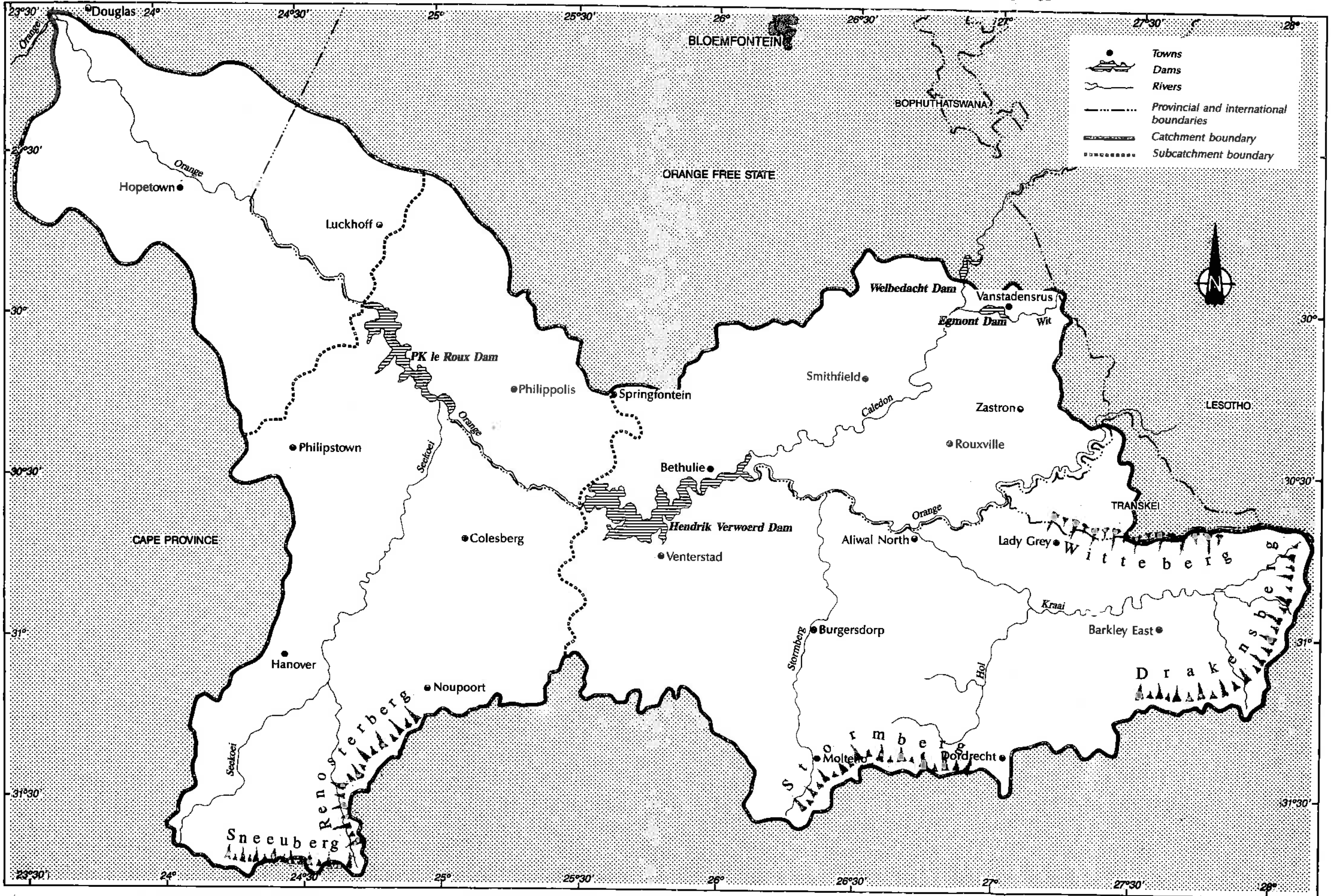
Table 3.13: Proportion of crops irrigated in the Caledon catchment.

Crop	Porportion
Lucerne	0,50
Ryegrass	0,20
Wheat	0,20
Maize	0,10
Fruit	0,08
Cabbage	0,05

3.2.3 Orange Catchment from Welbedacht Dam to the Orange-Vaal confluence

3.2.3.1 General

The Orange River catchment upstream of the Orange-Vaal confluence consists of the Caledon River downstream of Welbedacht Dam and the Orange River downstream of the Oranjedraai gauging weir (D1M09). Figure 3.8 shows the location of this catchment along with the major rivers and dams. This catchment also includes the main tributaries of the Orange River, namely the Kraai and Stormberg Rivers higher up the catchment and the Seekoei River lower down. The Hendrik Verwoerd and P.K. le Roux Dams have been constructed in this section of the Orange River and form part



ORANGE RIVER SYSTEM ANALYSIS

Orange catchment upstream of the Orange-Vaal confluence : rivers and towns

3.8

of the inter-basin transfer schemes to the Riet River in the Orange Free State and the Great Fish River in the Eastern Cape.

A substantial amount of irrigation has developed along the major rivers and especially downstream of P.K. le Roux Dam. Due to the flat gradients around the Hendrik Verwoerd Dam and varying water levels very little irrigation has been established on the riparian farms. The construction of the P.K. le Roux Dam now ensures the control of most of the irrigation downstream the Orange River due to the stabilisation of the flow. The dam also supplies water to downstream irrigations via a canal, and supplements the irrigation supply in the Riet River area by means of an inter-basin transfer. Lower down the Orange River at Marksdrift, the new Orange-Vaal canal augments the supply to irrigators in the Douglas area.

Many small farm dams have been constructed in the upper reaches of the catchment and are mainly used for stockwatering. Small patches of irrigation from ground water sources also occur throughout the catchment in the lower lying areas, however, this irrigation is not considered.

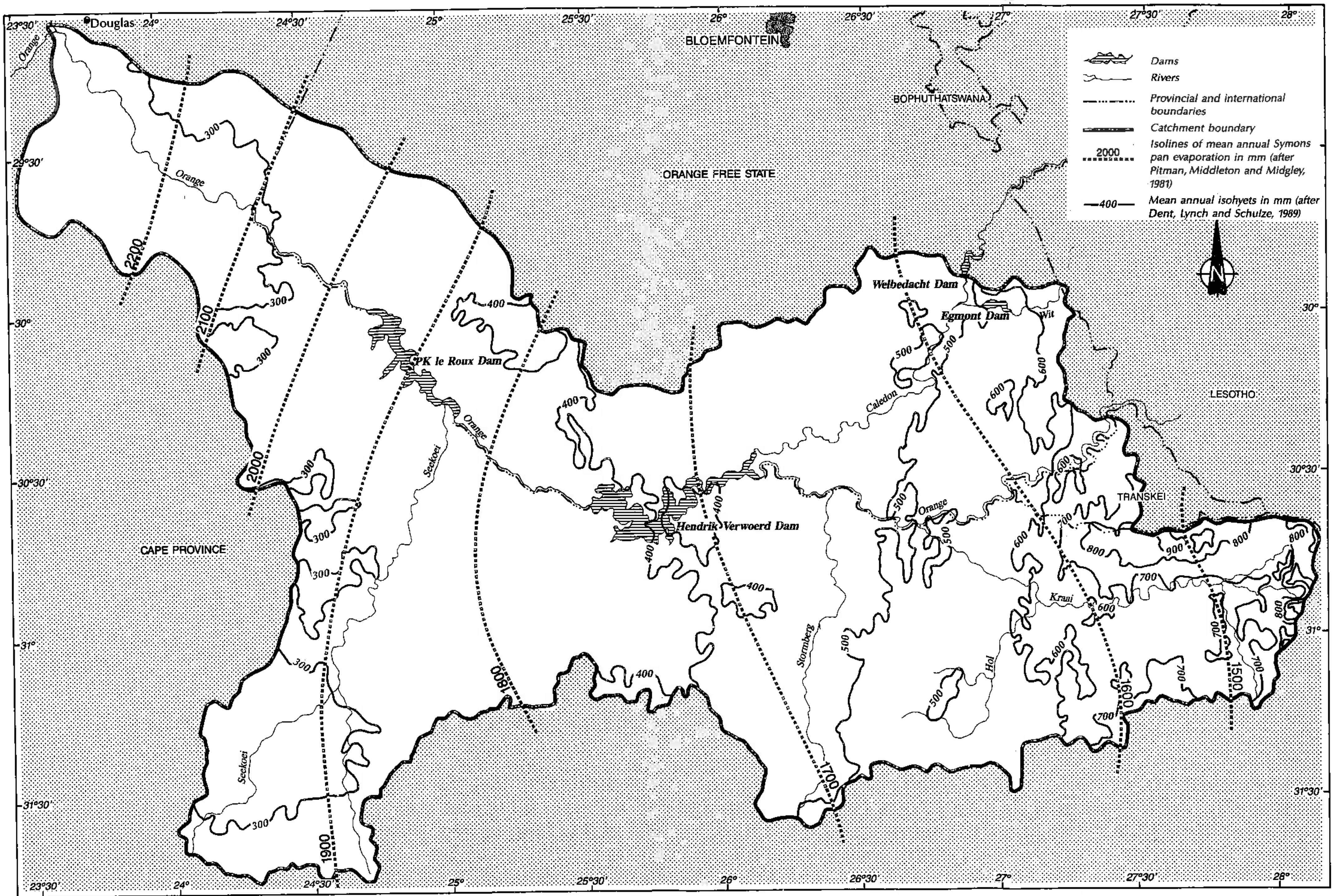
3.2.3.2 Catchment description

The Orange River catchment from Welbedacht Dam to the Orange-Vaal confluence covers an area of about 59 000 km^2. Of this area more than 6 000 km^2 is ineffective as it consists of enclosed drainage basins due to the flat topography (Pitman et al., 1981). These areas may give rise to local streamflow or contribute to pans, marshes and vleis, however, they do not contribute to the major river system.

The catchment consists of the Orange River downstream of Oranjedraai gauging weir (D1M09) near the Lesotho border and the Caledon River downstream of Welbedacht Dam. The confluence of the Caledon and Orange Rivers is at Bethulie in the upper reaches of the Hendrik Verwoerd Dam. There are three tributaries which contribute to the flow in the Orange River in this catchment as is shown in figure 3.8. They are the Kraai River which drains the southern Drakensberg in a westerly direction joining the Orange River just upstream of Aliwal North, the Stormberg River which flows in a northerly direction to the Orange River from the Stormberg Plateau, and the Seekoei River which flows north from the Renosterberg and Sneeuberg ranges into the P.K. le Roux Dam.

The catchment for the most part is situated in the arid interior of RSA with the result that it receives a rather low annual rainfall. However, a steep rainfall gradient exists in the south east along the Kraai valley and up the Witteberg escapment and up the southern Drakensberg. The MAP ranges from well above 1 000 mm on top of the Drakensberg and Witteberg to below 600 mm at Aliwal North along the Kraai River valley. Elsewhere the rainfall gradients are not as pronounced but the annual rainfall diminishes slowly in a westerly direction to about 300 mm at the Orange-Vaal confluence. The rainfall patterns over the catchment are indicated by the isohyets of MAR in figure 3.9. The annual evaporation from an open water surface follows a similar trend but increases from around 1 500 mm at the top end of the Kraai River to above 1 700 mm at Hendrik Verwoerd Dam, and rises to almost 2 300 mm at the western boundary of the catchment. These trends are depicted in figure 3.9 by the isolines at annual evaporation as measured by Symons pan evaporimeters.

There is a marked variability in topography with the lower portion of the catchment being very flat land and covered with a karoo or sparse grassveld type of vegetation. These plains gradually give way to undulating hills of grassveld further up the valley, which in turn make way for the steeply sloped alpine type veld of the Drakensberg and Witteberg



Orange catchment upstream of the Orange-Vaal confluence : rainfall and evaporation isolines

3.9

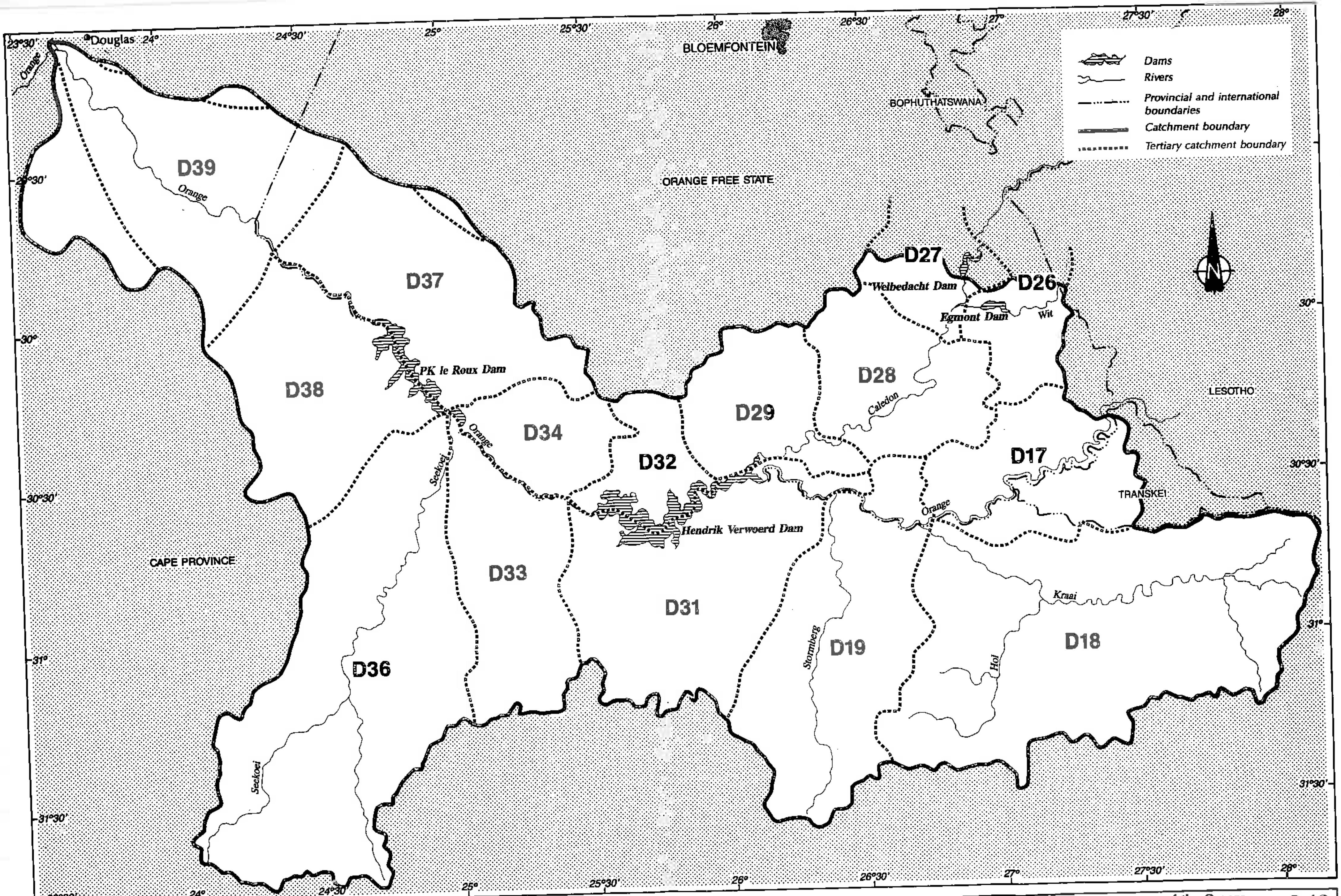
ranges and the sweetveld of the Stormberg Plateau. The Sneeuberg and Renosterberg ranges are also covered with the typical mountain veld type of vegetation.

3.2.3.3 Overview of existing irrigation studies

The large volumes of water available from the Orange River, the good soils and the warm temperatures in this arid climate have made this region favourable for irrigation development. The construction of the P.K. le Roux Dam and associated canal networks as well as the Orange-Vaal Canal has enhanced development in this area. The dam also controls irrigation along the entire downstream length of the River by regulating releases. Thus much of the irrigated areas downstream of the P.K. le Roux Dam are controlled, however, substantial uncontrolled irrigation occurs throughout the rest of the catchment.

The abundance of small farm dams further up the Caledon and Orange valleys does not indicate the existence of irrigation as most of these dams were built early in the Century for stock watering purposes. Other irrigation away from the main perennial rivers is from ground water sources and is for the cultivation of pastures and fodder crops.

Pitman et al. (1981) determined the areas under irrigation in the Orange catchment according to the source of the water. The irrigated areas tabulated in table 3.14 are for the tertiary catchments within the Orange basin between Welbedacht Dam and the confluence of the Orange and Vaal Rivers as established by Pitman et al. (1981). Figure 3.10 displays the tertiary catchment boundaries as depicted by Pitman et al. (1981). The tertiary subcatchments D26 and D27 lie partly within this catchment and partly within the catchment of Welbedacht Dam. The estimated areas under irrigation in these tertiary catchments downstream of Welbedacht Dam are the 610 ha of controlled irrigation in D26



Orange catchment upstream of the Orange–Vaal confluence : HRU tertiary subcatchments **3.10** and the 3 000 ha diffuse irrigation in D27. Thus the total area under irrigation in the Orange Catchment upstream of the Orange-Vaal confluence is 47 910 ha as estimated by Pitman et al. (1981).

Table 3.14: Areas irrigated (ha) according to the source of water in the tertiary catchments of the Orange River between Welbedacht Dam and the Orange-Vaal confluence (Pitman et al., 1981).

HRU tertiary catchment	Source of water				Total
	State schemes	Irrigation boards	Springs & rivers	Farm dams	
D17	130	170	880	1 450	2 630
D18A	-	80	2 910	490	3 480
D18B	20	50	2 470	4 210	6 750
D19	10	200	2 260	5 820	8 290
D26	230	380	860	1 540	3 010
D27	130	320	1 070	1 930	3 450
D28	60	240	1 600	1 930	3 830
D29	10	60	1 140	980	2 190
D31	10	30	1 360	2 790	4 190
D32	-	20	660	330	1 010
D33	90	-	940	390	1 420
D34	-	-	570	400	970
D35	-	10	930	560	1 500
D36	70	-	1 040	480	1 590
D37	510	60	870	460	1 900
D38	40	-	150	140	330
D39	2 430	410	2 050	90	4 980
Total	3 740	2 030	21 760	23 990	51 520
	5 770		45 750		

The areas under irrigation in the magisterial districts falling within the catchment were outlined by the Census of Agriculture (1981). The results of this survey have been summarised in table 3.15. The areas given by both Pitman et al. (1981) and the Census of Agriculture (1981) indicate that the majority of the irrigation falls under uncontrolled private schemes. The total areas of the two surveys tend to differ slightly as some of the magisterial districts indicated in the Census of Agriculture (1981) which lie partially inside the catchment have not been included. The majority of the districts not included are in the upper reaches of the catchment where little irrigation is practised.

Table 3.15: Areas irrigated (ha) according to the source of water in the magisterial districts of the Orange River between Welbedacht Dam and the Orange-Vaal confluence (Census of Agriculture, 1981).

Magisterial district	State water schemes	Irrigation board schemes	Springs, rivers & streams	Farm dams	Total
Colesberg	80	60	1 284	370	1 794
Molteno	-	-	281	954	1 235
Barkly East	45	-	1 521	90	1 656
Wodehouse	-	-	298	1 906	2 204
Lady Grey	-	8	367	243	618
Aliwal North	-	43	668	1 279	1 990
Albert	43	39	1 162	2 872	4 116
Venterstad	-	-	127	207	334
Steynsburg	-	-	246	1 238	1 484
Zastron	13	-	103	865	981
Rouxville	350	11	1 543	1 048	2 952
Smithfield	-	38	427	530	995
Bethulie	5	16	1 253	528	1 802
Wepener	141	615	1 342	832	2 930
Dewetsdorp	4	-	300	1 227	1 531
Philippolis	10	-	514	134	658
Hopetown	1 429	43	973	2	2 447
Philipstown	1	63	134	47	245
Hanover	-	-	345	189	534
Noupoort	-	-	333	96	429
Herbert	2 843	1 787	1 894	9	6 533
Fauresmith	1 381	-	114	13	1 508
Total	6 345	2 723	15 229	14 679	38 976
	9 068		29 908		

A field survey of the irrigation development in this catchment was conducted in order to confirm these results as well as to gain some knowledge of the history of the irrigation development. Discussions were held with various local Department of Agriculture personnel and a brief account of this survey follows.

The steepness of the valley slopes has limited irrigation development in the upper reaches of the Kraai River. Very little of this area is cultivated and less than half of the cultivated crops are under irrigation. Irrigation has been confined to the narrow valley bottoms where pastures of annual ryegrass or wheat are grown. The irrigated areas occur in small patches and the total area under irrigation upstream of the confluence of the Kraai and Hol Rivers is approximately 1 500 ha. Downstream of the confluence along the Kraai River to the Orange River the land becomes flatter and the size of the irrigated lands increase, although a lot of good irrigable land still lies too far above the river bed. The total area irrigated along this stretch of the Kraai River comes to about 1 000 ha.

The Stormberg River is much smaller than the Kraai River with the result that not much irrigation has developed. There is little irrigation from its tributaries arising on the Stormberg Plateau. Some irrigation does occur upstream of the J.L. de Bruin Dam on the Buffels River, which is a tributary of the Stormberg. This is in the vicinity of Burgersdorp and patches of irrigation occur along the Stormberg River from Burgersdorp to the Orange River. These patches are made up of small plots and are not regularly irrigated, some being under temporary irrigation. The total area irrigated from the Stormberg River is of the order of 1 500 ha.

The Orange River downstream of the Lesotho border carries a sizable volume of water throughout the year making it invaluable to riparian irrigators. Prior to the Second World War not much irrigation had been developed along this reach of the Orange River and less than 1 000 ha was under irrigation. In the late 1950's and early 1960's a lot of development was undertaken, particularly near Bethulie where approximately 2 000 ha was put under irrigation. With news that the Hendrik Verwoerd Dam was to be built, a lot of farmers riparian to the River downstream of Bethulie developed irrigation to increase the value of their land.

However, little irrigation was actually applied and these farms have since been flooded with the construction of the dam. No irrigation occurs on the farms along the banks of the dam now as the valley slopes are very flat and the fluctuating water levels cause the dam to recede from the full water level for considerable distances. This makes the positioning of a permanent pumphouse difficult.

A survey was carried out in the late 1970's of the irrigable land along the Orange River and a subsequent proclamation in the Government Gazette gave the allocation of water rights for these farms. Unfortunately, this information is as yet unavailable. A water balance study by the Department of Water Affairs (1989) as at June 1986, revealed that some 4 114 ha of irrigation occurs along the Orange upstream at Hendrik Verwoerd Dam. The crop water requirement was estimated at 8 000 m^3/ha/a.

Irrigators riparian to the Caledon River downstream of Welbedacht Dam are supplied by releases from Welbedacht Dam. Evidence from the field study indicates that most of the irrigation has been developed fairly recently, probably since the construction of Welbedacht Dam, which now regulates the flows downstream. It must be noted that the operating policy of the dam is not to release on demand, and only normal flow is released. A survey quoted in White Paper LL-68 indicated that some 2 570 ha of irrigable land existed between the Welbedacht Dam site and the

Orange-Caledon confluence. By 1968 only 1 030 ha was being irrigated and the requirements were estimated at 9 000 m^3/ha/a. The Department of Water Affairs (1989) stated in a water balance study that in 1986 some 2 900 ha of land was under irrigation downstream of Welbedacht Dam. The latest information from the Department of Water Affairs (1989) is that 4 837 ha of irrigation occurred in this region during 1988 showing a large amount of development in recent years.

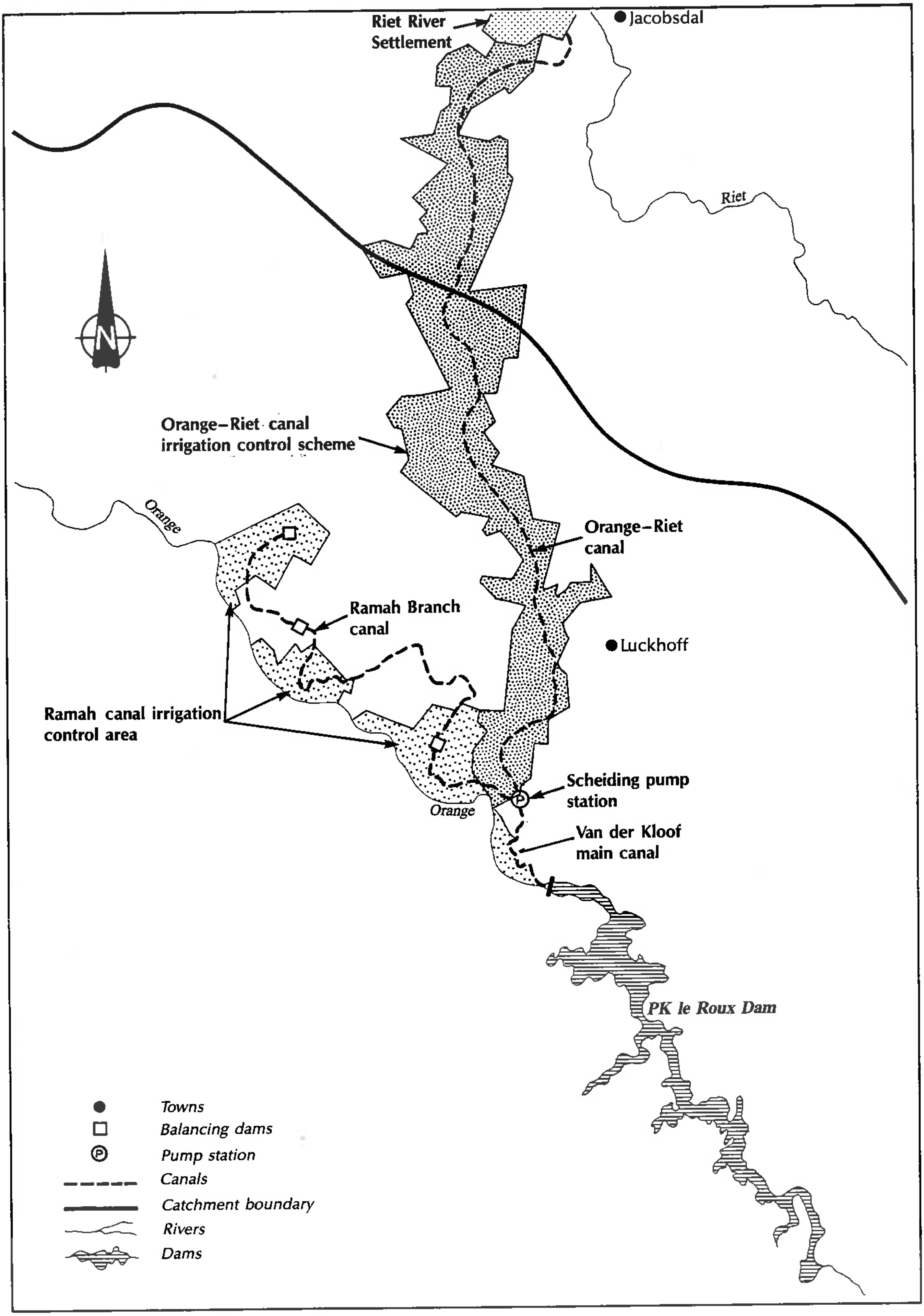
The P.K. le Roux Dam has been constructed in a deep valley with steep sides that winds its way back to the Hendrik Verwoerd Dam. Most of the agriculturally productive lands lie well above the river bed making it expensive and unviable to irrigate. Consequently little irrigation occurs on the banks of the P.K. le Roux Dam and only small patches have been developed up to the Hendrik Verwoerd Dam. The Department of Water Affairs (1989) determined that some 1 400 ha of irrigation occurs between the Hendrik Verwoerd Dam and P.K. le Roux Dams. Downstream of the P.K. le Roux Dam the valley is much flatter making the pumping of irrigation water less expensive, hence a lot of irrigation on riparian farms has been developed. According to the Department of Water Affairs (1989) some 8 351 ha of land was irrigated between P.K. le Roux Dam and Hopetown in 1986. This value includes the areas irrigated on farms riparian to the Orange River which are supplied by a canal from the P.K. le Roux Dam.

The Orange River in this catchment is the centre of expansion for the Orange River Development Project which entails the transfer of water to other catchments. One of the purposes of the Hendrik Verwoerd Dam is to facilitate the interbasin transfer of water to the Great Fish and Sundays Rivers through the Orange-Fish tunnel. These catchments, however, are outside the study area and irrigation development within them is not considered.

The construction of the P.K. le Roux Dam with its high wall has enabled a lot of land to be put to irrigation. Figure 3.11 indicates the expanse of the canal system from the P.K. le Roux Dam and the irrigated lands. The Van der Kloof Right Bank Main Canal and the Ramah Branch Canal were built to supply the higher lying land of the riparian farmers downstream of the dam. This is a State controlled scheme and by 1984 some 5 200 ha had been put under sprinkler irrigation from these canals (White Paper H-84). The Van der Kloof canal has since been extended to bring further areas under irrigation. The facility for the Left Bank Canal exists, but as to date no canal has been constructed.

The inability of the Kalkfontein Dam to supply the scheduled area of the Riet River State Water Scheme with a firm assurance necessitated the building of the Orange-Riet Canal (Sarel Hayward Canal). This canal transfers water from the Scheiding pump station on the Van der Kloof Canal to the Riet River Settlement. White Paper H-84 gave the total irrigable area within economical reach of the Orange-Riet Canal as 17 600 ha. This figure included areas presently scheduled under the Riet River State Water Scheme and has been considered in a previous section. Irrigation is still being developed along the canal and it is expected that some 3 320 ha will eventually be developed along its route. Possible expansions at the Riet River Settlement and the supplementing of other schemes was also considered.

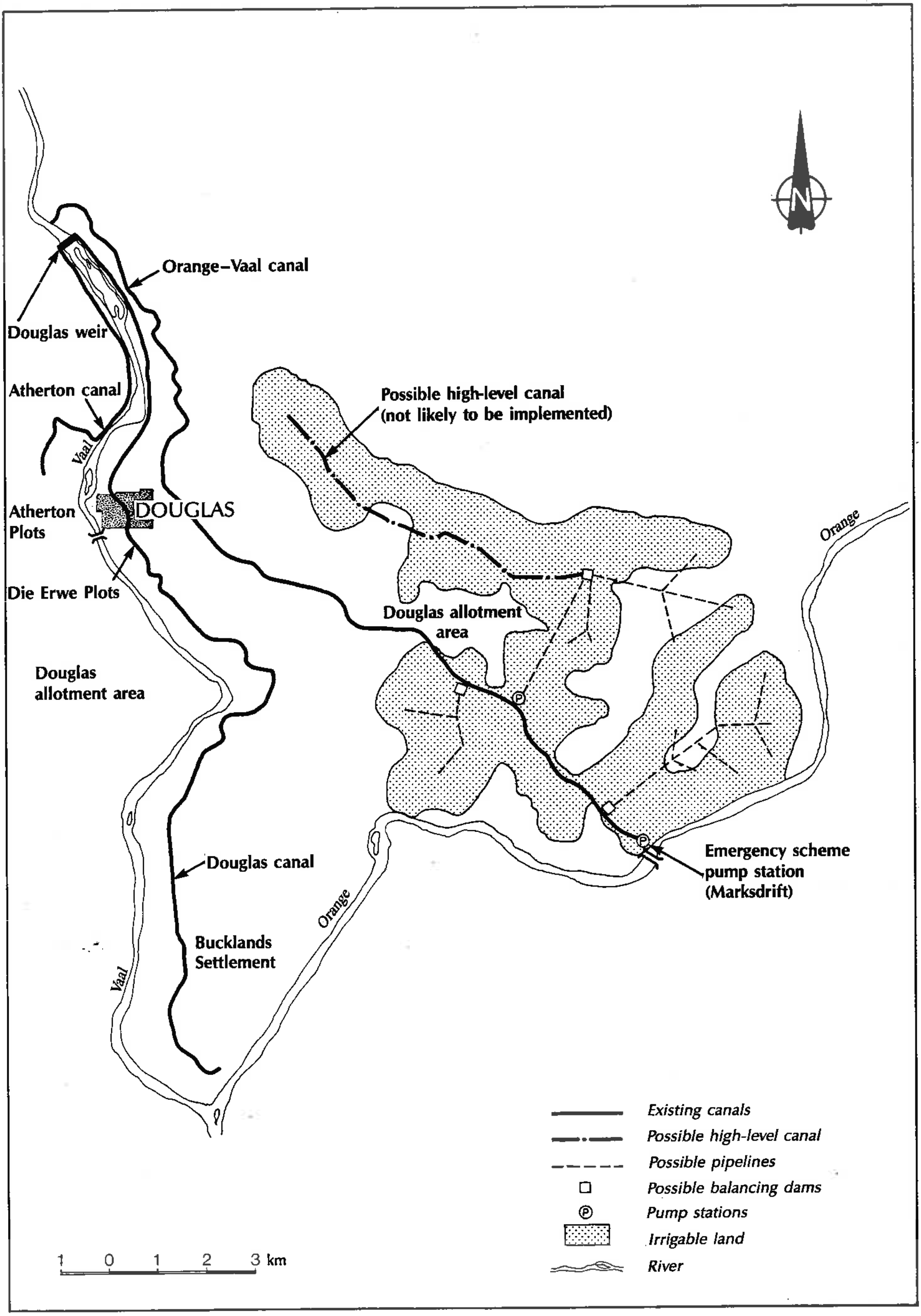
Downstream of the P.K. le Roux Dam another canal was built to transfer water to the Vaal River at Douglas as shown in figure 3.12. The Orange-Vaal emergency scheme was constructed in 1984 to overcome water restrictions at Douglas during the drought at that time and to combat the deterioration of the quality of the water in the Vaal River. The canal conveys water from the Orange River at



ORANGE RIVER
SYSTEM ANALYSIS

Orange-Riet
transfer scheme

3.11



Orange–Douglas transfer scheme

3.12

Marksdrift to Douglas Weir on the Vaal River. The scheme was originally commissioned by the Douglas Co-operative, however, due to financial difficulties has been declared a State Water Scheme. The State is in the process of lining the canal and upgrading the scheme.

The total area scheduled from the Douglas Weir was given as 7 380 ha in White Paper C-86, most of which is now supplied by Orange River water. Surveys detailed in White Paper C-86 show that 1 500 ha of irrigable land lies along the route of the canal, 3 000 ha of potential irrigation in the basin at the weir and a further 2 000 ha owned by the State may be developed for irrigation purposes. A further 300 ha of potentially good irrigated land lies upstream of the Orange-Vaal confluence which may be developed by means of pumping. This totals 6 500 ha of development potential on top of the 7 380 ha already under irrigation in the Douglas area that can be supplied by the Orange River. The present quota for Douglas irrigators is 9 140 m^3/ha/a from the Vaal and 10 000 m^3/ha/a from the Orange, however, the proposed quota is 10 000 m^3/ha/a throughout the area.

3.2.3.4 Summary of the irrigated areas

A summary of the areas under irrigation at present in the Orange catchment from Welbedacht Dam to the Orange-Vaal confluence is presented in table 3.16. These results have been tabulated according to the various river sections within the catchment. The areas quoted for the Kraai and Stormberg Rivers (sections 1 and 2) are subjective estimates made by local experts. The areas stated for the rest of the river sections are from the most up-to-date information in the White Papers and annual reports from the Department of Water Affairs.

Table 3.16: Summary of the areas under irrigation at present in the various river sections of the Orange catchment between Welbedacht Dam and the Orange-Vaal confluence.

No.	River Section	Area (ha)
1	Kraai River	2 500
2	Stormberg River	1 500
3	Orange River upstream of Hendrik Verwoerd Dam	4 100
4	Caledon River downstream of Welbedacht Dam	4 840
5	Orange River upstream of P.K. le Roux Dam	1 400
6	Orange River downstream of P.K. le Roux Dam	11 000
7	Orange-Riet canal	6 350
8	Orange-Vaal canal	4 500
Total		36 190

Information is also available on the estimated crop water requirements for some of the river sections mentioned above. Details of these requirements are listed in table 3.17. The requirements for river sections 3, 4, 7 and 8 are quotas as stated in the various white papers, whilst the other requirements are only estimates.

Table 3.17: Estimated crop water requirements for the irrigated areas on the various river sections of the Orange catchment between Welbedacht Dam and the Orange-Vaal confluence.

River Section Number *	Requirement (m^3/ha/a)
1	8 000
2	8 000
3	8 000
4	9 000
5	11 000
6	11 000
7	11 000
8	10 000

* River sections as in table 3.16

3.2.3.5 Crop water requirements

The determination of the irrigation requirements of crops in the Orange catchment from Welbedacht Dam to the Orange-Vaal confluence requires information on the types of crops irrigated, the proportion of the total irrigated area these crops occupy, the crop factors and a representative estimate of the monthly A-pan evaporation. Information on the area of the crop types under regular irrigation was given in the Census of Agriculture (1981) and is summarised in table 3.18. These results indicate that 38 % of the irrigated area is under annual crops whilst most of the remaining 62 % of the land has been put to pastures and fodder crops such as lucerne.

The proportion of the crops that are irrigated in the various river sections have been given in table 3.19. Much of this information is subjective and has been derived from details gathered on a field trip into the catchment as well as from particulars in the White Papers. Irrigation along the Kraai River is confined to the valley bottoms where annual ryegrass and wheat is grown. Further downstream the Kraai River, maize is irrigated as well as lucerne and other pasture crops. It may be assumed that no double cropping occurs in this area due to the lengthy growing seasons experienced. No information is available on the crops that are irrigated in the Stormberg Valley, and the information from the Kraai River has been transposed and adjusted. The major crop type irrigated along the Caledon River downstream of Welbedacht Dam is pastures, however, cashcrops such as maize and wheat are also irrigated. The same applies to the crops irrigated from the Orange River upstream of Hendrik Verwoerd Dam. The areas of the individual crops that are irrigated from the Orange-Riet and Orange-Vaal canals were obtained from the relevant White Papers.

Table 3.18: Areas of the crop types under regular irrigation (ha) in the magisterial districts of the Orange River between Welbedacht Dam and the Orange-Vaal confluence (Census of Agriculture, 1981).

Magisterial district	Annual plantings under regular irrigation	Perennial plantings under regular irrigation		
		Vineyards/ orchards	Fodder/ pastures	Timber
Colesberg	321	2	2 166	-
Molteno	244	8	1 102	-
Barkly East	436	3	1 217	-
Wodehouse	251	-	1 978	-
Lady Grey	174	1	573	-
Aliwal North	615	16	1 406	-
Albert	1 281	9	3 323	4
Venterstad	216	5	565	-
Steynsburg	401	1	1 623	-
Zastron	345	1	715	-
Rouxville	939	12	2 023	-
Smithfield	334	8	803	-
Bethulie	570	5	1 783	2
Wepener	979	-	2 039	-
Dewetsdorp	554	27	1 096	-
Philippolis	268	5	698	-
Hopetown	2 263	48	198	-
Philipstown	167	12	176	-
Hanover	106	-	766	-
Noupoort	127	-	483	-
Herbert	4 884	495	1 569	-
Fauresmith	1 598	45	388	2
Total	17 073	703	26 690	8
		27 401		

Detailed information on the individual crop factors, monthly A-pan evaporation values and the proportion of the total area the crops cover for the river sections previously mentioned is given in Appendix B . The tables may be used to determine the total crop water requirements for uncontrolled areas where quota systems are not in existence. The irrigation requirements are calculated from estimates of the evapotranspiration rates of the crop.

Table 3.19: Proportion of crops irrigated in the various river sections of the Orange catchment from Welbedacht Dam to the Orange-Vaal confluence.

Crop	River section number*							
	1	2	3	4	5	6	7	8
Maize	0,20	0,20	0,25	0,20	0,30	0,25	0,30	0,10
Wheat	0,30	0,30	0,35	0,30	0,40	0,30	0,15	0,25
Lucerne	0,30	0,40	0,35	0,40	0,40	0,30	0,30	0,15
Perennial pastures	0,10	-	-	-	-	-	-	-
Annual pastures	0,30	0,20	0,10	0,15	-	-	-	-
Cotton	-	-	-	-	0,10	0,30	0,15	0,15
Potatoes	-	-	-	-	-	0,10	0,05	0,10
Grapes	-	-	-	-	-	-	-	0,20
Fruit	-	-	-	-	-	-	0,05	-
Vegetables	-	-	-	-	-	-	0,05	0,20

* 1 : Kraai River

2 : Stormberg River

3 : Orange River upstream of Hendrik Verwoerd Dam

4 : Caledon River downstream of Welbedacht Dam

5 : Orange River upstream of P.K. le Roux Dam

6 : Orange River downstream of P.K. le Roux Dam

7 : Orange-Riet canal

8 : Orange-Vaal canal

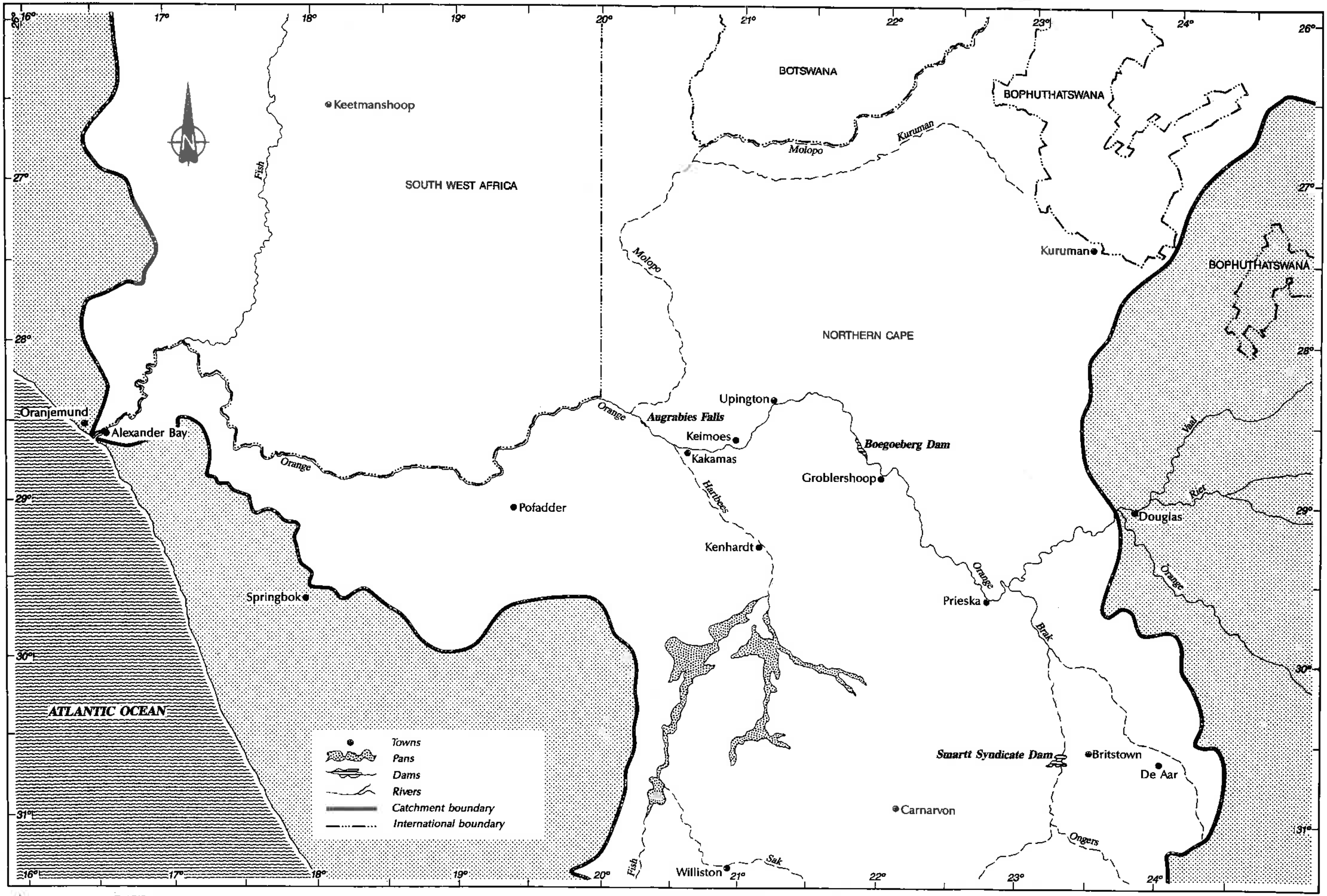
3.3 ORANGE CATCHMENT DOWNSTREAM OF THE ORANGE-VAAL CONFLUENCE

3.3.1 General

The Orange River traverses some 1 200 km from the Orange-Vaal confluence to the mouth at Alexander Bay. This catchment includes an extensive length of the Orange River, however, it only contributes a small portion of the flow in the river. This is due to the extremely low rainfall and high evaporative demands, as well as the existence of large enclosed drainage basins. All of the crops cultivated in this area require irrigation and, with ample low lying land available, large tracts of irrigation have been developed. Figure 3.13 shows the layout of the river system as well as the location of the towns. The Prieska district has sizeable areas under irrigation and considerable development has occurred between Boegoeberg Dam and Augrabies Falls. Vast canal systems exist in this region, however, downstream of Augrabies Falls the river flows through a deep, narrow valley for the rest of its course. The only irrigation here has been developed in the alluvial soils alongside the river on the valley bottom.

3.3.2 Catchment description

The Orange River Catchment downstream of the Orange-Vaal confluence consists for the most part of the flat western interior covered with a Karoo or semi-desert vegetation. A small strip of true desert projects inwards from the coast along the Orange River. Much of the course of the river downstream of Augrabies to the mouth is through very rugged terrain with a sparse vegetation cover. The Richtersveld forms the lower part of this stark country which then gives way to the Namib desert.



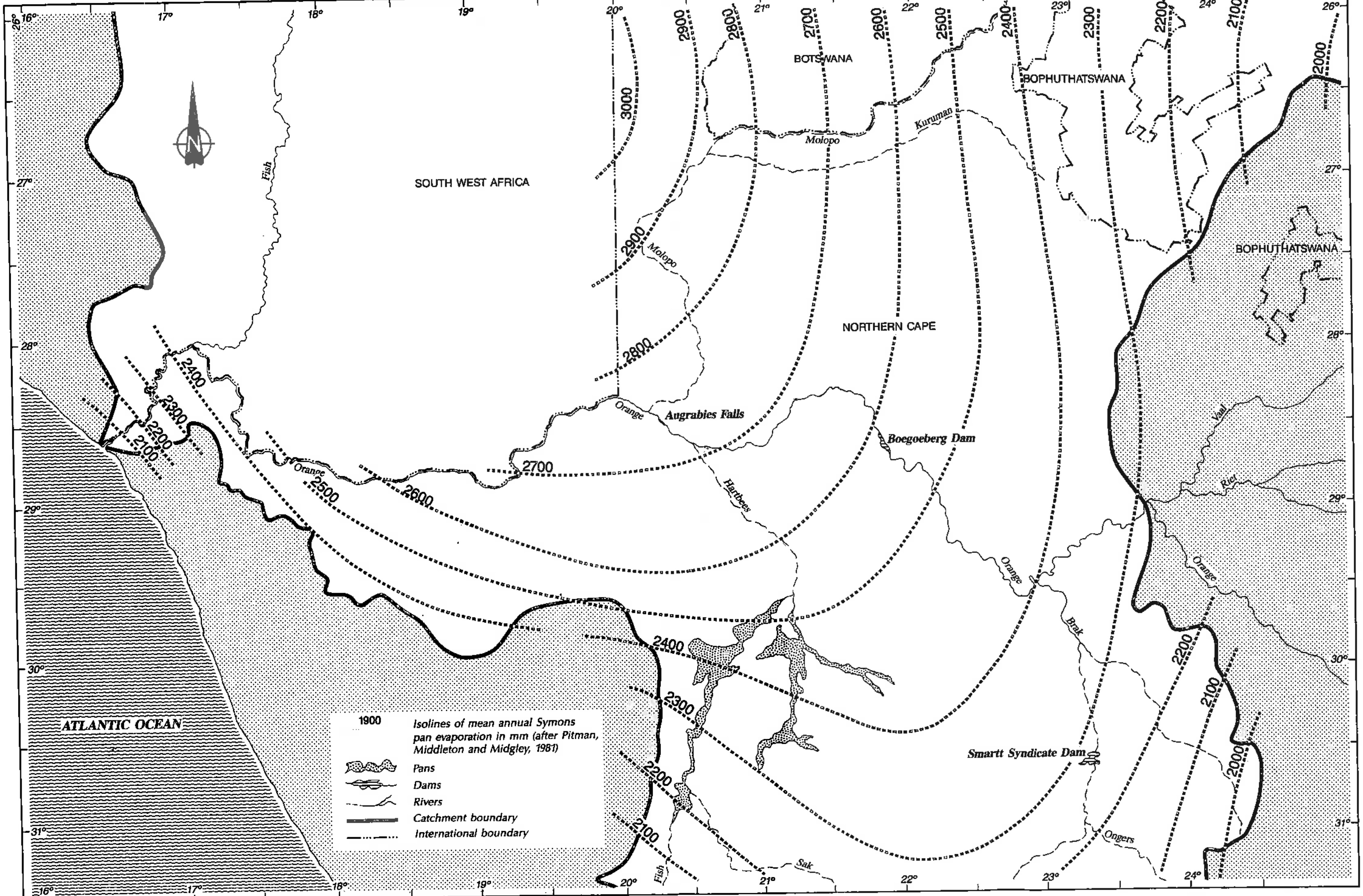
ORANGE RIVER SYSTEM ANALYSIS

Orange catchments downstream of the Orange–Vaal confluence : rivers and towns

3.13

No major rivers join the Orange along this lower section so no additional flow is contributed. The Brak River, of which the Ongers River is a tributary, converges with the Orange River just upstream at Prieska. The Smartt Syndicate Dam is situated on the Ongers River near Britstown and is used for irrigation purposes. The course of the Molopo River, which drains the Kalahari from the north, merges into the Orange downstream at Augrabies Falls, however, there has been no evidence of flow in the Molopo River for years. The confluence of the Orange and Hartbees Rivers is near Kakamas. The Hartbees River drains a massive pan area to the south, but due to the very high evaporation rates in this area most of the water flowing from the south western Cape mountains is lost to the atmosphere. Irrigation has developed in the headwaters region around Williston, however, this is not considered as the water would evaporate had it not been irrigated. The Fish River which flows southward through SWA to join the Orange River just upstream of the mouth is the only river making a contribution to the flow in the Orange. Any flow the Fish River contributes to the Orange will only affect the few downstream users, and due to the flow being inconsistent it will not be taken into account.

Rainfall on this catchment is very low and unreliable. The MAP for the whole area is below 200 mm and declines gradually in a westerly direction. Evaporation, on the other hand, is very high and the average annual evaporation as measured from an open water surface is above 2 500 mm for most of the area. Isolines of both the mean annual rainfall and annual evaporation losses are given in figure 3.14. Temperatures are also fairly high with the average maximum daily temperature in Upington being 35 °C, and the winter minimums are rarely below 5 °C. The area is practically free of frost.



Orange catchment downstream of the Orange-Vaal confluence : evaporation isolines

3.14

3.3.3 Overview of existing irrigation studies of the Middle Orange River Region

The Middle Orange river stretches from the confluence of the Orange and Vaal Rivers to Boegoeberg Dam. It comprises of most of the Prieska and Hay magisterial districts and includes the Ongers River which is a tributary of the Brak River. The Brak River enters the Orange upstream of Prieska. Due to the very small input of flow made by the catchment downstream of the Orange-Vaal confluence, any irrigation from dams and rivers in this area will be insignificant with respect to the streamflow in the Orange River. With this in mind, only the irrigation making direct use of Orange River water is considered.

The assessment of irrigation areas in the Middle Orange region made by Pitman et al. (1981) is summarised in table 3.20. The tertiary catchments as determined by Pitman et al. (1981) are depicted on figure A-4 in Appendix A. The only tertiary catchments making an impact on the water resources are D47, D48, D49 and D62 which consist of the Lower Brak and Ongers Rivers and the Orange River itself. The totals from these tertiary catchments are 4 200 ha of controlled irrigation and 3 150 ha of diffuse irrigation. Most of this irrigation makes use of the Orange River water directly, however, the Smartt Irrigation Board controlled about 1 800 ha on the Ongers River at the time the Smartt Syndicate Dam was built in 1962 (White Paper Y-67). Hence, irrigation along the Ongers and Brak Rivers probably takes up about 3 000 ha now, leaving about 4 350 ha to be scheduled from the Orange River. The irrigation in the rest of the tertiary catchments totalling over 3 000 ha is of a diffuse nature and makes use of sources which would otherwise evaporate and not contribute to the flow in the Orange River. Hence, these irrigated areas will not be considered in the final analysis.

Table 3.20: Areas irrigated (ha) according to the source of water in the tertiary catchments of the Middle Orange Region (Pitman et al., 1981).

HRU tertiary catchment	Source of water				Total
	State schemes	Irrigation boards	Springs & rivers	Farm dams	
D41	-	-	160	120	280
D42	-	-	200	150	350
D43	-	-	330	300	630
D44		530	50	40	620
D45	-	150	220	150	520
D46	-	130	380	260	770
D47	1 110	260	2 010	160	3 540
D48	30	780	220	80	1 110
D49	220	1 330	210	10	1 770
D61	-	-	80	30	110
D62	440	30	440	20	930
Total	1 800	3 210	4 300	1 320	10 630
	5 010		5 620		

The Census of Agriculture, (1981) indicates the areas under irrigation in the various magisterial districts of the Middle Orange River. The districts of interest and their associated areas are given in table 3.21. Part of the district of Hopetown lies in the Orange catchment downstream of the P.K. le Roux Dam and should not be included in this catchment. Some magisterial districts with only small portions of irrigation lying within the catchment have not been included. Hence a value of almost 6 000 ha should be representative of the irrigation here, although it seems somewhat low in comparison with the value of 7 350 ha obtained by Pitman _et al_. (1981).

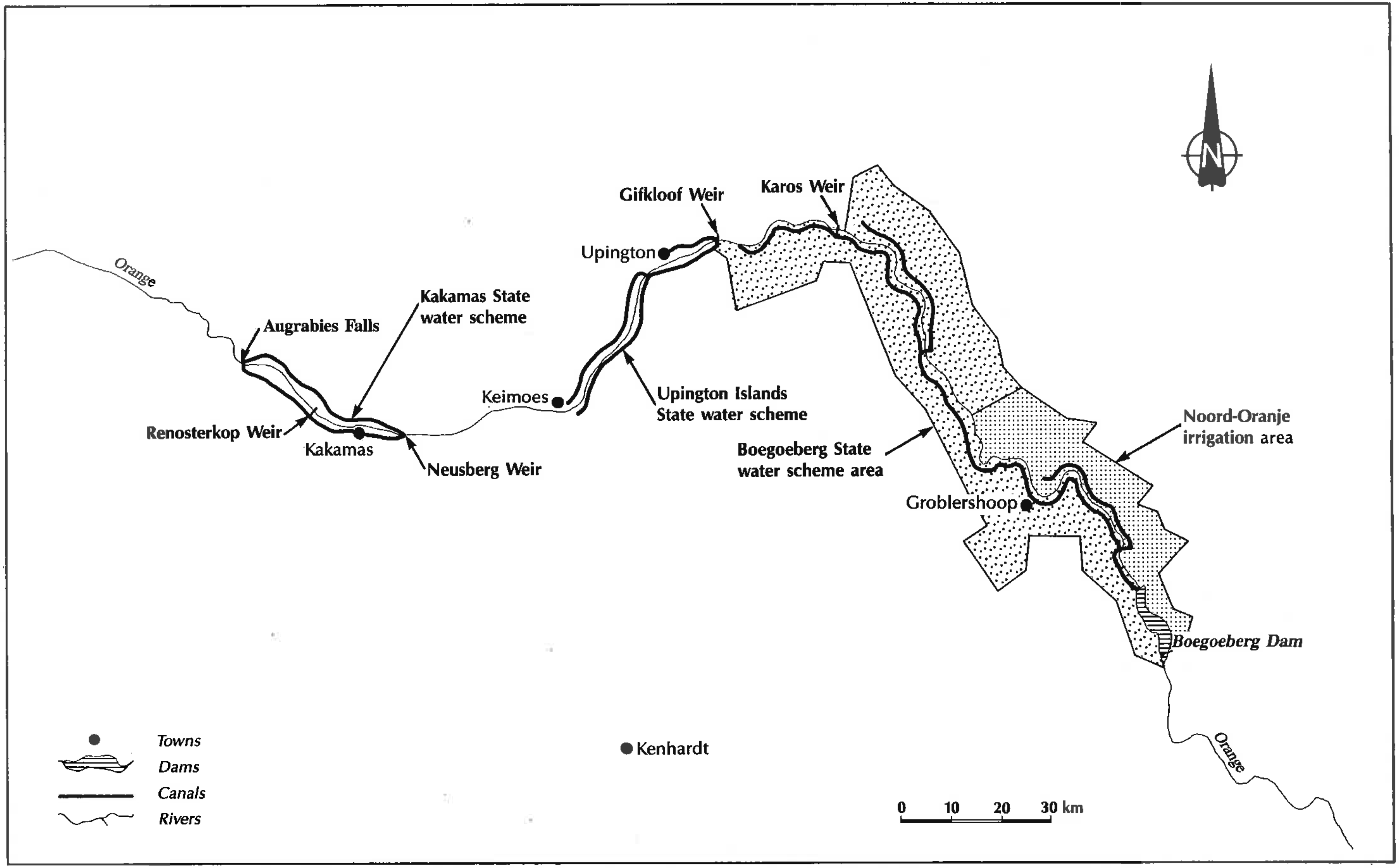
Table 3.21: Areas irrigated (ha) according to the source of water in the magisterial districts of the Middle Orange Region (Census of Agriculture, 1981).

Magisterial district	State water schemes	Irrigation board schemes	Springs, rivers & streams	Farm dams	Total
Hopetown	1 429	43	973	2	2 447
Britstown	-	973	130	2	1 105
De Aar	-	19	19	53	91
Prieska	283	308	1 325	6	1 922
Hay	240	64	55	15	374
Total	1 952	1 407	2 502	78	5 939
	3 359		2 580		

The results from a water balance survey of 1986 conducted by the Department of Water Affairs (1989) indicated that some 10 644 ha is irrigated along the Orange River from Hopetown to Boegoeberg Dam. Some of this irrigation takes place upstream of the Orange-Vaal confluence, thus, the 7 350 ha given by Pitman et al. (1981) is reasonable. Unfortunately most of this stretch of river is uncontrolled and consequently information on the irrigation development is sparse.

3.3.4 Overview of existing irrigation studies of the Lower Orange River Region

This Lower Orange River region is bounded by Boegoeberg Dam in the east and Augrabies Falls in the west and accommodates three State Water Schemes as well as the Karos and Kalahari West Rural Water Supply Schemes. The majority of the controlled irrigation takes place within the Boegoeberg, Upington Islands and Kakamas State Schemes. This irrigation has developed on the flat alluvial banks of the Orange River and on islands within the river. Figure 3.15 shows the



ORANGE RIVER SYSTEM ANALYSIS

Orange catchment downstream of the Orange–Vaal confluence : State water schemes

3.15

location of these schemes as well as the major supply canals. A maze of canals supply more than 26 000 ha of irrigated land on these schemes, and development is still ongoing.

The flat alluvial banks of the river, the slow meandering nature of the river and the well defined channel has made the harnessing and diversion of the water for irrigation purposes relatively straightforward. Irrigation in these parts was being developed as far back as 1883 when the first canal was built at Upington. Various weirs have been constructed over time to divert water to irrigation canals along this stretch of river. The Boegoeberg Dam was the first major man-made barrier across the Orange River and was built in 1931 for irrigation purposes.

Various surveys have been made in the past and close monitoring of the development of irrigation has enabled a reasonable record of irrigation in the region to be kept. Pitman et al. (1981) summarised the irrigation in tertiary catchments of the Orange River system (figure A-4 in Appendix A), and the areas irrigated in these tertiary catchments have been given in table 3.22. This information indicates that there is substantial irrigation in this region, and some 23 700 ha is uncontrolled.

The uncontrolled or diffuse irrigation making direct use of the Orange River Water is known, however, there is little information on the diffuse irrigation elsewhere. The tertiary catchments numbered D51 to D59 make up the Hartbees River catchment of which the Fish, Riet and Sak Rivers are major tributaries. These drain northwards from the south western Cape mountains into a massive pan system in the Brandvlei and Kenhardt regions. Much of the flow into these pans is evaporated before it can reach the Orange River. Hence any existing or proposed irrigation development in these headwater regions will not make any impact on the

Table 3.22: Areas irrigated (ha) according to the source of water in the tertiary catchments of the Lower Orange Region (Pitman et al., 1981).

HRU tertiary catchment	Source of water				Total
	State schemes	Irrigation boards	Springs & rivers	Farm dams	
D51	-	20	500	180	700
D52	-	70	960	450	1 480
D53	-	90	1 680	390	2 160
D54	-	100	1 620	330	2 050
D55	50	670	2 650	1 010	4 380
D56	10	690	7 670	1 610	9 980
D57	400	310	640	90	1 440
D58	120	510	1 350	320	2 300
D59	60	140	240	170	610
D63	6 410	7 790	760	30	14 990
D64	1 560	1 860	220	40	3 680
D81	3 340	4 030	380	10	7 760
D81	470	3 130	330	70	4 000
Total	12 420	19 410	19 000	4 700	55 530
	31 830		23 700		

Orange River System. The area under irrigation in these tertiary subcatchments is about 25 000 ha, and it is unlikely that Orange River water will ever be used to supplement supplies here. Thus, the irrigation that does influence the flow in the Orange River is the State and Board controlled irrigation along the river itself (28 600 ha), and the uncontrolled or private irrigation that takes up 1 840 ha according to Pitman et al. (1981).

The results from the Census of Agriculture (1981) of the areas under irrigation for those magisterial districts of the Lower Orange Region are given in table 3.23. This table gives a breakdown of the irrigation according to the source of water for the Gordonia and Kenhardt Magisterial Districts. These two districts lie on either side of the

River in the Lower Orange Region and encompass most of the essential irrigation areas. The results from the Census are slightly lower than those determined by Pitman _et al._ (1981), since only the main magisterial districts have been considered. Small sections of other districts containing irrigation also fall within this river section but have not been included as the major portion falls within an adjoining section.

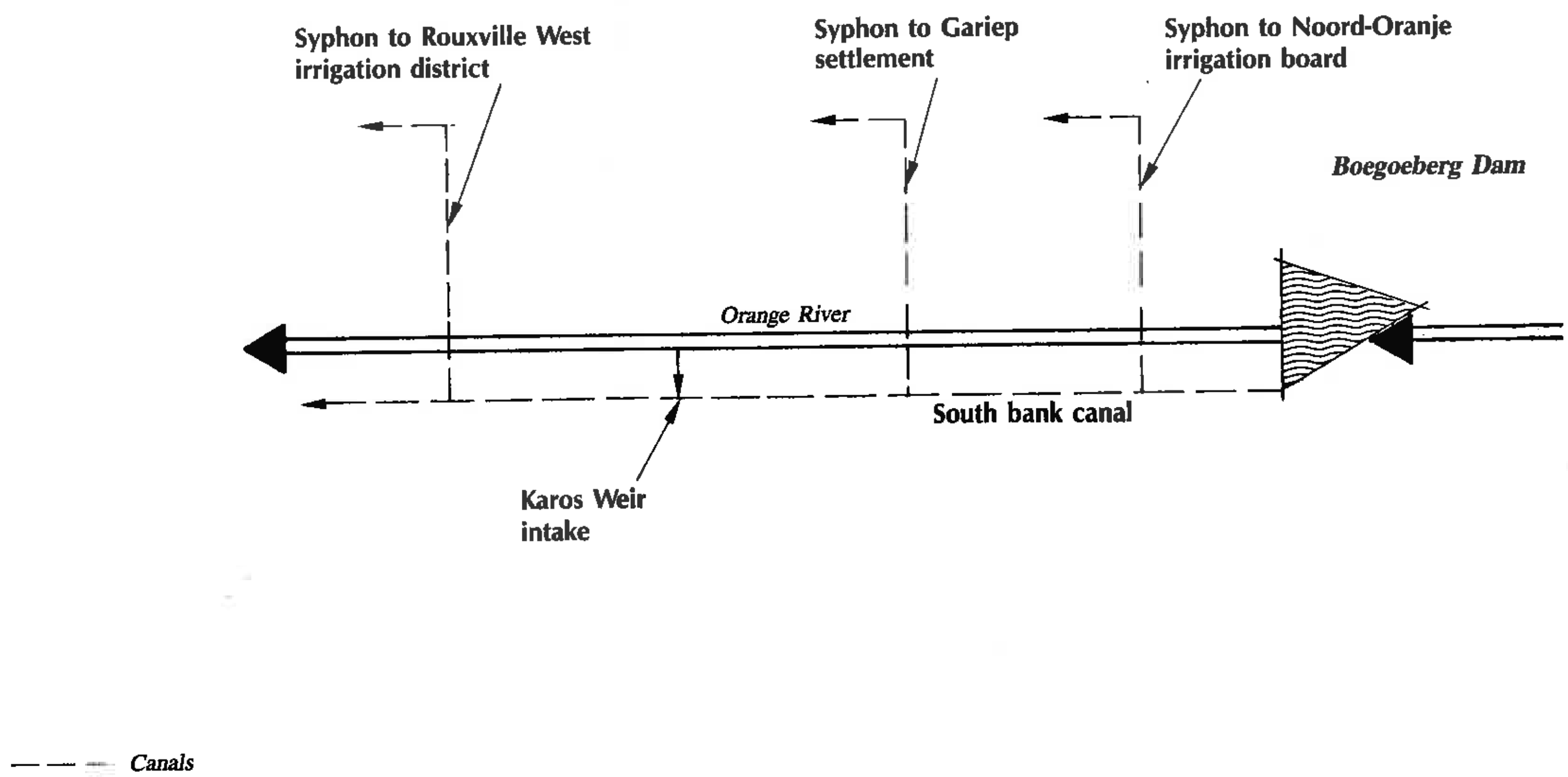
Table 3.23: Areas irrigated (ha) according to the source of the water in the magisterial districts of the Lower Orange Region (Census of Agriculture, 1981)

Magisterial district	State water schemes	Irrigation board schemes	Springs, rivers & streams	Farm dams	Total
Gordonia Kenhardt	11 065 1 021	7 649 384	1 377 75	15 30	20 106 1 510
Total	12 086	8 033	1 452	45	21 616
	20 119		1 497		

The Boegoeberg State Water Scheme is the first of the major schemes on the Lower Orange River with a large canal system Figure 3.16 shows a schematic layout of this scheme. Information from White Paper Y-67 on the irrigation in the Boegoeberg State Water Scheme is that the areas scheduled were:

- Gariep Settlement 1 027 ha,
- Rouxville West Irrigation Board 253 ha, and
- Boegoeberg-Karos Scheme 4 723 ha.

Thus, the scheme supplied water for a total of over 6 000 ha of irrigation by 1967.



ORANGE RIVER
SYSTEM ANALYSIS

Schematic of the Boegoeberg State water scheme **3.16**

During 1967 it was decided to provide for the expansion of the scheme and the existing irrigated areas and the proposed development included:

-	New areas on the north bank	1 113 ha,
-	Gariep Settlement	1 278 ha,
-	Rouxville West Irrigation Board	257 ha, and
-	Boegoeberg-Karos Scheme	5 114 ha.

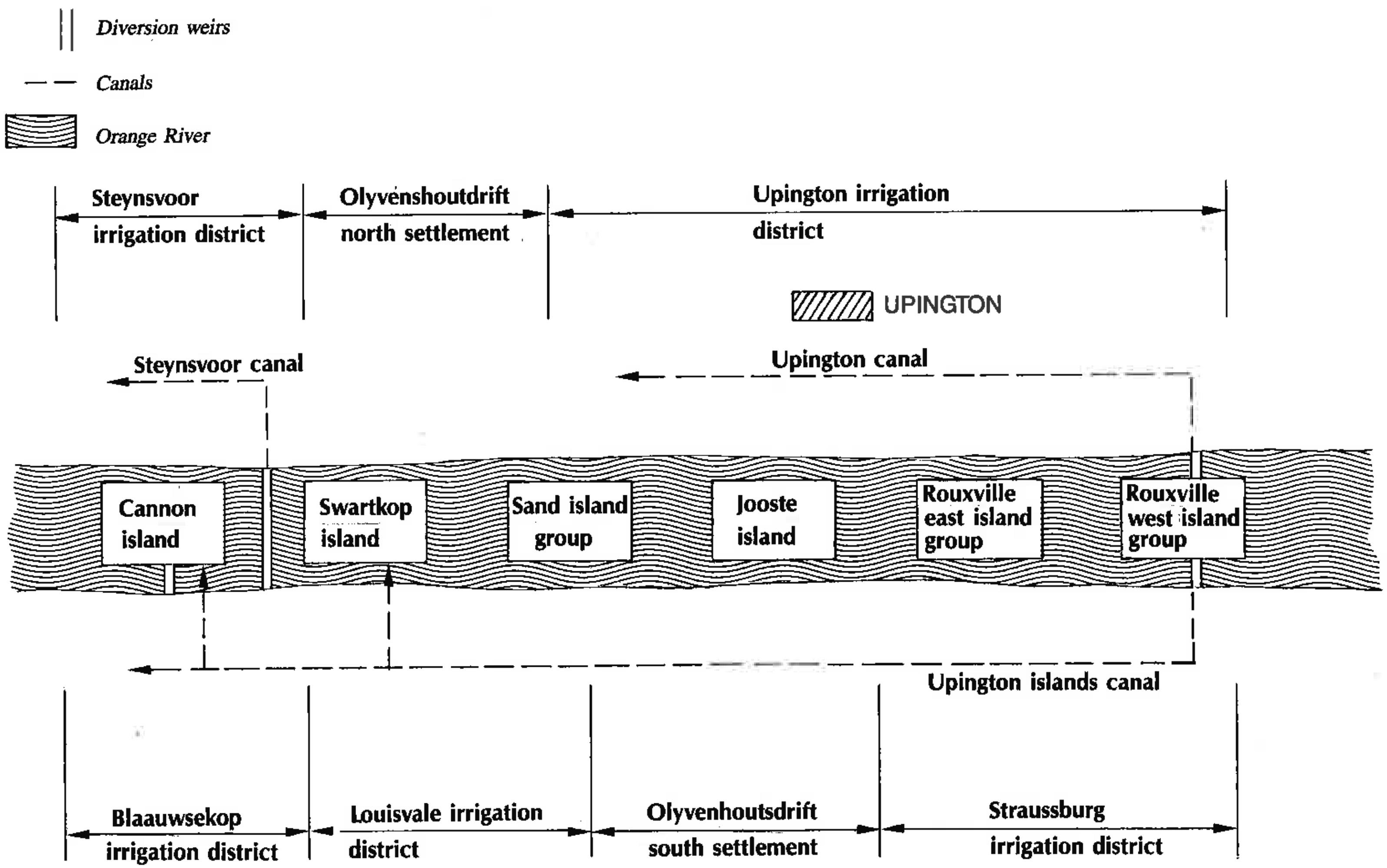
The total of the proposed irrigated area was 7 762 ha. The new areas on the north bank fall under the Noord Oranje Irrigation Board and by 1970 the scheduled area was 985 ha.

More up to date information from the Department of Water Affairs (1988) is that the areas scheduled during 1988 were:

-	Boegoeberg - Karos Scheme	6 578 ha,
-	Noord Oranje Irrigation Board	981 ha, and
-	Private pumping	1 224 ha.

The total area under irrigation along the Orange River commanded by Boegoeberg Dam by 1988 was 8 783 ha. This State Water Scheme ends just upstream of Upington where the Upington Islands State Water Scheme begins.

Irrigation in the Upington area began as far back as 1883 when the first canal was constructed. Many large islands exist in this part of the river and their deep, rich alluvial soils and abundant supply of water is conducive to good crop production. The upstream intake for the Scheme is at the Rouxville West island group and the south bank canal extends a fair distance downstream of Upington. Both banks of the river and the islands are irrigated and water is supplied via a maze of secondary canals and syphons. A schematic of the canal system, distribution points and irrigation districts is shown in figure 3.17. Five Irrigation Boards exist within the Scheme as well as various settlements and islands which are supplied.



Schematic of the Upington Islands State water scheme **3.17**

In 1976 the White Paper P-76 stated that 6 110 ha was scheduled under the Upington Islands State Water Scheme and a quota of 15 000 m^3/ha/a was administered. A survey of the irrigated areas in the Lower Orange River was undertaken by the Department at Water Affairs (1988) and has been summarised in table 3.24. The area controlled by the State Scheme has increased to 6 496 ha.

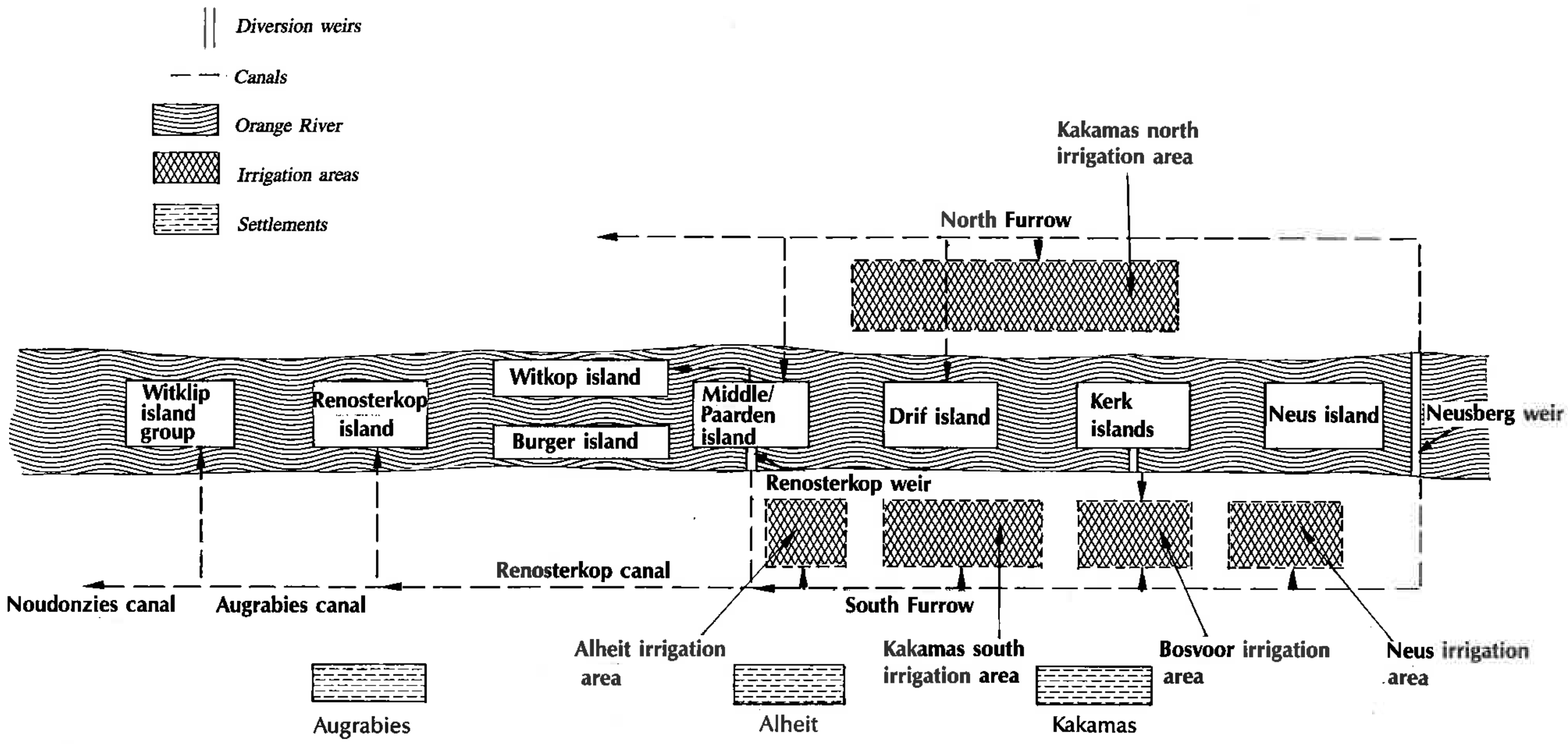
Table 3.24: Areas irrigated (ha) in the various sectors of the Upington Islands irrigation district (Department of Water Affairs, 1988).

Sector	Area (ha)	Total
UPINGTON STATE WATER SCHEME:		1 847
BOARDS IRRIGATING FROM THE STATE CANAL:		
Straussburg	470	
Lousvale	1 256	
Blaauwsekop	459	
Upper Kanon Island	521	
Steynsvoor	1 250	
Rooikop Island	154	
Skanskop Island	467	
Pokkies Island	72	4 649
BOARDS IRRIGATING FROM THEIR OWN CANALS:		
Upington	721	
Kousas	442	
Friersdale	983	
Malanshoek	108	
Brakbos	156	
Neilersdrift	375	
Lower Kanon Island	884	
Onderstekams	511	4 180
PRIVATE IRRIGATION:		1 355
Total		12 031

The final State controlled scheme before Augrabies Falls is the Kakamas State Water Scheme. Figure 3.18 shows a schematic of the canals and distribution points. Irrigation in the Kakamas area started in the late nineteenth century and takes place on various islands in the Orange River as well as on the alluvial flood banks on either side. 4 080 ha of land was scheduled in the Kakamas area by 1965 and was made up of land along the north and south banks of the river. This land is supplied by furrows from Neusberg Weir (White Paper W-65). White Paper D-75 mentioned that there was 4 315 ha of land scheduled in 1975, the majority of which under surface irrigation. The latest information from White Paper G-88 reveals that some 5 070 ha at land was being irrigated by 1988. A survey conducted by the Department of Water Affairs, (1988) showed that 4 247 ha of land was scheduled under the State Scheme and 1 194 ha of private land was irrigated by means of pumping, making a total of 5 441 ha in the Kakamas area.

3.3.5 Overview of Existing irrigation studies of the Namaqualand Region

Namaqualand covers the lower reaches of the Orange River from Augrabies Falls to the mouth at Alexander Bay. The river flows along a deep ravine for most of its course through Namaqualand. The gorge has cut into rugged terrain such as the Richtersveld in the north western Cape Province. Thus, irrigation in this region is limited to the immediate vicinity of the Orange River where pumping heads are low. In most cases the flat alluvial flood planes at the bottom of the gorge are cultivated and irrigated by means of canals. The irrigation occurs in isolated patches along the River up to the coast. The only tributary making any contribution to the flow in the Orange River in this region is the Fish River. The Fish River flows south through a canyon in SWA, however, irrigation making use of Fish River water is not considered. Information on the irrigation from the Orange River is available and summarised below.



ORANGE RIVER
SYSTEM ANALYSIS

Schematic of the Kakamas State water scheme **3.18**

Pitman et al. (1981) made an assessment of the irrigation from various sources in Namaqualand which is summarised in table 3.25. These results are tabulated according to the tertiary catchments shown on figure A-4 in Appendix A. Most of this irrigation is controlled by irrigation boards which have been set up at the various settlements along the river. The results of the Census of Agriculture (1981) on the area irrigated is given in table 3.26. The total irrigated area is far higher than that given by Pitman et al. (1981) as most of the magisterial districts of Gordonia and Kenhardt lie in the Lower Orange River Region and should not be included here. The irrigation in the Calvinia magisterial district is basically centred around the Sak and Riet River area in the south west of the study area. Runoff from this area drains into a vast pan system and is evaporated before it can reach the Orange River. This indicates that any consumption of this water in these areas will not affect the flow in the Orange River.

Table 3.25: Areas irrigated (ha) according to the source of water in the tertiary catchments of Namaqualand (Pitman et al., 1981).

HRU tertiary catchment	Source of water				Total
	State schemes	Irrigation boards	Springs & rivers	Farm dams	
D82	470	3 130	330	70	4 000
D83	-	40	860	160	1 060
D84	-	10	60	30	100
D85	110	5 300	550	-	5.960
Total	580	8 480	1 800	260	11 120
	9 060		2 060		

Table 3.26: Areas irrigated (ha) according to the source of water in the magisterial districts of Namaqualand (Census of Agriculture, 1981).

<table>
<tr><th>Magisterial district</th><th>State water schemes</th><th>Irrigation board schemes</th><th>Springs, rivers & streams</th><th>Farm dams</th><th>Total</th></tr>
<tr><td>Namaqualand</td><td>69</td><td>166</td><td>822</td><td>39</td><td>1 096</td></tr>
<tr><td>Calvinia</td><td>410</td><td>817</td><td>3 581</td><td>1 520</td><td>6 328</td></tr>
<tr><td>Gordonia</td><td>11 065</td><td>7 649</td><td>1 377</td><td>15</td><td>20 106</td></tr>
<tr><td>Kenhardt</td><td>1 021</td><td>384</td><td>75</td><td>30</td><td>1 510</td></tr>
<tr><td rowspan="2">Total</td><td>12 565</td><td>9 016</td><td>5 855</td><td>1 604</td><td rowspan="2">29 040</td></tr>
<tr><td colspan="2">21 581</td><td colspan="2">7 459</td></tr>
</table>

A survey quoted by the Department of Water Affairs (1988) indicated the areas under irrigation in the Namaqualand Region. The information from the survey for this region has been summarized in table 3.27 where it is seen that a total of 2 252 ha is irrigated in Namaqualand. The Department of Water Affairs Annual Report (1982) indicated that no additional irrigation has been developed in the stipulated irrigation areas. It is also unlikely that much more irrigation will be developed in Namaqualand as most of the accessable cultivated land is already under irrigation.

Table 3.27: Areas irrigated (ha) in Namaqualand (Department of Water Affairs, 1988).

Irrigation area	Area (ha)
Vioolsdrift irrigation Board	753
Onseepkans irrigation Board	267
Private irrigation (R.S.A)	1 588
Private irrigation (S.W.A)	894
Noordoewer Irrigation Area (S.W.A)	750
Total	4 252

3.3.6 Summary of the irrigated areas

The irrigation from the Orange River downstream of the Orange-Vaal confluence has been monitored closely and information on the areas concerned is freely available. The previous three sections have given an outline of the development of the irrigation in this area. Table 3.28 is a summary of the areas under irrigation at present in the river sections within the catchment. The values stated for the Brak/Ongers Rivers area and the Middle Orange area (river sections 1 & 2) are estimated from all the available data, whilst the values of the irrigated areas for the rest of this catchment are taken from the survey conducted by the Department of Water Affairs, (1981).

Table 3.28: Summary of the areas under irrigation at present in the various river sections of the Orange catchment downstream of the Orange-Vaal confluence.

No.	River Section	Area (ha)
1	Brak/Ongers Rivers	3 000
2	Middle Orange River	8 000
3	Boegoeberg Scheme	8 780
4	Upington Islands Scheme	12 930
5	Kakamas Scheme	5 440
6	Namaqualand	4 250
Total		42 400

Estimates of the crop water requirements for the irrigation zones established in table 3.28 are given in table 3.29. The irrigation requirement for river section 4 (Upington) is taken as the quota stated in White Paper P-76, whilst the requirements for the rest at the areas are only estimates. The crop water requirements may also be estimated from the evapotranspiration rates for the particular crops.

Table 3.29: Estimated crop water requirements for the irrigated areas of the various river sections of the Orange catchment downstream of the Orange-Vaal confluence.

River section number*	Requirement (m^3/ha/a)
1	13000
2	13000
3	15000
4	15000
5	15000
6	15000

* River sections as in table 3.28

3.3.7 Crop Water requirements

The total irrigation requirements may be calculated from estimates of the evapotranspiration which requires not only information on the areas the particular crops cover, but also details of the monthly crop factors and A-pan evaporation data. The Census of Agriculture (1981) disclosed details on the areas of the crop types under regular irrigation in the Orange catchment below the Orange-Vaal confluence. The results have been summarised for the magisterial districts within the catchment in table 3.30. The magisterial districts of Britstown and De Aar include all the irrigation from the Brak and Ongers Rivers (Smartt Syndicate Dam), more than 80 % of which is under pastures or fodder crops. The magisterial districts of Hopetown, Prieska, Hay, Gordonia, Kenhardt and Namaqualand comprise all the areas surrounding the Orange River from the Orange-Vaal confluence to the mouth. The ratios of the areas of the crop types under regular irrigation to the total area in those districts is 0,32, 0,42 and 0,26 for annual crops, vineyards and pastures respectively.

Table 3.30: Areas of the crop types under regular irrigation (ha) in the magisterial districts of the Orange catchment downstream of the Orange-Vaal confluence (Census of Agriculture, 1981).

Magisterial district	Annual plantings under regular irrigation	Perennial plantings under regular irrigation		
		Vineyards/ orchards	Fodder/ pastures	Timber
Hopetown	2 263	48	198	-
Britstown	202	25	1 030	-
De Aar	61	15	229	-
Richmond	210	6	738	-
Victoria West	91	9	856	-
Prieska	668	166	1 162	-
Hay	194	104	313	2
Gordonia	5 085	10 557	4 466	59
Kenhardt	561	556	413	-
Carnarvon	15	8	334	-
Williston	339	4	1 486	-
Namaqualand	225	233	756	-
Total	9 944	11 731	11 981	61
		23 773		

The areas the particular crops cover have also been estimated at a more localised scale on the controlled schemes in this catchment. The White Paper Y-67 gives information on the crops under irrigaton in the Boegoeberg region. Of this area approximately 50 % is put to vineyards from which export quality sultanas and table grapes are produced. The remaining area is under lucerne and vegetables, with the majority being lucerne. Cotton is also grown on a small scale.

The Upington area is renowned for its agricultural potential and has become the centre of the largest area of grape production in RSA. Other cultivated crops include sultanas, cotton, maize, wheat and vegetables. White Paper P-76 gave a breakdown of the ratio of the crops that are irrigated per hectare which has been summarised in table 3.31. Information from local personnel suggest that a far larger proportion of grapes are irrigated and the crop ratio is likely to be as high as 0,5.

Table 3.31: Proportion of crops irrigated in the Upington area (White Paper P-76).

Crop	Crop ratio	
PERENNIAL CROPS:		
Lucerne	0,25	
Vines/fruit	0,30	
ANNUAL CROPS:	Summer	Winter
Cotton	0,30	
Beans	0,05	
Others	0,05	
Wheat		0,20
Peas/Lentils		0,15
Others		0,05

The Kakamas State Water Scheme is also a highly productive agricultural area. White Paper G-88 gave a breakdown of the proportion of the crops that are irrigated in the Kakamas region which are tabulated in table 3.32. This information probably also applies to the Upington area at present bearing in mind that the information in table 3.31 was valid for the mid 1970's.

The proportion of the total irrigated area that the individual crops cover are given for the various river sections in table 3.33. These proportions are based on

Table 3.32: Proportion of crops irrigated in the Kakamas area (White Paper G-88).

Crop	Crop ratio
Sultanas	0,65
Rotation Agriculture	0,20
Lucerne	0,15

published information and adjusted according to information obtained from a field trip into this region. The details for river sections 1 and 6 (Smartt Syndicate Irrigation area and the Namaqualand irrigation area) are estimates based on all the available information. The proportions of the crops for the rest of the river sections are based on more accurate observations from the White Papers.

Table 3.33: Proportion of crops irrigated in the various river sections of the Orange catchment downstream of the Orange-Vaal confluence

Crop	River section number *					
	1	2	3	4	5	6
Sultanas	-	0,30	0,50	0,55	0,60	0,60
Lucerne	0,80	0,30	0,25	0,20	0,15	0,20
Maize	0,10	0,20	0,15	0,10	0,10	0,10
Wheat	0,10	0,20	0,15	0,20	0,15	0,20
Cotton	-	0,15	0,10	0,30	0,10	0,10
Vegetables	-	-	0,10	0,10	-	-

* 1 : Brak/Ongers Rivers
2 : Middle Orange River
3 : Boegoeberg Scheme
4 : Upington Islands Scheme
5 : Kakamas Scheme
6 : Namaqualand

Detailed information on the monthly A-pan evaporation and crop factors for the individual crops are listed in Appendix B. The information has been listed according to the River sections shown in table 3.33. The crop factors and A-pan evaporation rates will be used in the determination of the crop water requirements, whilst the proportions of the crops under irrigation will give the total demand for the particular area.

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4. URBAN AND INDUSTRIAL DEMANDS AND RETURN FLOWS

4.1 GENERAL

The urban and industrial demands on the Orange River water are small in comparison with the agricultural demands, but are by no means insignificant. The most important of these is the supply to the urban centres in the Orange River basin. Industry in this area is still small in extent and there are no power stations making use of water for cooling. An account of all the water used by these consumers is important to the System Analysis, and provision must be made to satisfy their future demands. Water returned to the system should also be accounted for as it may be used by downstream consumers. The use of return flows becomes critical when the system is operating at capacity and no more water is available.

The approach in assessing the urban and industrial demands and return flows is to consider the major user centres in each catchment separately. In most cases only one requirement for a centre has been stated and this is the total of the household, industrial and irrigation requirements of the centre. Since industrial needs are small, the major portion of the water is used by household consumers. A summary of the water use at each centre is given below and is based on information returned in a questionnaire sent to the various municipalities, as well as details from the White Papers and information from personal communication with local authorities. In some cases the details on the water use for selected settlements have not been included as they either make use of water which would not have entered the Orange River system due to evaporation, or depend entirely on groundwater resources which are not being replenished. The future supply from the system to some areas presently using groundwater should be considered as the groundwater reserves may not be able to cope with the increasing demands.

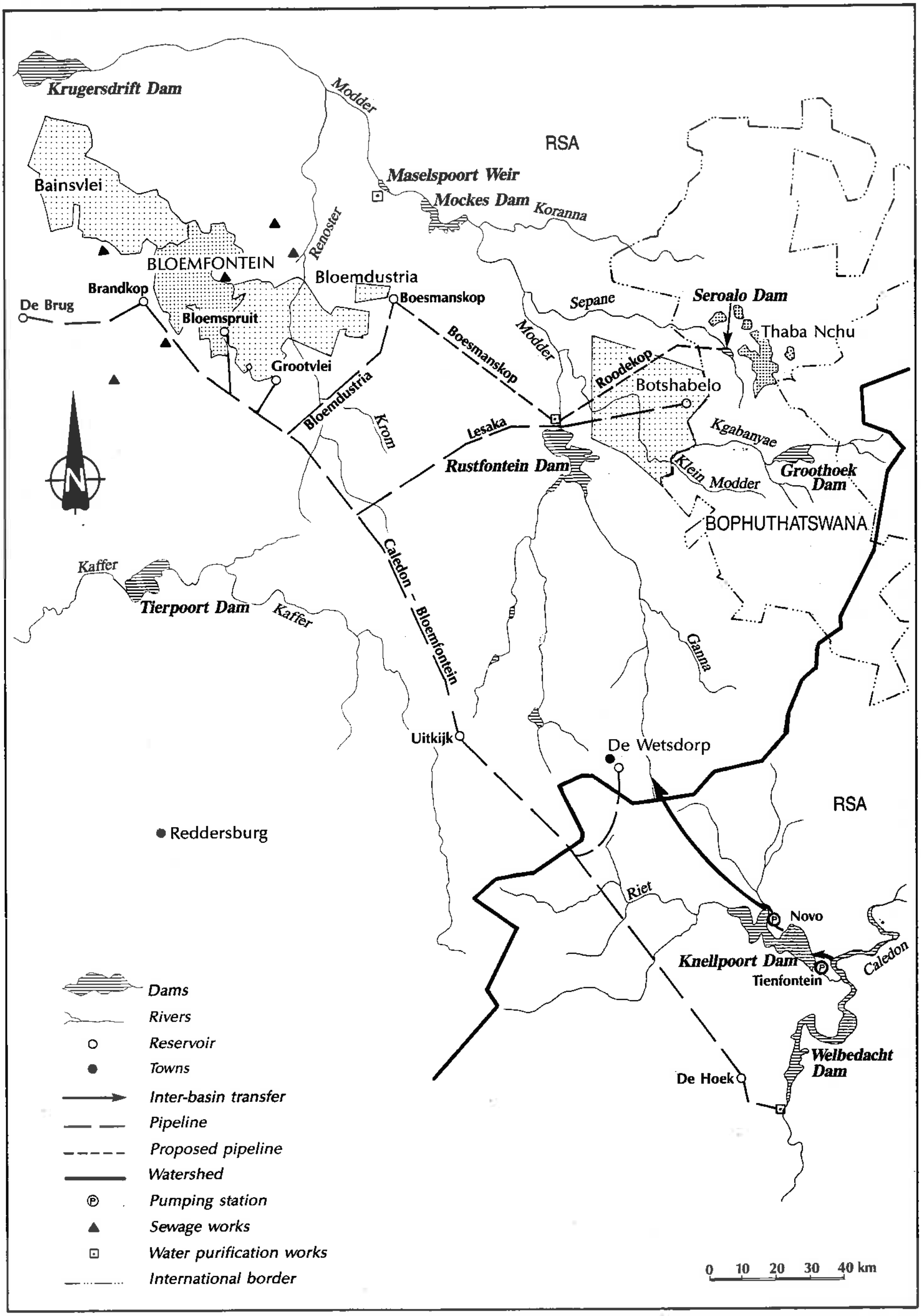
4.2 RIET AND MODDER CATCHMENT

The Riet and Modder catchment covers most of the southern Orange Free State. It is also the site of the largest urban water consumption in the whole study area. Bloemfontein and the nearby peri-urban centres including Botshabelo are supplied with water by a vast network abstracting from both the Modder and Caledon Rivers. Substantial settlements in Bophuthatswana such as Thaba'Nchu derive their water from dams on tributaries of the Modder. A few towns situated in the northern sector of the catchment are supplied with water from the Vaal River system. The majority of the small towns, however, make use of groundwater to satisfy their demands. An assessment of water use by the various urban centres in the Riet and Modder catchment is now undertaken.

Bloemfontein

Bloemfontein is the largest urban consumer of water in the Orange River basin and it obtains water from the Modder and Caledon Rivers. The town was originally supplied from Maselspoort Weir on the Modder River, but this resource has become insufficient. The Caledon-Bloemfontein pipeline was then implemented in 1974 to supply potable water from the Welbedacht Dam on the Caledon River to consumers along its route and to the Bloemfontein municipality. The volumes of water consumed annually by Bloemfontein from the purification plants at Maselspoort Weir and Welbedacht Dam are listed in table 4.1.

Other consumers also make use of the pipeline from Welbedacht Dam to Bloemfontein and the distribution system is indicated in figure 4.1. The water use by those consumers who are supplied from the Caledon River is shown in table 4.2. The sedimentation of Welbedacht Dam has decreased the yield significantly, so much so that the Caledon-Bloemfontein pipeline is now operating at capacity.



ORANGE RIVER SYSTEM ANALYSIS

Caledon – Modder transfer scheme **4.1**

Table 4.1: Annual water consumption ($10^6 m^3$) for Bloemfontein

Year	Maselspoort	Welbedacht	Total
1971	15,983	-	15,983
1972	20,645	-	20,645
1973	17,346	-	17,346
1974	16,115	3,198	19,313
1975	12,179	7,033	19,212
1976	12,906	7,261	20,167
1977	15,662	7,714	23,376
1978	16,633	8,680	25,313
1979	17,750	9,855	27,605
1980	14,510	11,674	26,184
1981	17,682	10,959	28,641
1982	15,522	17,360	32,882
1983	6,021	18,323	24,344
1984	3,882	24,903	28,785
1985	11,222	21,415	32,637
1986	11,971	20,277	32,248

Table 4.2: Annual water consumptions ($10^6 m^3$) supplied from Welbedacht Dam.

Year	Bloemfontein	Botshabelo	Others	Total
1974	3,198	-	-	3,198
1975	7,033	-	-	7,033
1976	7,261	-	-	7,261
1977	7,714	-	-	7,714
1978	8,680	-	-	8,680
1979	9,855	-	0,242	10,097
1980	11,674	0,157	1,058	12,889
1981	10,959	0,485	0,923	12,367
1982	17,360	0,700*	0,940	19,000
1983	18,323	0,750*	0,927	20,000
1984	24,903	0,955	0,742	26,600
1985	21,415	0,849	3,630	25,894
1986	20,277	0,873	4,020	25,170

* Estimates based on measured consumptions.

This has led to the construction of Knellpoort Dam which will facilitate the transfer of water into the upper reaches of the Modder River, thus supplementing the water supply to Bloemfontein from Maselspoort Weir (figure 4.1). Knellpoort Dam is an off-channel storage dam on the Rietspruit which is supplied by water from the Caledon River via a system of pumps, sediment traps and a canal. It in turn supplements the yield from Welbedacht Dam by releases when this dam drops to a critical level. The construction of an inter-basin transfer scheme is being assessed at present.

The return flow from Bloemfontein represents a sizeable amount of water and is approximately 30 % of that consumed. Two sewage works are in operation in the Bloemfontein area. The Bloemspruit works disposes of the treated water into the Bloemspruit which flows into the Modder River via the Renosterspruit. The balance of the treated sewage water is discharged from the Welvaart Works into the Kaalspruit which joins the Modder River downstream of the Krugersdrift Dam. This sewage treatment plant is fairly new and handles a small proportion of the return flow. The measured annual return flows from the two plants are given in table 4.3.

Table 4.3: Annual return flows ($10^6 m^3$) for Bloemfontein.

Year	Bloemspruit	Welvaart	Total
1974	5,680	-	5,680
1975	6,273	-	6,273
1976	6,593	-	6,593
1977	5,087	-	5,087
1978	5,016	-	5,016
1979	5,306	-	5,306
1980	9,201	-	9,201
1981	12,534	-	12,534
1982	12,075	0,776	12,851
1983	8,641	0,518	9,159
1984	7,588	0,589	8,177

Brandfort

Brandfort is situated in the north-east of the catchment and is supplied by water from Erfenis Dam on the Sand-Vet Scheme. This scheme is part of the Bloemhof Dam subsystem and water from the Riet and Modder catchment is not consumed in Brandfort. The method of sewage disposal is via oxidation dams so it is assumed that there are no return flows and all the water is lost from the system.

Dewetsdorp

Municipal water for Dewetsdorp is obtained from the Caledon-Bloemfontein pipeline as well as from boreholes. The consumption for the period July 1988 to June 1989 was 116 582 m^3 from groundwater sources and 40 834 m^3 from Welbedacht Dam. The future expansion in urban water requirements will have to be supplied by the boreholes as the pipeline is now operating at capacity. It is assumed that oxidation dams or septic tanks treat the sewage, so there will be no return flows to the system.

Edenburg

This town is supplied with water from boreholes and the consumption in 1988 was 49 275 m^3. No future expansion is envisaged here and all future demands should be able to be met by groundwater sources. The method of effluent treatment is not likely to give rise to any return flows.

Fauresmith/Jagersfontein

Fauresmith and Jagersfontein lie to the south of Kalkfontein Dam and are supplied with water from boreholes as well as from the old mine shaft at Jagersfontein. There was a rapid increase in consumption of water from the mine shaft during the early 1980's which may have been due to the establishment of the distribution system from the mine rather than growth in the population or industry. Table 4.4 shows the consumption of water from the mine shaft of both Jagersfontein and Fauresmith. Indications are that any growth in urban and industrial requirements should be satisfied by the existing water resources without problems. The sewage from Fauresmith is treated in oxidation dams so no return flows exist, and return flows from Jagersfontein are assumed to be negligible.

Table 4.4: Annual water consumptions (m^3) from the mine shaft at Jagersfontein.

Year	Jagersfontein	Fauresmith	Total
80/81	239 234	-	239 234
81/82	336 086	-	336 086
82/83	378 003	-	378 003
83/84	334 080	33 387	367 467
84	64 783	878	65 661
84/85	401 572	20 278	421 850
85/86	446 988	52 191	499 179
86/87	483 094	123 180	606 274

Jacobsdal

Household water is supplied to Jacobsdal from boreholes, but some water for irrigation purposes is obtained from the Riet River canal downstream of Kalkfontein dam. The annual consumption from groundwater sources was 56 250 m^3 in 1985 and a growth rate of 2,5 % p.a. in the urban demands is assumed. The growth in water demand should be fulfilled by the groundwater sources. The return flow from Jacobsdal is discharged in the veld and does not find its way into the river system.

Kimberley

Kimberley obtains its water from the Vaal River at Riverton which is outside the area of interest to the Orange River System Analysis. The return flows are directed to large evaporation pans outside the city.

Koffiefontein

Apart from Kimberley, Koffiefontein is the largest mining centre in the Riet and Modder catchment. It is supplied with water from the Riet River canal for both urban and mining uses. During the period July 1988 to June 1989 the town consumed 690 000 m^3 and the mine consumed 628 800 m^3. Potable water on the other hand must be obtained from boreholes. Return flows from both the town and mine are discharged into the Riet River, the return flow from the town for the above period being 13 200 m^3. The return flows from the mine have not been measured, but are assumed to be of the same order of magnitude as the return flows from the town.

Petrusburg

Boreholes are the source of water for Petrusburg and the average demand is estimated as 112 000 m^3/a. The groundwater reserves should be able to supply all future demands and any growth is likely to be small. The return flows, if any, are considered to be insignificant.

Reddersburg

The municipality of Reddersburg obtains its domestic water from boreholes and the sewage is treated in oxidation dams. The predicted future water requirements and return flows are summarised in table 4.5. The demands should at all times be met by the reserves of groundwater, but the return flows seem to be unrealistically high. It is assumed that after the sewage has been treated in the oxidation dams no return flows will exist.

Table 4.5: Estimated future water requirements and return flows (m^3/a) for Reddersburg.

Year	Requirements	Return flows
1990	105 772	74 040
1995	123 604	86 523
2000	142 178	99 525
2005	161 001	112 701
2010	179 457	125 620
2015	184 840	129 388
2020	190 385	133 269
2025	196 096	137 267
2030	201 979	141 385
2040	208 038	145 626
2050	214 279	149 995

Ritchie

Ritchie is supplied with urban water from boreholes and the average annual requirement is approximately 240 000 m^3. No future expansion is predicted, thus the demand will always be able to be supplied by the groundwater sources. An oxidation dam is being planned to treat the effluent and to date there have been no return flows.

Trompsburg

The urban water requirements of Trompsburg are supplied from boreholes and the estimated annual demand is 100 000 m^3 of which about half is for irrigation. This is expected to remain fairly constant in the future. The effluent is treated in oxidation dams and no return flows will reach the rivers.

4.3 CALEDON CATCHMENT

The Caledon catchment contains a number of small towns, some of which are dependent on the rivers for water supply. The towns on the South African side of the river are small settlements with a strong agricultural basis. Water requirements are solely for domestic purposes and for the maintainance of any light idustry. The settlements across the border in Lesotho are for the most part semi-urban communities whom are not supported by any water distribution network. Water for urban use is obtained from the rivers in buckets, or from wells and boreholes. It is assumed that this consumption is insignificant and will have no effect on the System Analysis. The quantity of water utilised by Maseru is not known but must be considerable. Indications are that purifation plants, sewage treatment works and a large number of urban and industrial consumers exist. Details on the water use by Maseru are as yet not available and this requires urgent attention. The demands and return flows of the various centres in the Caledon catchment follows.

Clocolan

Clocolan is a small town supported by water from two small dams on the Mopelispruit. One of these dams, the Lucretia Dam, was constructed recently and water has been supplied to the town since October 1986. Clocolan has received water from the other dam since 1926. Approximately 20 % of this water is used by industry. The estimated future water requirements of Clocolan are shown in table 4.6. The effluent is treated in oxidation dams and irrigated, thus no return flows exist.

Table 4.6: Estimated future water requirements (m^3/a) for Clocolan.

Year	Requirements
1990	342 900
1995	394 700
2000	454 600
2005	603 700
2010	696 200
2015	803 200
2020	927 200
2025	1 070 700
2030	1 237 200
2040	1 430 200

Ficksburg

Ficksburg is the major agricultural centre in the catchment and makes use of water from both the Caledon River and a dam on the Meulspruit. Water from the Caledon has been abstracted for many years, and the dam has been in operation since 1976. Only 70 % of this requirement is for domestic use and the balance is consumed by industry. The estimated future requirements are listed in table 4.7 along with the estimated return flows. The sewage passes through an activated sludge process and is said to be discharged into the Caledon River, although irrigation is more likely. The values given in table 4.7 for the annual return flows seem unrealistically high and should be in the region at 20 to 40 % of the water consumed. The treatment plant only came into operation in 1965.

Table 4.7: Estimated future water requirements and return flows (m^3/a) for Ficksburg.

Year	Requirements	Return flows
1990	1 678 500	1 470 000
1995	2 081 000	1 796 000
2000	2 517 000	2 180 000
2005	3 009 000	2 630 000
2010	3 622 000	3 080 000
2015	4 315 000	3 382 000
2020	4 739 000	3 735 000
2025	5 204 000	4 120 000
2030	6 285 000	5 025 000
2040	7 568 000	6 130 000
2050	9 136 000	7 470 000

Fouriesburg

No demand and return flow information is availabe for Fouriesburg. The water requirements may be estimated from the population statistics given in a later section. The return flows can be assumed to be negligible as it is a small town and is not situated near the river system. Thus, even if a small return flow exists it is not likely to find its way into the main rivers.

Ladybrand

The water requirements of Ladybrand are not available, however, since it is remote from a river the demands and return flows to the system are likely to be small. The demands are probably met by groundwater sources and the volumes involved may be calculated from the population statistics in a following section.

Wepener

Details on the demands and return flows of Wepener are not available. The town is situated on the Sandspruit just upstream of its confluence with the Caledon River. The urban water requirements may be determined from the population statistics given in a later section, and these are more than likely supplied by boreholes. The return flows, if any, will be too small to have any significant effect on the System Analysis.

4.4 ORANGE CATCHMENT FROM WELBEDACHT DAM TO THE ORANGE-VAAL CONFLUENCE

The catchment of the Orange River upstream of the Orange-Vaal confluence is for the most part sparsely populated. A larger concentration of towns occurs further up the catchment where the agriculture is more intensive, however, the towns are scantily distributed in the Karoo region. Only urban centres with present populations of about 2000 have been considered as the water use by the smaller settlements is not likely to be significant. Other centres have not been included in the assessment as they are remote from the river system and are making use of water resources that otherwise would not have found their way into the Orange River.

Aliwal North

Aliwal North is the largest town in this catchment and is situated just downstream of the Orange-Kraai confluence. The town obtains its water from the Orange River and its present consumption is in order at $2.10^6 m^3/a$. Industry and irrigation account for 20 % and 10 % of the urban water use respectively, whilst the remaining 70 % is taken up by household requirements. The estimated future water requirements and return flows are summarised in table 4.8. The sewage is treated with biological filters and the return flow is irrigated on lands along the river bank.

Table 4.8: Estimated future water requirements and return flows (m^3/a) for Aliwal North.

Year	Requirements	Return flows
1990	2 000 000	550 000
1995	2 100 000	577 500
2000	2 205 000	606 000
2005	2 315 250	630 000
2010	2 431 000	668 000
2015	2 552 560	681 000
2020	2 680 190	700 000
2025	2 814 200	730 000
2030	2 954 910	766 000
2040	3 102 650	790 000
2050	3 257 790	805 000

Barkly East

Barkly East is located in the foot hills of the Drakensberg range on the Langkloof River which flows into the Kraai River a short distance downstream. The urban water requirements are supplied from the Langkloof River and from boreholes, although the proportion of the total requirement each source supplies is unknown. A summary of the total water requirement estimated at five year intervals for the next 60 years is given in table 4.9. No information is available on the return flows from Barkly East, but it is assumed that the method of sewage treatment and the small requirement of the town will yield very little return flow.

Table 4.9: Estimated future water requirements (m^3/a) for Barkly East.

Year	Requirements
1990	339 163
1995	355 299
2000	372 226
2005	389 982
2010	408 611
2015	428 153
2020	448 653
2025	470 162
2030	492 726
2040	516 400
2050	541 237

Bethulie

The town of Bethulie is positioned on the banks of the Hendrik Verwoerd Dam just downstream of the Orange-Caledon confluence. Unfortunately, no information is available on the demands and return flows of Bethulie, but the water requirements can be estimated from the population statistics given in a later section. The return flows may be of significance as the location of the town will enable any return flow to enter the system directly.

Burgersdorp

The sources of the urban water for Burgersdorp are the J.L.de Bruin Dam on the Buffelspruit, directly from the Stormberg River and from boreholes. The town has utilised water from the dam since 1962 and the boreholes came into operation in 1950. Water has been supplied to the town from the Stormberg River since the mid 1800's. The proportion of the total demand that each source supplies is unknown.

Only 80 % of the water requirement is consumed by household users and the rest is taken up by industry. The estimated future annual water requirements are given in table 4.10. The sewage is treated in oxidation dams and the plant has been in operation since 1962. It is unlikely that any return flows reach the river system and the values of the return flows given in table 4.10 must be the peak capacities as the annual totals are greater than the requirements which is impossible. A new plant using biological filters or activated sludge is also being planned.

Table 4.10: <u>Estimated future water requirements and return flows for Burgersdorp.</u>

Year	Requirements (m^3/a)	Return flow (m^3/day)
1990	590 000	1912
1995	600 000	
2000	620 000	
2005	635 000	
2010	650 000	3000
2015	680 000	
2020	710 000	
2025	740 000	
2030	770 000	
2040	800 000	
2050	840 000	

<u>Colesberg</u>

Little information is available on the water use of Colesberg. In the past the town has made use of groundwater to supply its requirements, however, a scheme supplying water from the Orange River was implemented early in 1989. It can be assumed that there will be no substantial return flows due to the size of the town and its remoteness from the river system.

Hanover

Hanover is supplied with water from boreholes and the present consumption is in the order of 140 000 m^3/a. Any future growth in the demands should be catered for by the groundwater reserves. The sewage is not treated in any way and it is assumed that no return flow exists.

Hopetown

Hopetown is located on the Orange River upstream of the Orange-Vaal confluence, but no information is available as to its water use. It does not have a large population but by virtue of its locality it must make use of Orange River water. The water consumption can be estimated from the population statistics given in a later section, but return flows can be taken as negligible as a sophisticated treatment plant is not likely to exist.

Lady Grey

No information is available on the water demands and return flows of Lady Grey. The town is located in the Witteberge at the top end of the catchment and has a very small population. Thus the water requirements will be insignificant and are probably satisfied by groundwater sources. Return flows are not likely to exist.

Molteno

Molteno is positioned on the Stormberg River upstream of Burgersdorp. The town obtains its water from a dam in the river and its present requirement is around 200 000 m^3/a. Prior to 1985 water was obtained from boreholes. A growth rate in the water demand of 5 % p.a. is predicted. The effluent from Molteno is treated in oxidation dams and no return flows exist.

Noupoort

The urban requirements of Noupoort are satisfied by ground-water resources and the estimated future household requirements are listed in table 4.11. The sewage has been treated in oxidation dams since 1984 and the future predicted return flows are also given in table 4.11. The return flows are approximately 60 % of the water supplied to the town and due to the nature of the sewage treatment plant these values are probably the volumes of effluent processed rather than volumes discharged. Thus, the return flows can be taken as negligible.

Table 4.11: Estimated future water requirements and return flows (m^3/a) for Noupoort.

Year	Requirements	Return flows
1990	249 900	149 900
1995	274 800	164 900
2000	288 600	173 100
2005	303 000	181 800
2010	333 300	200 000
2015	358 300	215 000
2020	385 200	231 100
2025	423 700	254 200
2030	466 100	279 600
2040	512 700	307 600
2050	564 000	338 400

Philippolis

Philippolis has a small population which is supplied with water from boreholes. The estimated future requirements and return flows are summarised in Table 4.12. The type of sewage treatment plant is not known and it may be assumed that it is not sophisticated. Thus, the values given in Table 4.12 are probably the annual volumes expected to be processed and the actual return flows to the system are negligible.

Table 4.12: Estimated future water requirements and return flows (m^3/a) for Philippolis.

Year	Requirements	Return flows
1990	48 000	24 000
1995	50 000	25 000
2000	52 000	26 000
2005	55 000	27 000
2010	55 000	27 000
2015	55 000	27 000
2020	56 000	28 000
2025	56 000	28 000
2030	58 000	29 000
2040	60 000	30 000
2050	60 000	30 000

Philipstown

Philipstown is supplied with its water from boreholes, and it is expected that this source will continue to supply all the demands in the future. The estimated annual water requirements are presented in table 4.13. The sewage is treated in oxidation dams and then discharged in the veld thereby exluding any return flows.

Table 4.13: Estimated future water requirements (m^3/a) for Philipstown.

Year	Requirements
1985	484 000
1990	572 000
2000	372 226
2005	389 982
2010	408 611
2015	428 153
2020	448 653
2025	470 162
2030	492 726

Rouxville

The urban requirements of Rouxville are not available, but the small population and its remoteness from any major river renders the requirements and the return flows insignificant. The demands are probably supplied from boreholes and the volumes required may be estimated from the population statistics given in a later section. The sewage treatment for such a small town will not give rise to any return flows.

Springfontein

Little information is available on the water use of Springfontein. The requirements are met from groundwater sources and may be determined from the population statistics in another section of the document. The return flows are considered to be negligible as oxidation dams are probably in use.

Zastron

Zastron is a substantial town situated in the eastern portion of the catchment between the Orange and Caledon Rivers. It is supplied with water from the Montagu and Kloof Dams on tributaries to the Orange River. Water was first supplied from Kloof Dam in 1927, and since 1970 Montagu Dam has augmented this supply. Only 10 % of the urban requirement is used by industry and the balance is made up of household consumers. The sewage is processed in oxidation dams and the treated water is irrigated on lucerne field, thus not giving rise to any return flows into the system. Table 4.14 indicates the estimated demands of Zastron as well as the annual amount of water discharged from the effluent plant.

Table 4.14 Estimated future water requirements and return flows (m^3/a) for Zastron.

Year	Requirements	Return flows
1990	500 000	240 000
1995	525 000	264 000
2000	550 000	288 000
2005	575 000	324 000
2010	590 000	348 000
2015	620 000	384 000
2020	650 000	420 000
2025	680 000	456 000
2030	720 000	492 000
2040	760 000	528 000
2050	800 000	552 000

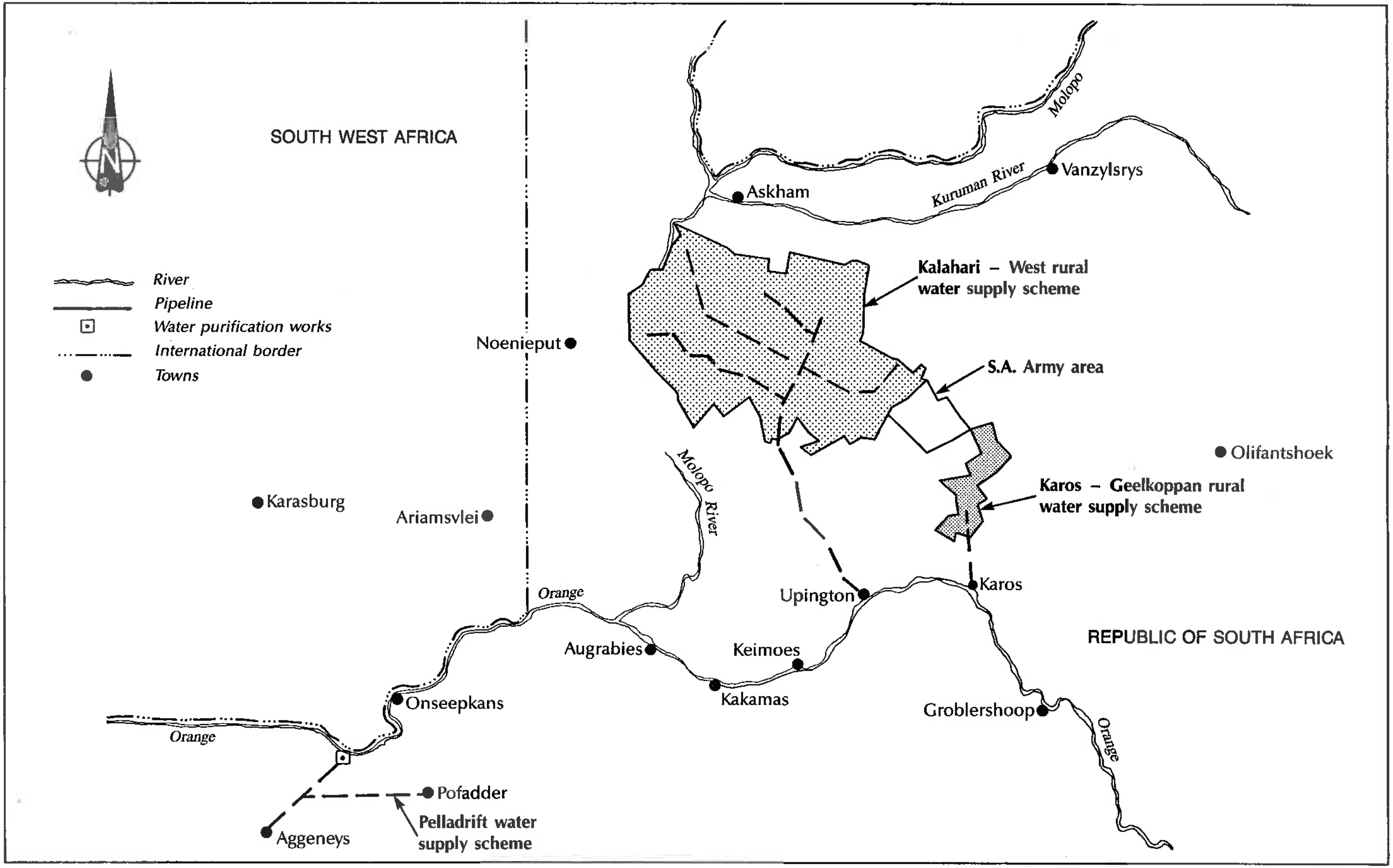
4.5 ORANGE CATCHMENT DOWNSTREAM OF THE ORANGE-VAAL CONFLUENCE

The downstream portion of the Orange River basin contains very few towns and most of the settlements are within the reach of Orange River water. The communities in the north-east of the catchment such as Postmasburg, Sishen and Black Rock are supplied with water from the Vaal-Gamagara Scheme. The water is derived from Delportshoop on the Vaal River above the Orange-Vaal confluence, which is outside the study area of the Orange River System Analysis. Any return flows from this scheme will be evaporated long before they become part of the Orange system. Thus, the water uses of these towns will not be considered as they will have no impact on the Analysis.

A number of regional water supply schemes exist within this catchment and water supply to some mining centres must be assured. Three of the water supply schemes are illustrated in figure 4.2, and another scheme exists further downstream the Orange River which supplies Springbok with water (figure 4.3). The water requirements and return flows of these urban and mining centres are now assessed.

De Aar

De Aar is situated in the south-east of the catchment and is remote from the river system. The water supply to the town is from boreholes and the historical consumptions and estimated demands are summarised in table 4.15. There is no information on the return flows from the town and it is assumed that they can be neglected as they will not contribute to the system.



ORANGE RIVER SYSTEM ANALYSIS

Lower Orange water supply schemes **4.2**

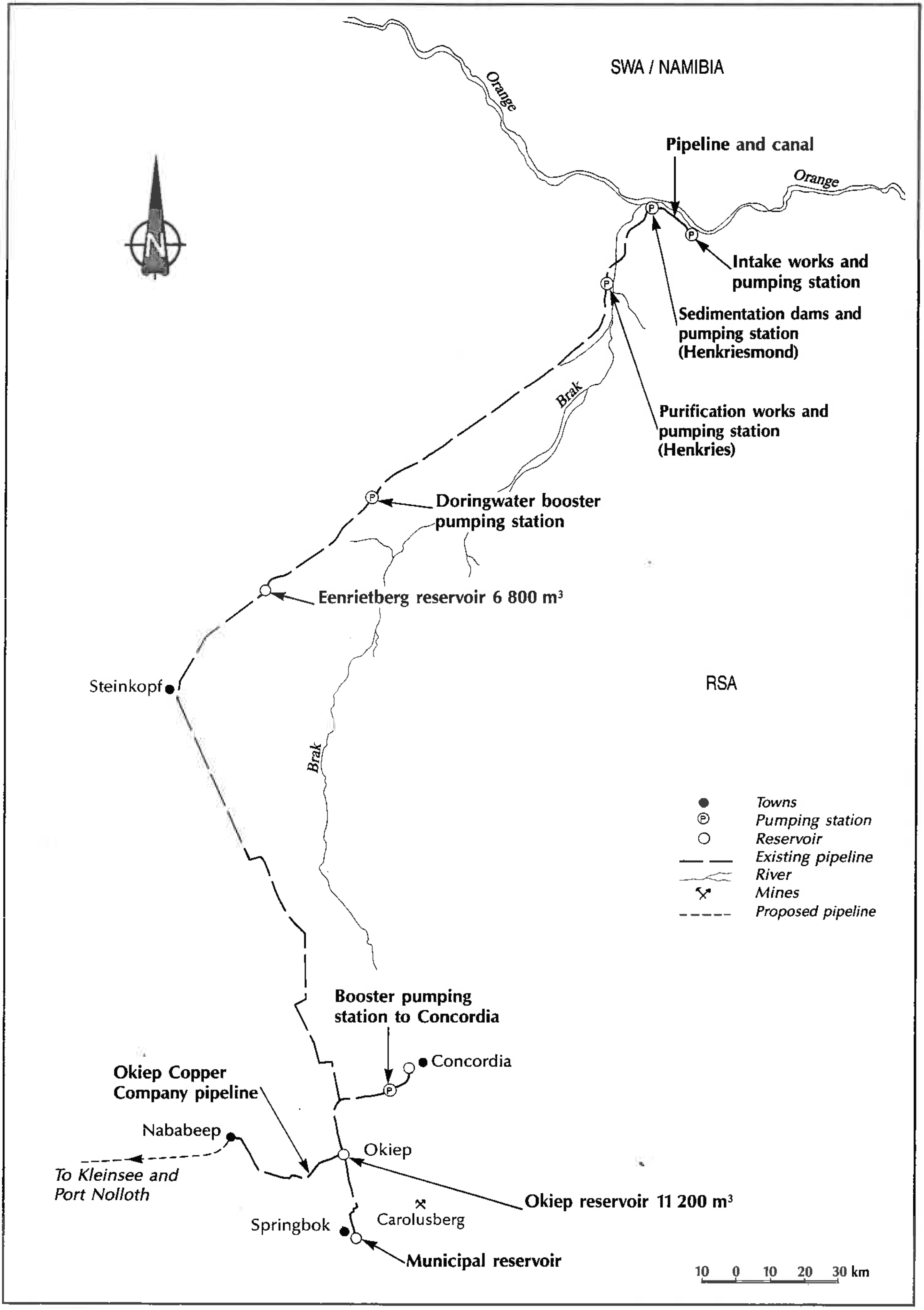

SWA / NAMIBIA
Orange
Pipeline and canal
Orange
Intake works and pumping station
Sedimentation dams and pumping station (Henkriesmond)
Purification works and pumping station (Henkries)
Brak
Doringwater booster pumping station
Eenrietberg reservoir 6 800 m³
Steinkopf
RSA
Brak
Towns
Pumping station
Reservoir
Existing pipeline
River
Mines
Proposed pipeline
Booster pumping station to Concordia
Concordia
Okiep Copper Company pipeline
Nababeep
To Kleinsee and Port Nolloth
Okiep
Okiep reservoir 11 200 m³
Carolusberg
Springbok
Municipal reservoir
10 0 10 20 30 km

Table 4.15: Historical and estimated future water requirements (m^3/a) for De Aar.

Year	Requirements
1955	912 500
1960	985 500
1965	1 131 500
1970	1 314 000
1975	1 606 000
1980	2 044 000
1985	2 555 000
1990	3 011 250
1995	3 504 000
2000	3 978 500
2005	4 453 000
2010	4 927 500

Kakamas

Kakamas is located on the Orange River downstream of Upington and is the centre of a large irrigation farming area. It obtains its water from the Orange River and the future estimated requirements are outlined in table 4.16. The effluent is treated in oxidation dams and it may be assumed that no return flows exist.

Table 4.16: Estimated future water requirements (m^3/a) for Kakamas.

Year	Requirements
1990	801 905
1995	927 830
2000	1 070 910
2005	1 170 555
2010	1 281 515
2015	1 405 615

Keimoes

The Orange River also provides water to Keimoes and has been doing so throughout the period of this study. The estimated annual demands are summarised in table 4.17 at five year intervals for the following 60 years. The growth rate in the water requirements given in table 4.17 is very high (about 33 % every five years) and should be reconsidered. Household consumers use 94 % of this demand and industry depletes the balance. The sewage is handled in oxidation dams, thus will not produce any return flows.

Table 4.17: Estimated future water requirements (m^3/a) for Keimoes.

Year	Requirements
1990	682 500
1995	931 600
2000	1 271 600
2005	1 735 700
2010	2 369 200
2015	3 234 000
2020	4 414 400
2025	6 025 600
2030	8 225 000
2040	13 982 524
2050	24 049 942

Oranjemund

Oranjemund is on the coast at the mouth of the Orange river and accommodates a large diamond mining enterprise. The water consumption of Consolidated Diamond Mines over the past ten years is summarised in table 4.18. The estimated future maximum annual requirement is taken as 15 10^6 m^3/a. Return flows from this area do not affect the system as Oranjemund is the further most downstream consumer.

Table 4.18: Historical water requirements (m^3/a) for Oranjemund.

Year	Requirements
1977	5 051 000
1978	5 027 394
1979	5 648 363
1980	6 203 638
1981	7 953 676
1982	7 774 820
1983	7 .750 250
1984	6 882 053
1985	6 431 978
1986	7 117 852
1987	6 974 689
1988	6 163 048

Pelladrift Water Board

The Pelladrift Water Board abstracts water from the Orange River at Pella Mission and supplies Black Mountain Mine, Pofadder, Aggeneys and Pella Mission with potable water. The scheme was first implemented in 1979, before which the various towns made use of groundwater to satisfy their demands. Table 4.19 summarises the estimated demands on the water to be supplied by the Board. Only 54 % of the total requirement is for household use, whilst the remaining amount is for mining. The only centre with an effluent treatment plant is Black Mountain whilst the other places make use of septic tanks and oxidation dams to dispose of their sewage. The treated sewage from Black Mountain is either evaporated or used for irrigation purposes.

Table 4.19: Estimated future water requirements (m^3/a) for consumers from the Pelladrift Water Board.

Year	Black Mountain	Pofadder	Pella Mission	Others (incl. Aggeneys)	Total
1990	4 400 000	90 000	40 000	20 000	4 550 000
1995	5 300 000	150 000	90 000	20 000	5 560 000
2000	5 800 000	250 000	150 000	20 000	6 220 000
2000	5 800 000	350 000	220 000	40 000	6 410 000

Prieska

Prieska is the first major settlement on the Orange River downstream of the Orange-Vaal confluence. The town obtains its water from the Orange River and the proportions of the demand used by household, industrial and agricultural consumers are 70 %, 5 % and 25 % respectively. Sewage has been treated in oxidation dams since 1986, thus no return flows into the river are expected. Table 4.20 outlines the estimated water demands of Prieska.

Table 4.20: Estimated future water requirements (m^3/a) for Prieska.

Year	Requirements
1990	600 000
1995	800 000
2000	922 400
2005	1 114 000
2010	1 245 000
2015	1 392 500

Upington

Upington is the largest single consumer of water in the study area after Bloemfontein. No historical information on the water use of this town is available, however, the estimated requirement in 1990 is in the order of 10 $10^6 m^3$/a. A growth rate of 5 % to 7 % per annum is envisaged in the urban demands. Household consumers use the majority of this water (73 %) whilst industry and the upkeep of parks and sports grounds accounts for 11 % and 16 % of the total requirement. The effluent is treated with biofilters and discharged into the Orange River. The annual return flow in 1988 was 2,88 $10^6 m^3$/a and the expected growth in this volume is about 8 % per annum.

4.6 URBAN DEMANDS BASED ON POPULATION STATISTICS

The urban demands of the larger centres can also be determined from the resident population. Values of the daily water consumption per capita for each population group have been ascertained as:

- whites = 230 l/day,
- blacks = 80 l/day, and
- coloureds = 100 l/day.

The average consumption of the towns can then be calculated from the population figures and the consumption rates. This information can also be used to confirm the urban demands which were determined in the questionnaires mentioned previously. The predicted population growth rates of the particular centres may also be used to extrapolate the estimated urban water demands in the future.

Towns with very small populations and remote from any major river have not been included in this assessment. The assumption here is that towns with small populations have small water demands which will be insignificant when considered in context with the total water consumption of the system. Centres located away from any major river are unable to make use of any significant volumes of water due to the lack of resources. These towns are probably making full use of groundwater resources to meet their demands. Therefore, only towns with total populations greater than two thousand are considered.

The populations of the towns within the Orange River catchment at various dates have been tabulated in Appendix C. These are the results of population censuses that have been conducted over time. An estimate of the expected future population growth rate can be based on the historical values presented.

5. ECOLOGICAL DEMANDS

The ecology of the Orange River is a sensitive matter. A tremendous amount of development has occurred in the Orange River System, especially since the implementation of the Orange River Development Project. The Hendrik Verwoerd and P.K. le Roux Dams have been built on the Orange River in recent times. These schemes and the Lesotho Highlands Water Project, whereby a large proportion of Orange water will be transferred to the Vaal River, have serious impacts on the ecology. The Orange River is highly regulated by the large impoundments and weirs along its course and vast quantities of water are also being used for agricultural purposes and inter-basin transfers. This regulation and extraction has induced ecological changes along the river, of which there has been no monitoring. In other words, the present status of the ecology is the result of a modified system which has been altered over the past two decades. Fear exists that further development will be detrimental to the ecosystem, therefore it is believed that the ecological demands should be defined and form part of the System Analysis.

Not much is known at present about the ecology of the Orange River System and it is not wideley documented. Benade (1986) considered the ecological problems of the Orange River and also found a serious paucity of prior data. Some attention has been paid to the river mouth by the CSIR in the report NR10 whereby the fresh water requirements of the Orange River estuary were assessed. This lack of information has created a serious need for an evaluation of the ecological situation, and has led to the formation of the Steering Committee for the Orange River Environmental Study. The aim of the Committee is to evaluate the ecosystem and consider various strategies which may be followed in order to maintain the ecological equilibrium or to improve on it. The volumes of flow in the river that will result in the well-being of all the flora, fauna and fish life are also to be determined by the Steering Committee.

Due to the vast extent of the Orange River ecosystem the Steering Committee decided to assess the situation at the river mouth and define the ecological requirements there and that the state of the ecology elsewhere in the catchment will be considered at a later stage. The Orange River mouth is a problematic area and two options on the future status of the mouth have been identified:

- maintain it as a river mouth (always fresh water), or
- let the mouth become an estuary (tidal actions occur and there is a mixing of sea and fresh water).

The ecology of the river mouth will be studied in greater detail and a decision as to the future of the mouth will only be made after the problem has been analysed in more detail. Suggestions by the Steering Committee include a requirement of 540.10^6 m^3/a to maintain the end of the river as a mouth. It is clear that the ecological demands at the mouth will not determine exclusively the operating policies for releases of flow but that the requirements of other users within the system will also have to be considered.

Two other aspects of the ecology of the Orange River are worthy of mention:

- the status of the fish life, and
- the control of gnat infestations.

The well-being of the fish life in the Orange River must be guaranteed, nonetheless, the detrimental efects may only be discovered after a considerable time of operating the system under a certain policy. On the other hand, the infestations of gnats have occurred simultaneously with the commencement of controlled flows in the Orange River. The adequate supply at water all year around has enabled gnat larvae to flourish, whereas previously the larvae would perish during low flows. This problem can be controlled by implementing a variable release operating policy at the P.K. le Roux Dam.

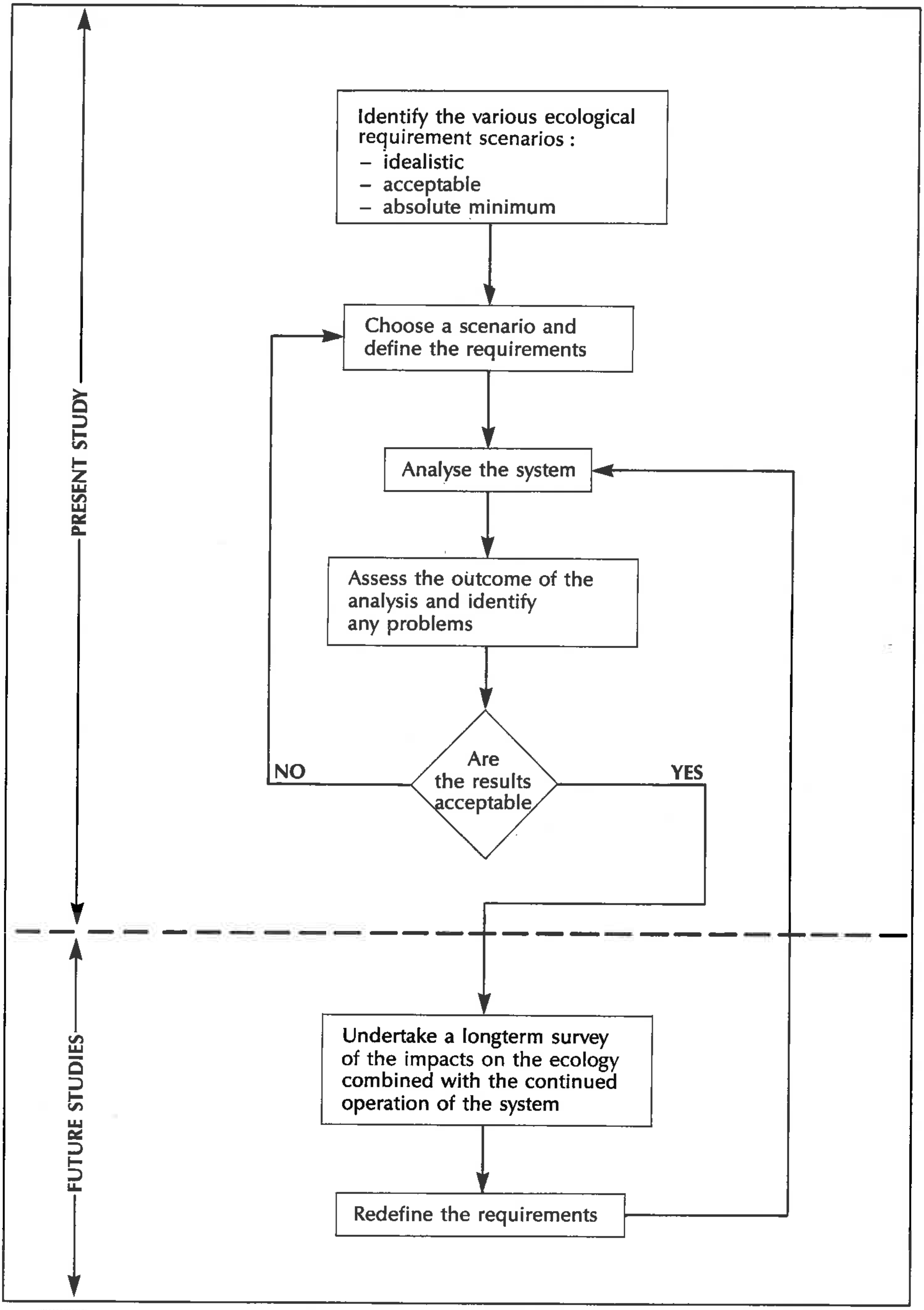
Other matters which are to be considered from an ecological point of view are the erosion of the river bed and the reduction in silt load due to the large upstream impoundments. The stability of the river bed is important and the constant flow throughout the year due to the controlled system may have an impact on the erosion of the bed. The attenuation of the large floods which normally would have cleared the river of weeds and other vegetation may now cause a proliferation. Finally, the P.K. le Roux and Hendrik Verwoerd Dams act as giant sediment traps, and this reduction in silt in the river downstream must influence the ecology in some way. The ecology of the Orange River is sensitive to many factors, all of which must be considered in order to make a reasonable estimate of the ecological water demands.

With respect to the Orange River System Analysis, information is required on both the ecological requirements and the risk level at which this must be supplied. Due to the immensity of the task of assessing the whole ecosystem and the time required to do so, the present analysis will not define the ultimate ecological needs. The idea is to estimate an ecological demand with all the present information. An operating policy will then be formed with enough feedback to evaluate and reconsider the policy, and make enough provision to change the policy if and when it is needed. Figure 5.1 indicates the requirement selection procedure and the feedback loops to re-assess the ecological demands.

Three scenarios of the ecological requirements have been identified:

- an idealist situation whereby all will be done to maintain the system or even to improve it with an ample water supply.
- an average level of demand where the ecology is sustained at a non-deteriorating state, and
- a minimum or absolute low requirement to just maintain the ecology.

Information on these three levels of demands are required for the decision making processes of the System Analysis, the results of which can be assessed by the Steering Committee. Adjustments can be made if the results are not acceptable, and finally, as more information comes to light on the demands, this can be incorporated in the system.



ORANGE RIVER SYSTEM ANALYSIS

Methodology adopted to define the ecological requirements of the Orange River system

5.1

6.1 Summary and conclusions

A comprehensive study on the water use within the Orange River system has been made and this report outlines the findings. Information has been gathered from a large number of sources including Government White Papers, data from questionnaires, a field study and personal communication with numerous local authorities. Problems were encountered with respect to conflicting information and lack of details in some specific areas, which led to various assumptions being made. The subjective statement of these assumptions was made using sound engineering judgement and an account was taken of all the information available at that time.

Irrigation is the largest consumer of water from the Orange River and an area of some 1 120 km^2 is irrigated making direct use of water from the Orange River system. Table 6.1 summarises all the areas under irrigation along the various sections of the Orange River and its tributaries. These areas include both the diffuse and controlled irrigation which are supplied from the surface water resources. Irrigation from groundwater resources or making use of water which otherwise would not contribute to the Orange River system due to evaporation has not been considered.

The volumes of water required for irrigation are estimated from the crop water requirements. These requirements are calculated from the crop factors and evaporation data for a particular locality. Various crop types and the areas they cover must also be taken into account. In some cases the irrigation requirements are given as the quotas established for the controlled irrigation zones. Table 6.2 outlines the estimated crop water requirements for the river sections mentioned above. The average requirement for the system as a whole is 10 750 m^3/ha/a. Thus, the total annual crop water requirement from the Orange River is in the order of $1200.10^6 m^3/a$, although the requirement is probably not supplied in full.

Table 6.1: Summary of the estimated areas under irrigation at present along the various river sections of the Orange River System

River Section	Area (ha)
Modder River upstream of Krugersdrift Dam	4 400
Riet River upstream of Kalkfontein Dam	7 700
Modder River downstream of Krugersdrift Dam	3 400
Riet River downstream of Kalkfontein Dam	7 750
Lower Riet River	2 640
Caledon River upstream of Welbedacht Dam	3 680
Caledon tributaries	3 850
Kraai River	2 500
Stormberg River	1 500
Orange River upstream of Hendrik Verwoerd Dam	4 100
Caledon River downstream of Welbedacht Dam	4 840
Orange River upstream of P.K. le Roux Dam	1 400
Orange River downstream of P.K. le Roux Dam	11 000
Orange-Riet Canal	6 350
Orange-Vaal Canal	4 500
Brak and Ongers River	3 000
Middle Orange River	8 000
Boegoeberg Scheme	8 780
Upington Islands Scheme	12 930
Kakamas Scheme	5 440
Namaqualand	4 250
Total	112 010

Table 6.2: Summary of the estimated crop water requirements along the various river sections of the Orange River System

River Section	Requirement (m^3/ha/a)
Riet and Modder Rivers	11 000
Caledon River upstream of Welbedacht Dam	7 500
Caledon River downstream of Welbedacht Dam	9 000
Orange River upstream of Hendrik Verwoerd Dam	8 000
Kraai River	8 000
Stormberg River	8 000
Orange River upstream of P.K. le Roux Dam	11 000
Orange River downstream of P.K. le Roux Dam	11 000
Orange-Riet canal	11 000
Orange-Vaal canal	10 000
Brak and Ongers Rivers	13 000
Middle Orange River	13 000
Lower Orange River	15 000
Namaqualand	15 000

The urban and industrial sectors must also be assured of water supply and should have first priority on available water. The urban centres are sparsely spread throughout the catchment and many are supplied from groundwater resources. Distribution networks are in operation and the water supply to the greater Bloemfontein area is one such example. The estimated annual requirements at present of towns throughout the basin utilizing water from the Orange River system are summarised in table 6.3. Many towns are excluded as they are remote from any major river and are supplied by water resources that do not contribute to the system. Return flows from most of the centres are assumed to be negligible and only those from the larger urbanized areas were considered.

Table 6.3: Summary of the estimated urban requirements at present of towns in the Orange River Basin

Town	Requirement (m^3/a)
Bloemfontein	31 300 000
Dewetsdorp	175 000
Koffiefontein	1 300 000
Clocolan	340 000
Ficksburg	1 678 500
Aliwal North	2 000 000
Burgersdorp	590 000
Zastron	500 000
Kakamas	801 900
Keimoes	682 500
Oranjemund	7 000 000
Pelladrift Water Board	4 550 000
Prieska	600 000
Upington	10 000 000
Total	61 517 400

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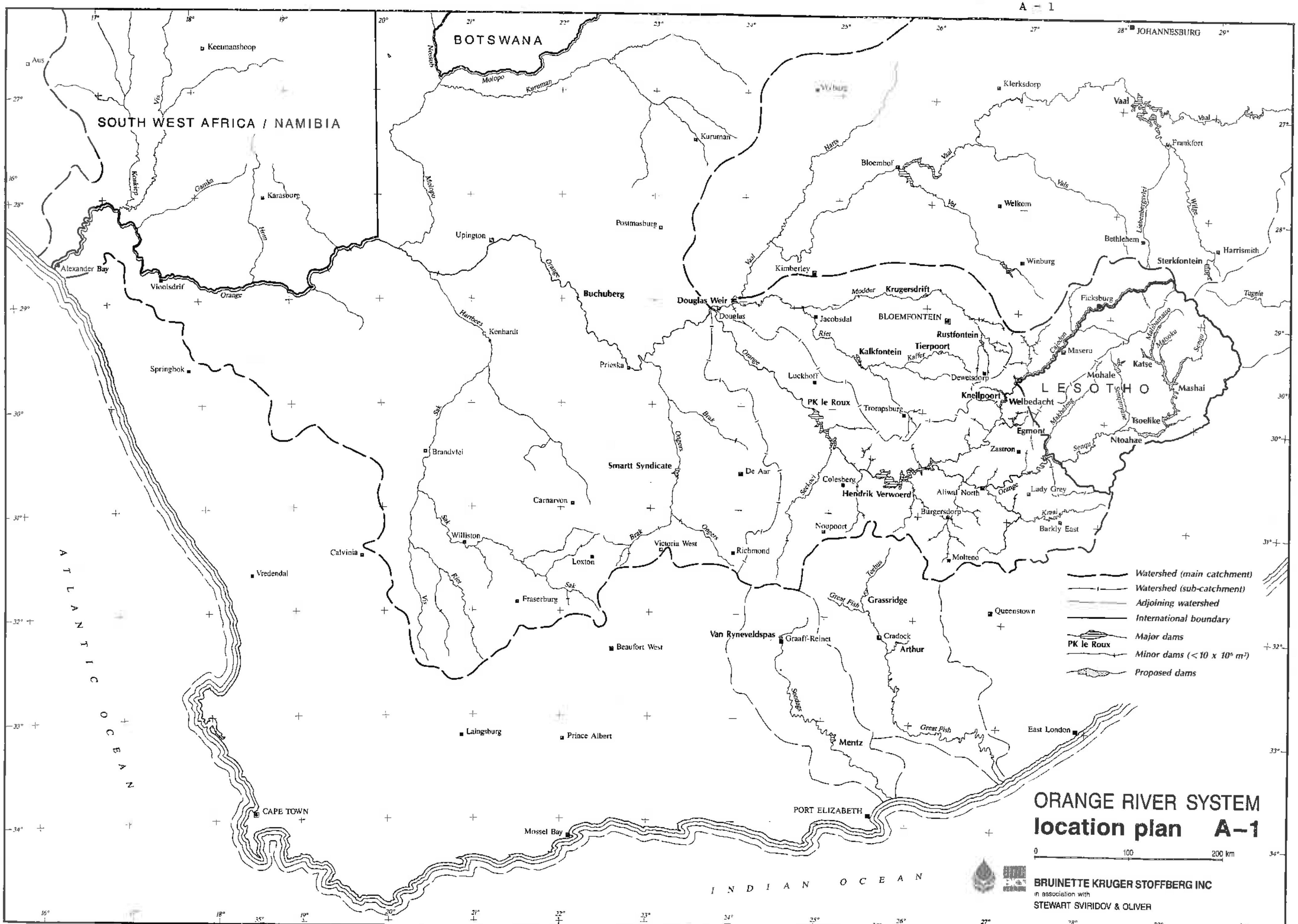
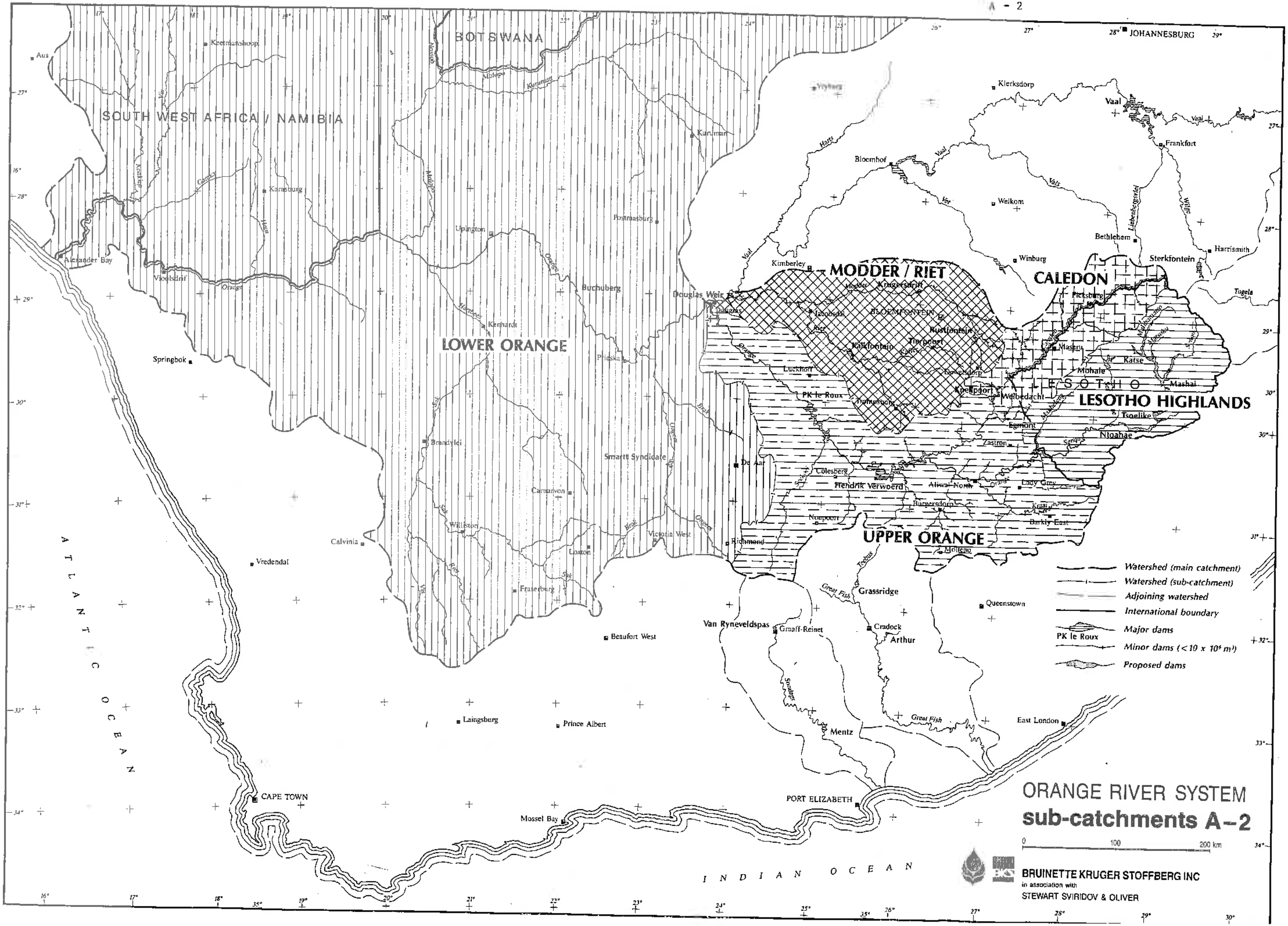
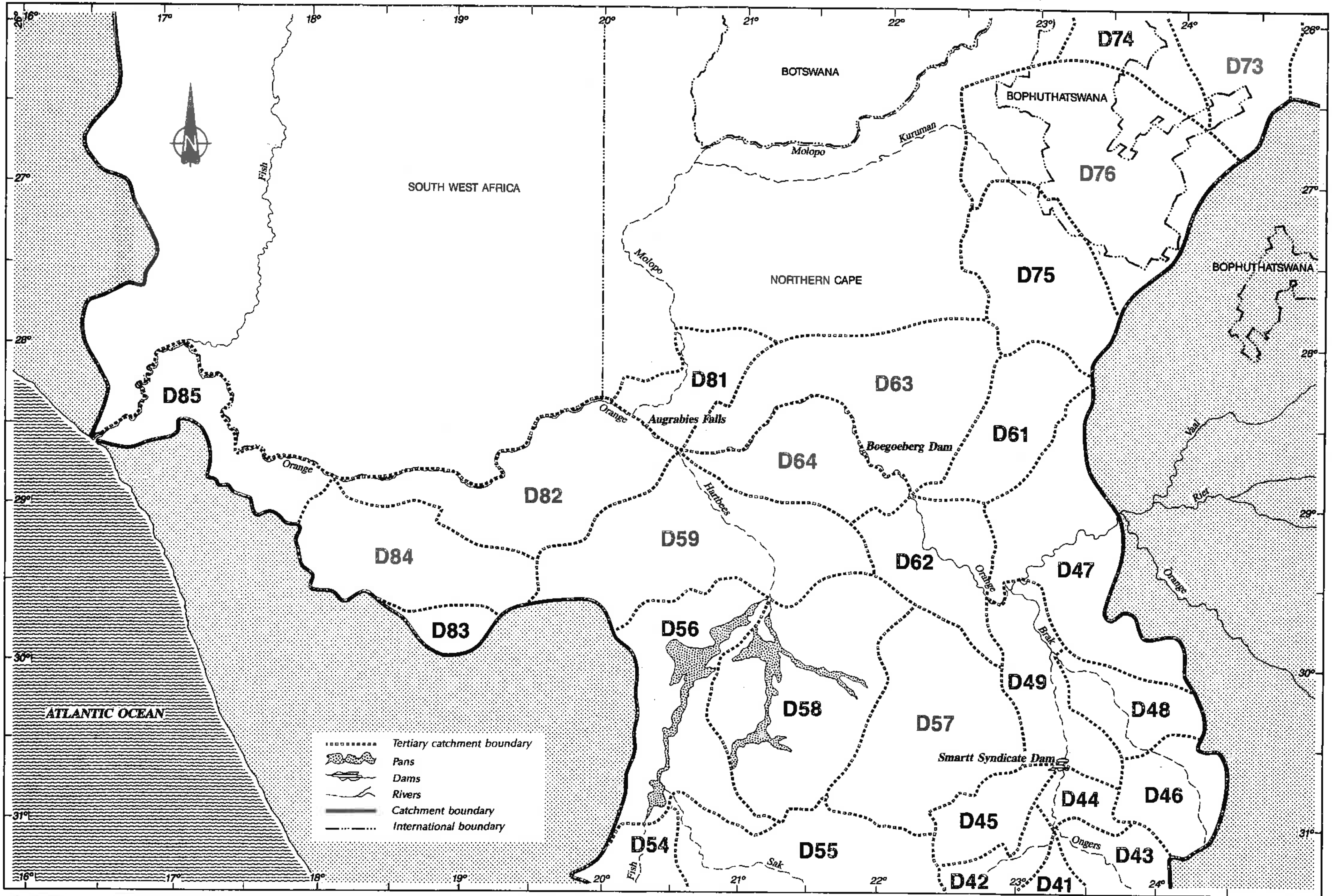
APPENDIX A

FIGURES


ORANGE RIVER SYSTEM
location plan A–1
BRUINETTE KRUGER STOFFBERG INC
in association with
STEWART SVIRIDOV & OLIVER
0 100 200 km
Watershed (main catchment)
Watershed (sub-catchment)
Adjoining watershed
International boundary
Major dams
PK le Roux
Minor dams (< 10 x 10⁶ m³)
Proposed dams
SOUTH WEST AFRICA / NAMIBIA
BOTSWANA
LESOTHO
ATLANTIC OCEAN
INDIAN OCEAN
JOHANNESBURG
BLOEMFONTEIN
CAPE TOWN
PORT ELIZABETH
East London
Kimberley
Upington
Douglas Weir
Buchuberg
Smartt Syndicate
Van Ryneveldspas
Hendrik Verwoerd
PK le Roux
Welbedacht
Knellpoort
Katse
Mohale
Mashai
Tsoelike
Ntoahae
Egmont
Sterkfontein
Vaal
Krugersdrift
Rustfontein
Tierpoort
Kalkfontein
Grassridge
Arthur
Mentz
Orange
Vaal
Caledon
Riet
Modder
Sak
Brak
Ongers
Great Fish
Sondags
Molopo
Kuruman
Nossob
Hartbees
Alexander Bay
Vioolsdrif
Springbok
Calvinia
Vredendal
Keetmanshoop
Karasburg
Aus
Prieska
Kenhardt
Brandvlei
Williston
Carnarvon
Fraserburg
Loxton
Victoria West
Richmond
De Aar
Colesberg
Noupoort
Graaff-Reinet
Beaufort West
Laingsburg
Prince Albert
Mossel Bay
Cradock
Queenstown
Molteno
Burgersdorp
Aliwal North
Lady Grey
Barkly East
Zastron
Dewetsdorp
Trompsburg
Luckhoff
Jacobsdal
Postmasburg
Bloemhof
Klerksdorp
Welkom
Winburg
Bethlehem
Harrismith
Frankfort
Ficksburg
Maseru



ORANGE RIVER SYSTEM
sub-catchments A-2
LOWER ORANGE
UPPER ORANGE
MODDER / RIET
CALEDON
LESOTHO HIGHLANDS
BOTSWANA
SOUTH WEST AFRICA / NAMIBIA
LESOTHO
ATLANTIC OCEAN
INDIAN OCEAN
JOHANNESBURG
CAPE TOWN
PORT ELIZABETH
Kimberley
Bloemhof
Upington
Springbok
Calvinia
Beaufort West
Queenstown
East London
Douglas Weir
Watershed (main catchment)
Watershed (sub-catchment)
Adjoining watershed
International boundary
Major dams
PK le Roux
Minor dams (< 10 x 10⁶ m³)
Proposed dams
0
100
200 km
BRUINETTE KRUGER STOFFBERG INC
in association with
STEWART SVIRIDOV & OLIVER



ORANGE RIVER SYSTEM ANALYSIS

Orange catchment downstream of the Orange–Vaal confluence : HRU tertiary subcatchments

A.4

APPENDIX B

MONTHLY CROP FACTORS AND A-PAN EVAPORATION

Modder River upstream of Krugersdrift Dam

A-pan evaporation (mm)	Month	Crop factors						
		Maize	Wheat	Lucerne	Annual Pastures	Potatoes	Cabbage	Fruit
264	Oct	0,50	1,00	0,70	-	-	0,70	0,27
299	Nov	0,90	0,65	0,80	-	-	0,70	0,31
338	Dec	1,10	-	0,80	-	-	-	0,41
318	Jan	1,00	-	0,80	-	0,28	-	0,50
252	Feb	0,50	-	0,80	-	0,70	-	0,59
224	Mar	-	-	0,70	0,50	0,98	0,40	0,42
156	Apr	-	-	0,50	0,70	1,00	0,55	0,20
112	May	-	-	0,40	0,70	-	0,65	0,20
86	Jun	-	-	0,30	0,70	-	0,70	0,20
101	Jul	-	0,30	0,30	0,70	-	-	0,20
146	Aug	-	0,50	0,40	0,70	-	-	0,20
204	Sep	-	0,95	0,50	0,70	-	0,50	0,23
Proportion of the total area covered by each crop		0,10	0,50	0,20	0,15	0,05	0,05	0,05

Riet River upstream of Kalkfontein Dam

A-pan evaporation (mm)	Month	Crop factors					
		Maize	Wheat	Lucerne	Annual Pastures	Vegetables	Cotton
264	Oct	0,50	1,00	0,70	-	0,70	-
299	Nov	0,90	0,65	0,80	-	0,70	0,18
338	Dec	1,10	-	0,80	-	0,50	0,29
318	Jan	1,00	-	0,80	-	0,30	0,69
252	Feb	0,50	-	0,80	-	0,70	0,82
224	Mar	-	-	0,70	0,50	0,60	0,62
156	Apr	-	-	0,50	0,70	0,80	0,46
112	May	-	-	0,40	0,70	0,60	-
86	Jun	-	-	0,30	0,70	0,60	-
101	Jul	-	0,30	0,30	0,70	0,70	-
146	Aug	-	0,50	0,40	0,70	0,60	-
204	Sep	-	0,95	0,50	0,70	0,50	-
Proportion of the total area covered by each crop		0,10	0,20	0,40	0,20	0,10	0,05

Riet River downstream of Kalkfontein Dam

A-pan evaporation (mm)	Month	Crop factors					
		Wheat	Lucerne	Potatoes	Vegetables	Fruit	Perennial Pastures
272	Oct	1,00	0,70	-	0,70	0,27	0,70
322	Nov	0,65	0,80	-	0,70	0,31	0,80
365	Dec	-	0,80	-	0,50	0,41	0,80
354	Jan	-	0,80	0,28	0,30	0,50	0,80
272	Feb	-	0,80	0,70	0,70	0,59	0,80
224	Mar	-	0,70	0,98	0,60	0,42	0,80
158	Apr	-	0,50	1,00	0,80	0,20	0,70
112	May	-	0,40	-	0,60	0,20	0,60
85	Jun	-	0,30	-	0,60	0,20	0,50
94	Jul	0,30	0,30	-	0,70	0,20	0,50
138	Aug	0,50	0,40	-	0,60	0,20	0,50
204	Sep	0,95	0,50	-	0,50	0,23	0,60
Proportion of the total area covered by each crop		0,10	0,70	0,05	0,05	0,05	0,10

Riet River downstream of Kalkfontein

A-pan evaporation (mm)	Month	Crop factors						
		Maize	Wheat	Lucerne	Potatoes	Vegetables	Fruit	Cotton
272	Oct	-	1,00	0,70	-	0,70	0,27	-
322	Nov	-	0,65	0,80	-	0,70	0,31	0,18
365	Dec	0,40	-	0,80	-	0,50	0,41	0,29
354	Jan	0,85	-	0,80	0,28	0,30	0,50	0,69
272	Feb	1,10	-	0,80	0,70	0,70	0,59	0,82
224	Mar	1,00	-	0,70	0,98	0,60	0,42	0,62
158	Apr	0,50	-	0,50	1,00	0,80	0,20	0,46
112	May	-	-	0,40	-	0,60	0,20	-
85	Jun	-	-	0,30	-	0,60	0,20	-
94	Jul	-	0,30	0,30	-	0,70	0,20	-
138	Aug	-	0,50	0,40	-	0,60	0,20	-
204	Sep	-	0,95	0,50	-	0,50	0,23	-
Proportion of the total area covered by each crop		0,30	0,15	0,30	0,05	0,05	0,05	0,15

Lower Riet River

A-pan evaporation (mm)	Month	Crop factors				
		Maize	Wheat	Lucerne	Potatoes	Cotton
272	Oct	-	1,00	0,70	-	-
322	Nov	-	0,65	0,80	-	0,18
365	Dec	0,40	-	0,80	-	0,29
354	Jan	0,85	-	0,80	0,28	0,69
272	Feb	1,10	-	0,80	0,70	0,82
224	Mar	1,00	-	0,70	0,98	0,62
158	Apr	0,50	-	0,50	1,00	0,46
112	May	-	-	0,40	-	-
85	Jun	-	-	0,30	-	-
94	Jul	-	0,30	0,30	-	-
138	Aug	-	0,50	0,40	-	-
204	Sep	-	0,95	0,50	-	-
Proportion of the total area covered by each crop		0,25	0,25	0,30	0,20	0,20

Caledon River upstream of Welbedacht Dam

A-pan evaporation (mm)	Month	Crop factors					
		Lucerne	Annual Ryegrass	Wheat	Fruit	Cabbage	Maize
220	Oct	0,70	-	1,00	0,27	0,70	0,50
232	Nov	0,80	-	0,65	0,31	0,70	0,90
270	Dec	0,80	-	-	0,41	-	1,10
253	Jan	0,80	-	-	0,50	-	1,00
196	Feb	0,80	-	-	0,59	-	0,50
169	Mar	0,70	0,50	-	0,42	0,40	-
112	Apr	0,50	0,70	-	0,20	0,55	-
89	May	0,40	0,70	-	0,20	0,65	-
68	Jun	0,30	0,70	-	0,20	0,70	-
85	Jul	0,30	0,70	0,30	0,20	-	-
123	Aug	0,40	0,70	0,50	0,20	-	-
183	Sep	0,50	0,70	0,95	0,23	0,50	-
Proportion of the total area covered by each crop		0,50	0,20	0,20	0,08	0,05	0,10

Kraai River

A-pan evaporation (mm)	Month	Crop factors				
		Maize	Wheat	Lucerne	Perennial Pastures	Annual pastures
196	Oct	0,50	1,00	0,70	0,70	-
216	Nov	0,90	0,65	0,80	0,80	-
248	Dec	1,10	-	0,80	0,80	-
247	Jan	1,00	-	0,80	0,80	-
191	Feb	0,50	-	0,80	0,80	-
168	Mar	-	-	0,70	0,80	0,50
131	Apr	-	-	0,50	0,70	0,70
111	May	-	-	0,40	0,60	0,70
90	Jun	-	-	0,30	0,50	0,70
106	Jul	-	0,30	0,30	0,50	0,70
133	Aug	-	0,50	0,40	0,50	0,70
163	Sep	-	0,95	0,50	0,60	0,70
Proportion of the total area covered by each crop		0,20	0,30	0,30	0,10	0,30

Stormberg River

A-pan evaporation (mm)	Month	Crop factors			
		Maize	Wheat	Lucerne	Annual pastures
196	Oct	0,50	1,00	0,70	-
216	Nov	0,90	0,65	0,80	-
248	Dec	1,10	-	0,80	-
247	Jan	1,00	-	0,80	-
191	Feb	0,50	-	0,80	-
168	Mar	-	-	0,70	0,50
131	Apr	-	-	0,50	0,70
111	May	-	-	0,40	0,70
90	Jun	-	-	0,30	0,70
106	Jul	-	0,30	0,30	0,70
133	Aug	-	0,50	0,40	0,70
163	Sep	-	0,95	0,50	0,70
Proportion of the total area covered by each crop		0,20	0,30	0,40	0,20

Orange River upstream of Hendrik Verwoerd Dam

A-pan evaporation (mm)	Month	Crop factors			
		Maize	Wheat	Lucerne	Annual pastures
196	Oct	0,50	1,00	0,70	-
216	Nov	0,90	0,65	0,80	-
248	Dec	1,10	-	0,80	-
247	Jan	1,00	-	0,80	-
191	Feb	0,50	-	0,80	-
168	Mar	-	-	0,70	0,50
131	Apr	-	-	0,50	0,70
111	May	-	-	0,40	0,70
90	Jun	-	-	0,30	0,70
106	Jul	-	0,30	0,30	0,70
133	Aug	-	0,50	0,40	0,70
163	Sep	-	0,95	0,50	0,70
Proportion of the total area covered by each crop		0,25	0,35	0,35	0,10

Caledon River downstream of Welbedacht Dam

A-pan evaporation (mm)	Month	Crop factors			
		Maize	Wheat	Lucerne	Annual pastures
196	Oct	0,50	1,00	0,70	-
216	Nov	0,90	0,65	0,80	-
248	Dec	1,10	-	0,80	-
247	Jan	1,00	-	0,80	-
191	Feb	0,50	-	0,80	-
168	Mar	-	-	0,70	0,50
131	Apr	-	-	0,50	0,70
111	May	-	-	0,40	0,70
90	Jun	-	-	0,30	0,70
106	Jul	-	0,30	0,30	0,70
133	Aug	-	0,50	0,40	0,70
163	Sep	-	0,95	0,50	0,70
Proportion of the total area covered by each crop		0,20	0,30	0,40	0,15

Orange River upstream of P. K. le Roux Dam

A-pan evaporation (mm)	Month	Crop factors			
		Maize	Wheat	Lucerne	Cotton
270	Oct	-	1,00	0,70	-
332	Nov	-	0,65	0,80	0,18
386	Dec	0,40	-	0,80	0,29
370	Jan	0,85	-	0,80	0,69
279	Feb	1,10	-	0,80	0,82
239	Mar	1,00	-	0,70	0,62
167	Apr	0,50	-	0,50	0,46
128	May	-	-	0,40	-
106	Jun	-	-	0,30	-
137	Jul	-	0,30	0,30	-
161	Aug	-	0,50	0,40	-
225	Sep	-	0,95	0,50	-
Proportion of the total area covered by each crop		0,30	0,40	0,40	0,10

Orange River downstream of P.K. le Roux Dam

A-pan evaporation (mm)	Month	Crop factors				
		Maize	Wheat	Lucerne	Cotton	Potatoes
270	Oct	-	1,00	0,70	-	-
332	Nov	-	0,65	0,80	0,18	-
386	Dec	0,40	-	0,80	0,29	-
370	Jan	0,85	-	0,80	0,69	0,28
279	Feb	1,10	-	0,80	0,82	0,70
239	Mar	1,00	-	0,70	0,62	0,98
167	Apr	0,50	-	0,50	0,46	1,00
128	May	-	-	0,40	-	-
106	Jun	-	-	0,30	-	-
137	Jul	-	0,30	0,30	-	-
161	Aug	-	0,50	0,40	-	-
225	Sep	-	0,95	0,50	-	-
Proportion of the total area covered by each crop		0,25	0,30	0,30	0,30	0,10

Orange-Riet canal

A-pan evaporation (mm)	Month	Crop factors						
		Maize	Wheat	Lucerne	Cotton	Potatoes	Fruit	Vegetables
270	Oct	-	1,00	0,70	-	-	0,27	0,70
332	Nov	-	0,65	0,80	0,18	-	0,31	0,70
386	Dec	0,40	-	0,80	0,29	-	0,41	0,50
370	Jan	0,85	-	0,80	0,69	0,28	0,50	0,30
279	Feb	1,10	-	0,80	0,82	0,70	0,59	0,70
239	Mar	1,00	-	0,70	0,62	0,98	0,42	0,60
167	Apr	0,50	-	0,50	0,46	1,00	0,20	0,80
128	May	-	-	0,40	-	-	0,20	0,60
106	Jun	-	-	0,30	-	-	0,20	0,60
137	Jul	-	0,30	0,30	-	-	0,20	0,70
161	Aug	-	0,50	0,40	-	-	0,20	0,60
225	Sep	-	0,95	0,50	-	-	0,23	0,50
Proportion of the total area covered by each crop		0,30	0,15	0,30	0,15	0,05	0,05	0,05

Orange-Vaal canal

A-pan evaporation (mm)	Month	Crop factors						
		Maize	Wheat	Lucerne	Cotton	Potatoes	Fruit	Vegetables
270	Oct	-	1,00	0,70	-	-	0,15	0,70
332	Nov	-	0,65	0,80	0,18	-	0,20	0,70
386	Dec	0,40	-	0,80	0,29	-	0,30	0,50
370	Jan	0,85	-	0,80	0,69	0,28	0,40	0,30
279	Feb	1,10	-	0,80	0,82	0,70	0,35	0,70
239	Mar	1,00	-	0,70	0,62	0,98	0,25	0,60
167	Apr	0,50	-	0,50	0,46	1,00	0,20	0,80
128	May	-	-	0,40	-	-	0,10	0,60
106	Jun	-	-	0,30	-	-	0,10	0,60
137	Jul	-	0,30	0,30	-	-	0,10	0,70
161	Aug	-	0,50	0,40	-	-	0,10	0,60
225	Sep	-	0,95	0,50	-	-	0,10	0,50
Proportion of the total area covered by each crop		0,10	0,25	0,15	0,15	0,10	0,20	0,20

Brak and Ongers Rivers

A-pan evaporation (mm)	Month	Crop factors		
		Lucerne	Maize	Wheat
312	Oct	0,70	–	1,00
370	Nov	0,80	–	0,65
425	Dec	0,80	0,40	–
421	Jan	0,80	0,85	–
324	Feb	0,80	1,10	–
280	Mar	0,70	1,00	–
194	Apr	0,50	0,50	–
141	May	0,40	–	–
109	Jun	0,30	–	–
123	Jul	0,30	–	0,30
169	Aug	0,40	–	0,50
234	Sep	0,50	–	0,95
Proportion of the total area covered by each crop		0,80	0,10	0,10

Middle Orange River

A-pan evaporation (mm)	Month	Crop factors				
		Vines	Lucerne	Maize	Wheat	Cotton
312	Oct	0,15	0,70	-	1,00	-
370	Nov	0,20	0,80	-	0,65	0,18
425	Dec	0,30	0,80	0,40	-	0,29
421	Jan	0,40	0,80	0,85	-	0,69
324	Feb	0,35	0,80	1,10	-	0,82
280	Mar	0,25	0,70	1,00	-	0,62
194	Apr	0,20	0,50	0,50	-	0,46
141	May	0,10	0,40	-	-	-
109	Jun	0,10	0,30	-	-	-
123	Jul	0,10	0,30	-	0,30	-
169	Aug	0,10	0,40	-	0,50	-
234	Sep	0,10	0,50	-	0,95	-
Proportion of the total area covered by each crop		0,30	0,30	0,20	0,20	0,15

Boegoeberg Scheme

A-pan evaporation (mm)	Month	Crop factors					
		Vines	Lucerne	Maize	Wheat	Cotton	Vegetables
356	Oct	0,15	0,70	-	1,00	-	0,70
434	Nov	0,20	0,80	-	0,65	0,28	0,70
506	Dec	0,30	0,80	0,40	-	0,53	0,50
509	Jan	0,40	0,80	0,85	-	0,85	0,30
402	Feb	0,35	0,80	1,10	-	0,88	0,70
343	Mar	0,25	0,70	1,00	-	0,67	0,60
240	Apr	0,20	0,50	0,50	-	0,43	0,80
176	May	0,10	0,40	-	-	0,31	0,60
136	Jun	0,10	0,30	-	-	-	0,60
145	Jul	0,10	0,30	-	0,30	-	0,70
194	Aug	0,10	0,40	-	0,50	-	0,60
259	Sep	0,10	0,50	-	0,95	-	0,50
Proportion of the total area covered by each crop		0,50	0,25	0,15	0,15	0,10	0,10

Upington Islands Scheme

A-pan evaporation (mm)	Month	Crop factors					
		Vines	Lucerne	Maize	Wheat	Cotton	Vegetables
356	Oct	0,15	0,70	-	1,00	-	0,70
434	Nov	0,20	0,80	-	0,65	0,28	0,70
506	Dec	0,30	0,80	0,40	-	0,53	0,50
509	Jan	0,40	0,80	0,85	-	0,85	0,30
402	Feb	0,35	0,80	1,10	-	0,88	0,70
343	Mar	0,25	0,70	1,00	-	0,67	0,60
240	Apr	0,20	0,50	0,50	-	0,43	0,80
176	May	0,10	0,40	-	-	0,31	0,60
136	Jun	0,10	0,30	-	-	-	0,60
145	Jul	0,10	0,30	-	0,30	-	0,70
194	Aug	0,10	0,40	-	0,50	-	0,60
259	Sep	0,10	0,50	-	0,95	-	0,50
Proportion of the total area covered by each crop		0,55	0,20	0,10	0,20	0,30	0,10

Kakamas Scheme

A-pan evaporation (mm)	Month	Crop factors				
		Vines	Lucerne	Maize	Wheat	Cotton
356	Oct	0,15	0,70	-	1,00	-
434	Nov	0,20	0,80	-	0,65	0,28
506	Dec	0,30	0,80	0,40	-	0,53
509	Jan	0,40	0,80	0,85	-	0,85
402	Feb	0,35	0,80	1,10	-	0,88
343	Mar	0,25	0,70	1,00	-	0,67
240	Apr	0,20	0,50	0,50	-	0,43
176	May	0,10	0,40	-	-	0,31
136	Jun	0,10	0,30	-	-	-
145	Jul	0,10	0,30	-	0,30	-
194	Aug	0,10	0,40	-	0,50	-
259	Sep	0,10	0,50	-	0,95	-
Proportion of the total area covered by each crop		0,60	0,15	0,10	0,15	0,10

Namaqualand

A-pan evaporation (mm)	Month	Crop factors				
		Vines	Lucerne	Maize	Wheat	Cotton
323	Oct	0,15	0,70	-	1,00	-
382	Nov	0,20	0,80	-	0,65	0,28
435	Dec	0,30	0,80	0,40	-	0,53
443	Jan	0,40	0,80	0,85	-	0,85
374	Feb	0,35	0,80	1,10	-	0,88
350	Mar	0,25	0,70	1,00	-	0,67
251	Apr	0,20	0,50	0,50	-	0,43
170	May	0,10	0,40	-	-	0,31
128	Jun	0,10	0,30	-	-	-
125	Jul	0,10	0,30	-	0,30	-
176	Aug	0,10	0,40	-	0,50	-
243	Sep	0,10	0,50	-	0,95	-
Proportion of the total area covered by each crop		0,60	0,20	0,10	0,20	0,10

7497D/sw/DA
1989-09-12

APPENDIX C

POPULATION STATISTICS

7556D/ec/sw

Aliwal North

Year	Whites	Blacks	Coloureds	Total
1904	1 758	2 876	932	5 566
1911	1 884	1 761	883	4 528
1921	2 444	2 969	884	6 297
1936	2 566	3 948	1 133	7 647
1946	2 684	4 911	1 188	8 783
1951	2 767	5 382	1 568	9 717
1960	2 631	6 478	1 653	10 762
1970	2 470	7 739	2 102	12 311
1980	2 845	8 852	2 501	14 198
1985	2 856	8 698	2 257	13 811

Barkly East

Year	Whites	Blacks	Coloureds	Total
1904	675	415	87	1 177
1911	914	604	120	1 638
1921	993	728	178	1 899
1936	1 043	1 341	231	2 615
1946	981	1 291	212	2 484
1951	911	1 497	217	2 625
1960	1 038	2 331	281	3 650
1970	868	2 598	557	4 023
1980	861	2 692	488	4 041
1985	708	2 459	379	3 582

7556D/ec/sw

Bethulie

Year	Whites	Blacks	Coloureds	Total
1904	822	864	-	1 686
1911	990	521	251	1 762
1921	1 308	1 025	182	2 515
1936	1 461	1 509	313	3 283
1946	1 461	1 413	291	3 165
1951	1 337	1 504	301	3 142
1960	1 121	1 960	411	3 492
1970	1 043	3 414	461	4 918
1980	1 196	5 351	901	7 448
1985	741	4 779	541	6 061

Bloemfontein

Year	Whites	Blacks	Coloureds	Total
1904	15 501	18 382	-	33 883
1911	14 720	10 475	1 730	26 925
1921	17 711	17 124	1 656	36 491
1936	24 110	26 524	2 403	53 037
1946	30 005	35 246	1 945	67 196
1951	32 292	42 181	3 259	80 732
1960	48 448	58 767	5 391	112 606
1970	62 348	78 081	9 407	149 836
1980	90 762	112 140	15 327	218 229
1985	92 291	98 432	18 436	209 159

7556D/ec/sw

Brandfort

Year	Whites	Blacks	Coloureds	Total
1904	930	1 047	-	1 977
1911	1 037	707	165	1 909
1921	1 414	1 042	65	2 521
1936	1 334	1 572	48	2 954
1946	1 571	1 990	40	3 601
1951	1 600	1 308	23	3 931
1960	1 736	2 674	76	4 486
1970	1 522	3 683	62	5 267
1980	1 868	6 097	168	8 133
1985	1 889	5 248	157	7 294

Burgersdorp

Year	Whites	Blacks	Coloureds	Total
1904	1 283	1 077	534	2 894
1911	1 304	822	423	2 549
1921	1 676	1 291	442	3 409
1936	2 058	2 203	594	4 855
1946	2 053	2 854	521	5 428
1951	2 317	3 183	684	6 184
1960	2 271	3 992	882	7 145
1970	2 009	5 191	1 140	8 340
1980	1 866	6 197	1 242	9 305
1985	1 755	5 608	1 411	8 774

7556D/ec/sw

Clocolan

Year	Whites	Blacks	Coloureds	Total
1904	408	296	32	736
1911	1 029	767	65	1 861
1921	1 113	1 463	44	2 620
1936	1 135	1 681	32	2 848
1946	1 195	2 438	21	3 654
1951	1 130	3 260	49	4 439
1960	967	4 369	45	5 381
1970	1 012	5 676	39	6 727
1980	1 012	5 676	39	6 727
1985	924	4 871	64	5 859

Colesberg

Year	Whites	Blacks	Coloureds	Total
1904	974	553	1 141	2 668
1911	909	749	711	2 369
1921	1 001	870	693	2 564
1936	1 000	924	989	2 913
1946	971	913	1 271	3 155
1951	1 064	1 183	1 420	3 667
1960	1 047	2 218	1 594	4 859
1970	1 150	3 387	2 551	7 088
1980	1 138	6 203	2 752	10 093
1985	1 091	6 028	2 371	9 490

7556D/ec/sw

De Aar

Year	Whites	Blacks	Coloureds	Total
1904	1 094	1 114	1 063	3 271
1911	937	620	850	2 407
1921	2 333	2 222	786	5 341
1936	3 332	1 852	2 131	7 315
1946	3 953	2 689	2 656	9 298
1951	4 241	3 447	3 387	11 075
1960	5 047	4 955	4 508	14 510
1970	5 167	5 576	7 314	18 057
1980	4 997	6 462	9 202	20 661
1985	4 655	5 942	11 887	22 484

Dewetsdorp

Year	Whites	Blacks	Coloureds	Total
1904	658	313	-	971
1911	781	315	86	1 182
1921	873	662	70	1 605
1936	1 040	1 193	195	2 428
1946	956	1 679	162	2 797
1951	969	1 669	185	2 823
1960	976	2 320	151	3 447
1970	704	2 558	85	3 347
1980	677	2 386	21	3 084
1985	744	2 323	11	3 078

7556D/ec/sw

Edenburg

Year	Whites	Blacks	Coloureds	Total
1904	726	836	-	1 562
1911	633	258	264	1 155
1921	840	516	249	1 605
1936	934	1 150	289	2 373
1946	932	1 173	287	2 392
1951	919	1 413	204	2 536
1960	901	1 828	389	3 118
1970	765	2 350	595	3 710
1980	621	2 675	637	3 933
1985	667	2 074	725	3 466

Fauresmith

Year	Whites	Blacks	Coloureds	Total
1904	783	580	-	1 363
1911	725	652	228	1 605
1921	936	782	296	2 014
1936	764	1 074	78	1 916
1946	666	1 020	75	1 761
1951	751	1 034	342	2 127
1960	696	1 060	429	2 185
1970	540	1 295	486	2 321
1980	681	2 291	1 314	4 286
1985	467	1 269	755	2 491

7556D/ec/sw

Ficksburg

Year	Whites	Blacks	Coloureds	Total
1904	1 021	933	-	1 954
1911	1 334	848	212	2 394
1921	1 987	1 147	181	3 315
1936	2 506	2 398	232	5 136
1946	2 838	3 493	201	6 532
1951	3 148	3 835	164	7 147
1960	2 823	5 112	211	8 146
1970	2 372	6 820	312	9 504
1980	3 090	9 441	465	12 996
1985	3 087	9 196	495	12 778

Fouriesburg

Year	Whites	Blacks	Coloureds	Total
1904	224	112	-	336
1911	412	169	44	625
1921	532	398	18	948
1936	580	672	27	1 279
1946	586	821	18	1 425
1951	563	962	4	1 529
1960	459	1 159	22	1 640
1970	497	1 663	14	2 174
1980	369	2 382	2	2 753
1985	384	2 360	7	2 751

Hanover

Year	Whites	Blacks	Coloureds	Total
1904	644	114	474	1 232
1911	635	52	373	1 060
1921	680	76	418	1 174
1936	610	158	520	1 288
1946	617	368	558	1 543
1951	562	536	650	1 748
1960	470	700	914	2 084
1970	300	1 044	1 149	2 493
1980	267	1 658	1 400	3 325
1985	203	1 464	1 375	3 042

Hopetown

Year	Whites	Blacks	Coloureds	Total
1904	598	386	510	1 494
1911	569	362	328	1 259
1921	711	248	426	1 385
1936	892	409	911	2 212
1946	884	138	1 320	2 342
1951	872	325	1 499	2 696
1960	739	374	1 518	2 631
1970	707	462	2 104	3 273
1980	911	760	5 080	6 751
1985	709	396	3 233	4 338

Jacobsdal

Year	Whites	Blacks	Coloureds	Total
1904	332	432	-	764
1911	336	186	141	663
1921	374	216	80	670
1936	406	356	102	864
1946	374	431	95	900
1951	340	324	48	712
1960	545	1 135	122	1 802
1970	461	1 154	374	1 989
1980	546	1 590	490	2 626
1985	437	1 176	598	2 211

Jagersfontein

Year	Whites	Blacks	Coloureds	Total
1904	1 293	4 364	-	5 657
1911	2 067	6 316	636	9 019
1921	1 729	2 183	184	4 096
1936	977	1 184	274	2 435
1946	645	1 118	142	1 905
1951	1 142	3 687	362	5 191
1960	827	3 868	207	4 902
1970	585	3 137	420	4 142
1980	879	3 417	306	4 602
1985	949	2 946	395	4 290

Kakamas

Year	Whites	Blacks	Coloureds	Total
1970	558	31	2 807	3 396
1980*	1 107	65	4 847	6 019
1985	795	16	3 299	4 110

* Includes Kenhardt

Keimoes

Year	Whites	Blacks	Coloureds	Total
1904	307	22	564	893
1911	437	5	821	1 263
1921	676	12	568	1 256
1936	778	111	916	1 805
1946	713	121	1 315	2 240
1951	776	314	1 539	2 629
1960	860	265	1 872	2 997
1970	953	77	3 504	4 534
1985	749	49	4 310	5 108

Kimberley

Year	Whites	Blacks	Coloureds	Total
1904	16 350	18 870	8 489	43 709
1911	17 002	52	373	1 060
1921	17 653	13 000	8 361	39 014
1936	15 457	14 610	10 457	40 524
1946	18 551	24 759	11 789	55 099
1951	19 980	26 499	15 212	61 691
1960	24 178	35 993	18 138	78 309
1970	29 722	49 662	25 874	105 258
1980	34 565	68 654	44 349	147 568
1985	32 862	61 001	46 085	139 948

Koffiefontein

Year	Whites	Blacks	Coloureds	Total
1904	534	1 123	-	1 657
1911	1 378	2 841	644	4 863
1921	1 253	675	203	2 131
1936	1 261	967	293	2 521
1946	1 278	1 381	306	2 965
1951	927	1 285	244	2 456
1960	839	1 814	334	2 987
1970	707	2 366	606	3 672
1980	1 176	3 911	959	6 046
1985	497	2 828	922	4 247

Ladybrand

Year	Whites	Blacks	Coloureds	Total
1904	2 334	1 528	-	3 862
1911	1 924	1 187	212	3 323
1921	2 050	1 489	225	3 664
1936	2 314	2 305	134	4 753
1946	2 257	3 626	121	6 004
1951	2 325	4 034	143	6 502
1960	2 211	4 593	245	7 049
1970	2 271	6 066	420	8 757
1980	2 009	6 456	425	8 890
1985	2 148	6 017	229	7 394

Lady Grey

Year	Whites	Blacks	Coloureds	Total
1904	759	616	171	1 546
1911	843	560	163	1 566
1921	873	708	133	1 714
1936	824	881	214	1 919
1946	781	1 039	254	2 074
1951	708	1 010	226	1 944
1960	646	1 066	405	2 117
1970	511	1 479	431	2 421
1980	496	1 764	507	2 767
1985	436	1 677	519	2 632

Molteno

Year	Whites	Blacks	Coloureds	Total
1904	1 072	1 492	161	2 725
1911	1 117	955	225	2 297
1921	1 060	936	273	2 269
1936	1 150	2 176	362	3 688
1946	970	1 995	338	3 303
1951	997	2 102	296	3 395
1960	877	3 225	278	4 380
1970	569	4 822	434	5 815
1980	599	6 595	461	7 655
1985	552	4 786	413	5 751

Noupoort

Year	Whites	Blacks	Coloureds	Total
1921	1 068	906	388	2 362
1936	1 562	784	767	3 113
1946	1 777	1 687	1 067	4 531
1951	1 769	2 207	1 114	5 090
1960	2 122	2 775	1 425	6 322
1970	2 057	3 251	2 095	7 403
1980	1 560	3 422	2 372	7 354
1985	1 321	3 956	2 239	7 506

Petrusburg

Year	Whites	Blacks	Coloureds	Total
1904	301	63	-	364
1911	511	162	27	700
1921	553	236	-	789
1936	712	485	38	1 235
1946	744	767	3	1 514
1951	756	858	8	1 622
1960	820	1 175	78	2 073
1970	552	1 537	28	2 117
1980	821	2 265	139	3 225
1985	855	1 956	166	2 977

Philippolis

Year	Whites	Blacks	Coloureds	Total
1904	567	242	-	809
1911	740	271	121	1 132
1921	810	486	20	1 316
1936	842	714	137	1 693
1946	711	957	87	1 755
1951	746	1 135	146	2 027
1960	662	1 315	100	2 077
1970	596	1 403	210	2 209
1980	477	1 329	474	2 280
1985	438	1 396	491	2 325

Philipstown

Year	Whites	Blacks	Coloureds	Total
1904	806	95	486	1 387
1911	790	196	190	1 176
1921	869	269	307	1 445
1936	777	490	525	1 792
1946	554	242	714	1 510
1951	567	243	571	1 381
1960	478	726	923	2 127
1970	408	881	950	2 239
1980	493	1 996	1 830	4 319
1985	256	1 073	1 089	2 418

Prieska

Year	Whites	Blacks	Coloureds	Total
1904	587	131	601	1 319
1911	881	240	527	1 648
1921	1 114	263	672	2 049
1936	1 310	612	1 178	3 100
1946	1 315	711	1 414	3 440
1951	1 548	1 025	2 254	4 827
1960	1 743	1 270	3 472	6 485
1970	1 558	1 943	5 020	8 521
1980	1 767	2 340	7 653	11 760
1985	1 486	64	5 926	7 476

Reddersburg

Year	Whites	Blacks	Coloureds	Total
1904	499	251	-	750
1911	637	240	78	955
1921	817	293	60	1 170
1936	624	590	76	1 290
1946	628	767	70	1 465
1951	747	923	72	1 742
1960	599	1 430	113	2 142
1970	533	1 469	124	2 126
1980	610	1 580	115	2 305
1985	670	1 504	98	2 272

Ritchie

Year	Whites	Blacks	Coloureds	Total
1911	211	417	89	717
1921	236	293	5	534
1936	214	364	96	674
1946	277	458	132	867
1951	303	759	350	1 412
1960	235	1 030	466	1 731
1970	173	1 802	1 376	3 351
1985	206	49	2 065	2 320

Rouxville

Year	Whites	Blacks	Coloureds	Total
1904	493	497	-	990
1911	496	475	94	1 065
1921	682	584	66	1 332
1936	946	951	257	2 154
1946	942	1 285	233	2 460
1951	882	1 632	29	2 543
1960	807	1 878	162	2 847
1970	516	1 987	143	2 646
1980	481	2 243	148	2 872
1985	551	1 981	132	2 664

Springfontein

Year	Whites	Blacks	Coloureds	Total
1904	237	763	-	1 000
1911	495	480	164	1 139
1921	772	658	121	1 551
1936	916	1 026	113	2 055
1946	839	1 236	18	2 093
1951	861	1 429	293	2 583
1960	764	1 832	264	2 860
1970	684	2 098	304	3 086

Upington

Year	Whites	Blacks	Coloureds	Total
1904	554	250	1 704	2 508
1911	659	230	1 336	2 225
1921	1 259	216	1 148	2 623
1936	2 416	895	3 069	6 380
1946	3 382	2 116	4 656	10 154
1951	4 482	3 091	5 730	13 303
1960	5 895	4 776	9 695	20 366
1970	6 587	5 337	16 708	28 632
1980*	10 215	7 170	25 082	42 467
1985	8 500	7 767	24 197	40 464

* Includes Keimoes

Wepener

Year	Whites	Blacks	Coloureds	Total
1904	822	544	-	1 366
1911	1 159	438	100	1 697
1921	1 114	759	100	1 973
1936	1 292	1 444	108	2 844
1946	1 187	1 580	153	2 920
1951	1 163	1 878	215	3 256
1960	1 196	2 431	297	3 924
1970	1 112	3 424	487	5 023
1980	891	3 926	654	5 471

Zastron

Year	Whites	Blacks	Coloureds	Total
1904	735	422	-	1 157
1911	1 148	386	93	1 627
1921	1 765	898	119	2 782
1936	1 726	1 607	144	3 477
1946	1 867	1 994	125	3 986
1951	1 835	2 210	140	4 185
1960	1 628	2 633	188	4 449
1970	1 228	3 087	168	4 483
1980	1 034	3 652	177	4 863
1985	1 300	3 571	157	5 028

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