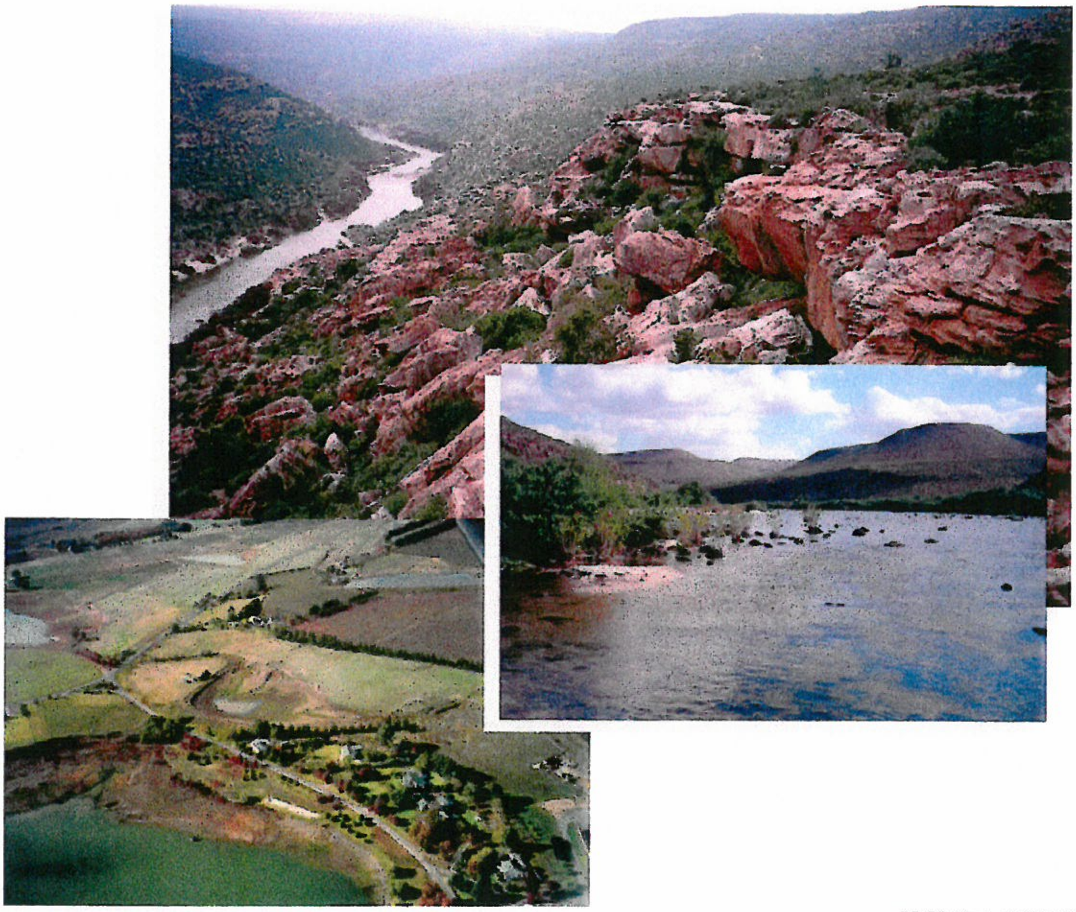
PE000/00/0198

Department of Water Affairs and Forestry
Directorate of Project Planning

OLIFANTS / DORING RIVER BASIN STUDY

Main Report



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OLIFANTS/DORING RIVER BASIN STUDY

MAIN REPORT

EXECUTIVE SUMMARY

The Olifants/Doring River drains the largest river basin in the south-western part of South Africa. While the resources of the Olifants River branch have largely been regulated with most of the water being used for irrigation, little development has taken place along the Doring River. Many options for further development were considered in the past, but were not implemented for various reasons.

A need for socio-economic development exists in the basin, and the large scale expansion of irrigation is seen as a possible option for employment creation and social upliftment. The Doring River which provides most of the undeveloped resource potential to support such irrigation, also enjoys a particularly high conservation status and is very sensitive to the further impoundment and large scale abstraction of water.

To facilitate decisions to be taken with respect to the most beneficial utilisation of water from the Olifants/Doring River system, the Department of Water Affairs and Forestry commissioned a comprehensive basin study to evaluate all development options on an equitable basis. Also included is the option for no further development of the resource.

The study confirmed the need for development as a means to socio-economic upliftment in the basin, as well as the existence of a good climate and suitable soils for irrigation. Although sufficient water may potentially be available for large scale irrigation development, the resulting reduction in river flow is expected to severely impact on the conservation status of the river. A detailed assessment of the environmental water requirements still needs to be done. This is expected to result in a lower water availability for irrigation development than provisionally assumed, leading to smaller and financially less attractive options for further development.

Of several scenarios analysed, expansion of the existing irrigation developments of the Koue Bokkeveld and Citrusdal areas, as well as possible new schemes in the Ceres Karoo and Coastal Zone were found to be financially and economically viable, subject to the validity of several assumptions which had to be made due to the lack of reliable information. Some of the key aspects requiring verification before the viability of the schemes/developments can be accepted are :

- ***Social***
  Further work is required to determine the actual needs and preferences as well as the potential capabilities of people. Irrigation, and in particular costly intensive irrigation schemes, may not always be the preferred option and there may be other means of creating opportunities and providing benefits to the previously disadvantaged.

- ***Environmental***
  Classification of the rivers and determination of the required Conservation State through appropriate stakeholder participation, is a prerequisite to the proper assessment of environmental impacts and of possible mitigating measures.

  A full instream flow assessment and determination of the estuarine flow requirements must be made, to ensure that further developments will still allow for a sustainable healthy biophysical environment. Investigations to date have shown that this would be one of the most important factors in any decision regarding future large scale irrigation development.

- ***Agricultural aspects***
  The financial and economic viability of new irrigation development depends on the cultivation of high income crops, requiring sophisticated farming practices and high levels of technical and management skills. Uncertainty still exists on whether this would conform to the needs, preferences and potential capabilities of those who are to benefit from the development. Training programmes and farmer settlement models need to be developed.

No field data exist on certain key production characteristics of the crops proposed for some of the regions, and the parameters devised from other sources need to be verified through the implementation of pilot schemes.

- ***Financial***

  Due to the extensive capital requirements, the large new schemes investigated can only be financially viable subject to full development being reached within a time period of about five years. There are no known cases where this has been achieved on large irrigation developments in South Africa and it needs to be verified whether this would be achievable in practice, given the size of the schemes and the extensive needs for training.

  The financial viability of the schemes is also sensitive to crop yields and to certain price levels being achieved.

There are still many uncertainties as reflected above, in particular with respect to the large new schemes, and a decision at this stage to proceed with any of these will hold unacceptably high risks. Considering the dire social needs in the area, a decision not to proceed with or not to allow any development, is regarded as not acceptable. An interim arrangement is therefore recommended which will allow for limited development, while retaining sufficient flexibility for future adjustment of allocations. This arrangement should be in place for a maximum of seven years, to allow time for further work aimed at firming up the recommendations.

The proposed maximum developments for which further permits may be issued during this period, subject to all the environmental and other requirements as stated in the report being met, are:

Koue Bokkeveld / Witzenberg	*950 ha*
Citrusdal/Clanwilliam area	*475 ha*
Ceres Karoo	*1 500 ha*
Middle Doring River	*150 ha*
Coastal Zone	*2 000 ha*

It is also recommended that a Catchment Advisory Committee be established as a matter of priority, to be followed by the creation of a Catchment Management Agency, to draft an overall plan for the development and management of the basin.

LIST OF STEERING COMMITTEE MEMBERS

Name	Organisation
FA Stoffberg	DWAF : Project Planning (Chairman)
MAR Khan	DWAF : Western Cape
AD Brown	DWAF : Project Planning
BC Weston	DWAF : Environmental Studies
FD van Heerden	DWAF : Western Cape
L Brink	DWAF : Northern Cape
MDJ Steenkamp	Doring River Committee N-Cape
JE Lensing	Nature Conservation Service N-Cape
Dr E Engels	Dept of Agriculture N-Cape
AS Roux	Dept of Agriculture W-Cape
CP vd Merwe	Breede River District Council
MJ Louw	Breede River District Council
CAT Smith	Hantam District Council
SF Nieuwoudt	Hantam District Council
C Gunter	West Coast District Council
JA du Plessis	West Coast District Council
MS Basson	BKS
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OLIFANTS/DORING RIVER BASIN STUDY

MAIN REPORT

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1. INTRODUCTION

1.1 Background

The Olifants/Doring River basin is the largest river basin in the south-western part of South Africa. While the resources of the Olifants River branch have largely been regulated with most of the water being used for irrigation, little development has taken place along the Doring River except for the extensive riparian developments in the Koue Bokkeveld. Many options for further development of the river system, and especially the Doring River, have been investigated in the past and several schemes have been proposed. The investigations to date have been at varying levels of detail and accuracy and focussed on selected development options only. Direct comparison of previous findings has therefore not been possible.

Recognising the pressures for development as well as the importance of holistic management of our finite and vulnerable fresh water resources, the Department of Water Affairs and Forestry (DWAF) commissioned a comprehensive study of the Olifants/Doring basin to enable the evaluation of all options for development of the resource on a reliable and equitable basis. It also serves to facilitate the objective selection of the overall most beneficial options for utilisation of the resource, considering water as an integral part of the ecosystem, a natural resource and a social and economic good.

Supporting the DWAF in the study were the Northern and Western Cape Provincial Governments and the West Coast, Breede River and Hantam District Councils.

1.2 Needs for development

As is true for many parts of South Africa and the developing world in general, widespread poverty and unemployment occur in the basin. A real need for socio-economic upliftment therefore exists. Irrigation, as one of the traditional instruments for employment creation and social upliftment, was identified as a primary option for development in this region due to the expected availability of water to support large new irrigation developments.

1.3 Needs for conservation

Apart from the possibility of supporting some new irrigation developments, the Doring River in particular has a very high conservation status, and is one of the last remaining rivers in the country largely unspoiled by humans. Great care should therefore be exercised to ensure the sustainability of the natural ecosystems and biodiversity dependent on the river.

1.4 Purpose of the study

The DWAF, as custodian of the water resources of the country, is responsible to oversee the overall most beneficial utilisation of water from local, regional and national perspectives. Water must be allocated on a just and equitable basis within the framework of basic human and social needs, sound economic uses and environmental sustainability. The DWAF is therefore not primarily involved with the actual development of resources (although it may do so), but rather with setting the national framework within which such development should take place. This requires supporting investigations and decision processes endeavouring to ensure that the best options are selected in the national interest, given the extent of knowledge and insight at the time. It is therefore the purpose of this study to investigate the broad options for the development, management and utilisation of the Olifants/Doring River to a comparable level of detail, in order to facilitate decisions which have to be taken with respect to the overall most beneficial allocation of water from this resource.

Should further development of the Olifants and Doring Rivers be approved by the DWAF, it is likely that it will have to be implemented by the provincial governments and/or private sector.

1.5 Terms of reference

The main elements from the Terms of Reference for the study are given below:

- **Project management and coordination**.
  This includes the overall directing of and control over the various elements of the study.

- **Base conditions and infrastructure**
  A basic element to any basin study, aimed at assessing and documenting the current conditions in the basin; both physical and socio-economic.

remain above zero in the lower lying areas. Evaporation varies evenly across the study area with a general increase from the south west to the north.

2.3 Towns and communities

An estimated 56 000 people live in towns and communities in the study area, with Vredendal being the biggest, followed by Calvinia and then several others of roughly the same size. The location of the towns is shown in **Figure 2.2.**

The rural population is more difficult to estimate as the magisterial boundaries do not necessarily coincide with the watershed boundary. The available statistics seem to indicate that the rural population could be roughly equal to the urban population.

2.4 Service infrastructure

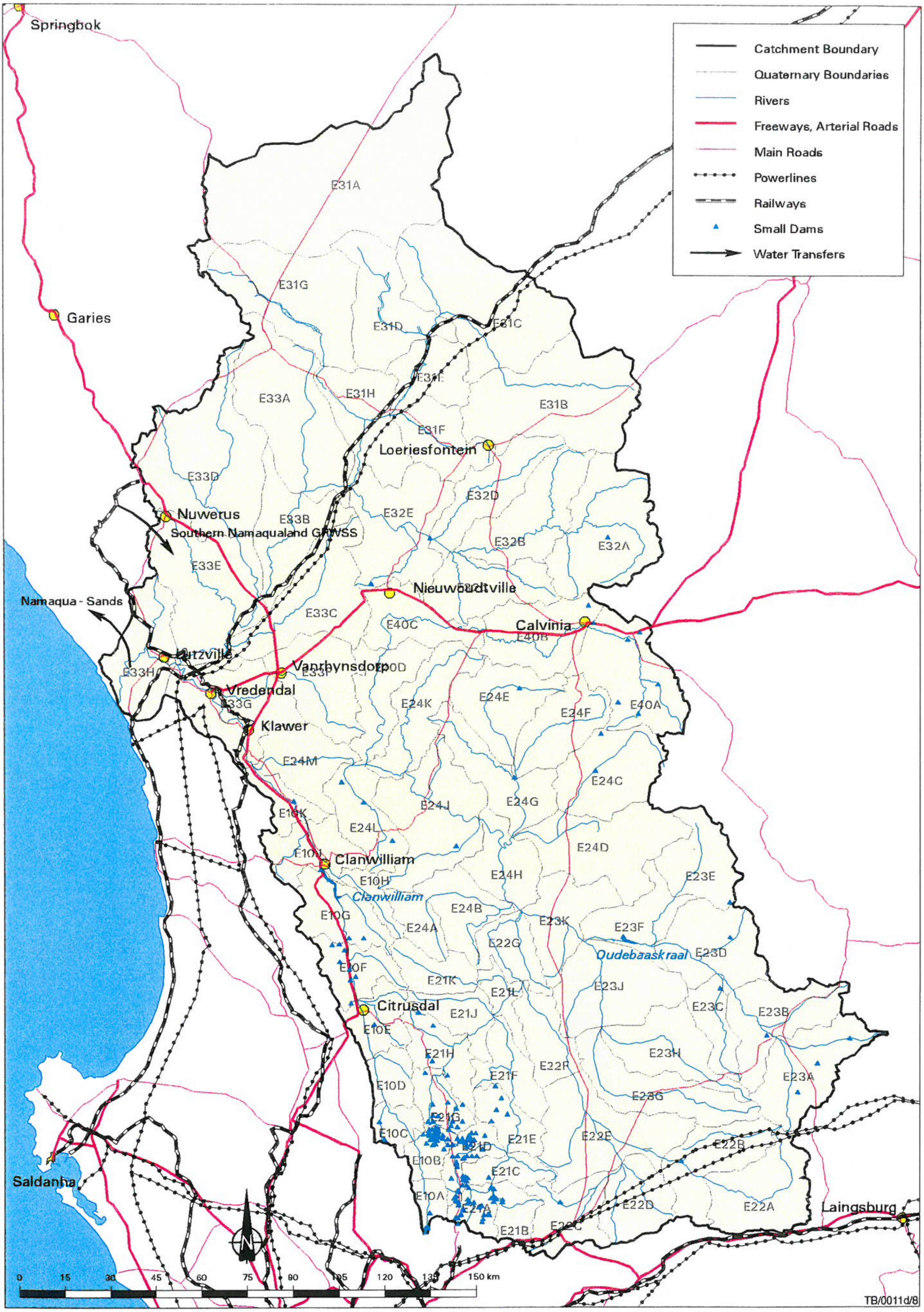
There is relatively little infrastructure development in most of the study area, probably due to the arid climate and low population density in these regions. Most of the development is concentrated along the western side of the study area.

Although there is a reasonable network of secondary and minor roads, major roads are limited to the N7 and R27. A rail service exists between Vredendal (from Bitterfontein) and Cape Town, while the Sishen Saldanha line crosses the study area. Apart from some minor low voltage power lines, the only major transmission is via a line that roughly follows the Sishen Saldanha railway, and a second line that crosses the southern most portion of the study area.

The existing infrastructure is shown in **Figure 2.2.**

2.5 Water infrastructure

The only major existing surface water scheme is the Olifants River Government Water Scheme. This is supplied from Clanwilliam Dam on the Olifants River, which releases water to the Bulshoek Barrage from where water is abstracted and distributed for irrigation through a canal system. Towns such as Clanwilliam, Klawer, Vanrhynsdorp and Vredendal also receive water from the scheme.



OLIFANTS / DORING BASIN STUDY

Towns and Infrastructure

Fig 2.2

A large number of farm dams have been constructed, especially in the Koue Bokkeveld area for the cultivation of fruit and vegetables.

The privately owned Oudebaaskraal Dam on the Tankwa River, a tributary of the Doring River, supplies water to approximately 250 ha of irrigation.

Various smaller river abstraction schemes as well as pumping from groundwater occur throughout the basin.

2.6 Existing irrigation

Existing irrigation is well developed along much of the length of the Olifants River; the largest scheme is the Olifants River Government Water Scheme with about 11 500 ha under irrigation. A further 5 400 ha is being irrigated in the vicinity of Citrusdal, with substantial developments also in the Clanwilliam area (1 650 ha) and in the Witzenberg/ Bo-Boskloof area (2 700 ha).

Irrigation from the Doring River is mainly concentrated in the upper reaches, where about 9 000 ha is irrigated in the Koue Bokkeveld area. Smaller areas are being irrigated along the Tankwa River (300 ha) and the Middle Doring River (700 ha), which is the Doring River valley between the confluences of the Bos and Brandewyn Rivers. Most of the irrigable soil along this part of the river occurs at Doringbos, where the Biedouw River joins the Doring River.

3. SOCIAL OVERVIEW [2]

3.1 Introduction

The Olifants/ Doring River basin is vast and the socio-economic characteristics of the population vary considerably. Some areas, especially those in the Northern Cape Province are sparsely populated and poor. Agriculture is the main economic activity and unemployment is high throughout the region. Measures to generate economic growth and social upliftment are therefore a priority.

The social study is of a preliminary nature, aimed at providing a broad overview of the socio-economic conditions in the study area and of the main issues at stake. It largely draws on information and statistics available. Limited field work was also undertaken, but did not specifically cover all the communities (such as in the Koue Bokkeveld area).

This chapter summarises the findings of the social study. It includes an overview of the socio-economic environment, and describes the needs and preferences of the communities. It also highlights the conditions considered necessary for the successful implementation of irrigation developments for emerging farmers and discusses where development would be most beneficial.

3.2 Current situation

The study area covers five magisterial districts, four in the Western Cape (Vredendal, Vanrhynsdorp, Clanwilliam and Ceres) and the Calvinia District in the Northern Cape. There are some 140 000 people in these magisterial districts. Just over half of the population live in the rural, as opposed to the urban areas. The population is essentially Coloured (80 %) and White (19 %). The home language of 93 % of the people is Afrikaans.

In the Western Cape districts, there are more males than females, whereas in the Calvinia district the reverse is true. This indicates a migratory pattern which is attributable to the strong agricultural sector around Ceres, Vredendal and Clanwilliam which attracts seasonal farm workers.

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2 For more detail refer to Report PE000/00/1098, "Social Impacts", and Report PE000/00/1198, "Public Participation".

The population of Calvinia is declining and ageing, and there is little economic growth or development. Between 1980 and 1991 formal employment in the agricultural sector grew in Ceres, Vredendal, Clanwilliam and Vanrhynsdorp, whilst it declined in Calvinia.

Vredendal is experiencing economic growth which is being further facilitated by the West Coast Investment Initiative of the Department of Trade and Industry. No such development initiatives have been proposed for the other areas.

The predominant economic activity in the basin is agriculture, followed by community, social and personal services, and manufacturing. The percentage of the population involved in agriculture in 1991 in Ceres was 64 %, 51 % in Vredendal, 47 % in Clanwilliam, 28 % in Vanrhynsdorp and 32 % in Calvinia. The comparative figure for the country as a whole is only 10 %.

3.3 Socio-economic indicators

The Northern Cape is one of the poorest provinces and has a relatively poor infrastructure. Approximately 33 % of the population is unemployed. The region is arid and large rural farms occupy most of the area. The population is concentrated in the few urban centres where there is some access to facilities.

The Northern Cape has the lowest population density in the country at 2,0/km^2. Approximately 80 % of the Northern Cape is literate, compared to the national average of 82 %. Only 46 % of the households have electricity in the home. Life expectancy of the inhabitants of the Northern Cape is the same as the national average of 63 years. The average household income of both Coloureds and Whites was the second lowest in the country.

The Western Cape has a population density of 28,8/km^2 which is similar to the rest of South Africa. The population of the Western Cape has the highest life expectancy (67,7 years) of all the provinces and 95 % of the adults are literate. These statistics may be misleading, however, and can only be taken as broadly representative of the south-western part of the study area as towns like Vanrhynsdorp, which falls within the Western Cape, rather resembles the Northern Cape profile of socio-economic characteristics.

3.4 Trends

The Calvinia District has a declining rural and urban population. This trend has been continuing for some 25 years and is likely to continue unless there is economic growth in the area. In the Western Cape, Vanrhynsdorp has experienced depopulation of the rural areas.

In contrast, Ceres is growing rapidly because of migration. This is particularly rapid in the rural areas surrounding Ceres and is related mainly to agricultural expansion. The population of the Clanwilliam and Vredendal magisterial districts has also grown.

3.5 Needs and preferences

The needs and preferences assessment was undertaken against the background of the new social dispensation and national policies which emphasise social upliftment, mainly the Reconstruction and Development Programme (RDP) and the Growth, Employment and Redistribution (GEAR) policy.

The needs and preferences in the study area was determined by a number of informal meetings with community groups. As the purpose was to provide input into the social implications of the various water resource development options, the study focussed on the previously disadvantaged group, and potential emerging farmers in particular.

The key development needs expressed by farm workers were security of tenure, adequate housing and access to productive land. Concern was expressed about the negative social impacts associated with the temporary work force required to construct a dam and associated infrastructure.

In order to achieve greater economic growth, it is necessary to revive the private sector, while maximising employment growth and narrowing income differentials between communities. Development must also redress the large inequalities in access to public services and facilities, and in land ownership and access to water resources. Investing in people (health, education, skills, services) is considered important. Women are a key resource and comprise about 50 % of the informal sector and provide about 35 % of the total agricultural labour. The existing gender discrimination limits economic growth and has important repercussions for economic efficiency and equity.

Lessons from Ebenhaezer (a community on the lower Olifants River, shown on **Figure 4.1**, with access to good soils and irrigation water, but where little irrigation farming is practised) suggest that voluntary participation is important. Unemployment as the main reason for development is not sufficient, and there needs to be pull factors such as real opportunities for sustainable economic activity and self-improvement. The key determinant for creating additional jobs in the agricultural sector is the availability of water for irrigation. Therefore, from a socio-economic perspective, the option of not developing the water resources is the least preferred.

3.6 Locational considerations

The northern and eastern parts of the study area have relatively high unemployment levels, are sparsely populated, have poor infrastructure and high poverty levels. The Calvinia and Vanryhnsdorp districts have generally low economic activity and it could be argued that these would therefore benefit the most from large local development projects.

Large irrigation developments would stimulate growth in the region. However, the contribution of such schemes to the regional economy and social upliftment, may be limited. This is because it is likely that most of the produce would be transported to the Cape Town area, and that many of the resources would be acquired in centres en route to the markets rather than locally. The isolation and lack of infrastructure and facilities would necessitate large inputs of capital.

The option of intensification of agriculture in the Koue Bokkeveld and Citrusdal areas would minimise the relocation of people. It is also likely that it would have a greater chance of success due to the close relationship with established agriculture, the availability of expertise, technical support services and markets, and access to existing social facilities such as schools, shops and clinics.

Development in the lower Olifants River valley would have similar benefits. The option of supplying further water from the Clanwilliam Dam by means of raising the dam wall could allow areas downstream of the dam, and further areas of suitable soils in the Vredendal area, to be developed by means of an extension of the existing canal system.

The Koue Bokkeveld, Citrusdal and Lower Olifants areas do, however, already enjoy greater economic growth. The proposed development would still benefit the lower socio-economic groups within these more developed and wealthier areas.

Agriculture is not the only economic sector which holds potential for the Olifants/ Doring basin. Tourism, mining and agro-tourism also offer potential for employment and economic growth. These options should be investigated further.

3.7 Conditions for successful settlement of irrigation farmers

The development of small scale farming produces a number of economic, social and political benefits - yet has proved in many instances to be fairly difficult to establish.

Irrigation farming is capital, labour, management and technology intensive, and as such private sector involvement would be beneficial. Joint ventures with commercial farmers result in more rapid skills transfer, greater liquidity and increased productivity. A full assessment of different settlement models should, however, be made.

The provision of land and water only is insufficient to ensure successful agricultural activities and associated social upliftment and economic development. The following is an outline of prerequisites for the successful establishment of emerging irrigation farmers:

***Training needs and capacity building*:**

- Training of farmers with respect to literacy, certification, soils, crops, water usage, management, pricing and marketing.
- Encouragement of entrepreneurs, for example in the field of marketing or transport.
- Support by government with respect to providing expert advice on farming matters, marketing and crop selection.
- Financing facilities to allow emerging farmers access to loans.
- Investigation of the potential for non-traditional products.
- Assistance in the form of partnerships and joint ventures between commercial farmers and emerging farmers in order to ensure skills transfer.

Social and community support services:

- The establishment of creches would assist women in realising their potential and allow them to fulfil a larger role in the economy.
- The provision of physical infrastructure in terms of roads, telecommunications, sewage disposal and potable water supply would be required.
- Social problems such as alcohol and drug abuse should be addressed as these entrench disempowerment and unemployment. In particular, economic growth (job creation), eradicating the "dop" system and drug and alcohol rehabilitation would be important.
- The seasonal influx of agricultural workers exacerbates conflicts and social problems and would need to be addressed.

Further involvement of the community in the proposed project would be important to ensure its success and to minimise conflict between opposing interest groups (such as commercial versus emerging farmers, farmers versus environmentalists, farmers from one geographical area versus another). In addition, communication and integration amongst planners, engineers and the authorities need to be improved.

It is clear from the above conditions that the success of any such development would depend on a host of factors beyond the responsibility of the Department of Water Affairs and Forestry. The involvement and assistance of numerous other government departments and private enterprise would be required.

3.8 Summarised findings and recommendations

There are a large number of people in the basin who aspire to become farmers. It is, however, not clear what sort of farming would be preferred. Furthermore, it is not clear to what extent people are prepared to relocate to where opportunities may be created.

Irrespective of the location of any new water resource scheme, a comprehensive development programme would have to be adopted for sustainable job creation, income generation and poverty alleviation to be achieved. This would involve a number of government departments and the private sector.

Integrated water resource management is important to achieve the social and economic goals of the region. From a social perspective, it was not possible to conclude which of the possible schemes would result in the greatest social benefit. There may be merit in investigating the possibility of a number of smaller water resource and associated irrigation schemes for emerging farmers throughout the basin.

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OLIFANTS / DORING BASIN STUDY

Potential dam sites and potentially irrigable soils **Fig 4.1**

i) Raising Clanwilliam Dam (lowest impact)

ii) Aspoort Dam

iii) Grootfontein Dam

Some species of particular interest, including rare species, occur in the Mountain Fynbos adjoining the site and within the dam basin.

iv) Melkboom Dam (highest impact)

Supports undisturbed Arid Fynbos and the riparian vegetation is an interesting mixture of saline/ drought tolerant vegetation and fynbos.

It is likely that any major dam would either reduce the extent of, or eliminate, plant communities in and on the banks of the river downstream due to the change in flow regime. If the decision is made to continue with the construction of any of the dams, it is recommended that detailed studies are undertaken of the flora at and below the dam site, as well as in any areas which could be disturbed.

b) Vegetation within the potential irrigation areas

Based on existing knowledge, a number of botanists assessed the conservation values of the six potential irrigation areas (**Figure 4.1**). The vegetation was characterised in general terms taking into account the total area, the condition and the homogeneity of the vegetation. Spot localities for rare species were added later to improve the assessment.

i) Citrusdal (lowest impact)

ii) Coastal Zone

iii) Ceres Karoo

iv) Urionskraal

v) Koue Bokkeveld

The vleis and seeps are very sensitive and the conservation value of the limited remnant natural vegetation is regarded as high.

vi) Aties-Karoo (highest impact)

Although there is a low level of cultivation, the small extent of the vegetation types present contribute to their value.

The riverine, estuarine, botanical, cultural as well as tourism, aesthetics and wilderness quality aspects have all been shown to have considerable importance and would be impacted upon by the proposed developments.

The Groot River Dam is not included in the table because the environmental impacts were not studied in as much detail as for the other dams. In most respects the impacts of this dam would be similar to those for the Aspoort Dam. The indications are, however, that the impact on cultural heritage sites would be less serious. Flooding of the Die Mond resort would be avoided but there would be a greater impact on the scenic gorge area of the Groot River.

In considering which water resource option, if any, to pursue, impacts on the riverine ecosystem should receive particular emphasis. Furthermore, it is doubtful that the impacts on the riverine system associated with any large dam on the Doring River, or those associated with the Grootfontein Dam, could be satisfactorily mitigated. These aspects need to be further addressed following on a detailed Instream Flow Assessment.

Possible impacts on the estuary cannot be used to differentiate between possible water resource options, but rather have implications for the scale of the development. Options which substantially change the flow regime and in particular, reduce inundation of the floodplain, would result in degradation of the estuarine system.

It can be tentatively concluded that, from an environmental perspective, that the Aspoort, Groot River, Melkboom and Grootfontein Dams would result in significant negative environmental impacts, while raising the Clanwilliam Dam and the further development of farm dams would result in moderate negative impacts.

The environmental studies have highlighted the potential impacts associated with the proposed water supply and irrigation schemes. Due to the complexity of the environment it is important to undertake further work to increase confidence in the assessment.

The final assessment with respect to what development may be acceptable and what not, should be judged against a formal catchment management strategy for the basin, and after classification of the rivers with respect to their desired conservation state.

5. WATER REQUIREMENTS [4]

5.1 Introduction

Generally for water resources planning purposes water requirements are categorised into present and future requirements. It is also generally assumed that present utilisation, or requirements, will continue to be met whilst spare capacity is available in the system. Currently in South Africa, the point is being reached in several river basins where capacity is, or will soon, match the use and existing utilisation must be critically reviewed.

It may be seen from what follows that the point has not yet been reached in the Olifants/Doring River basin and that uncertainty surrounding environmental water requirements at present precludes conclusive judgement on the spare capacity available.

In addition to categorising water requirements into present and future needs the various water user sectors and their utilisation should be identified. These sectors are as follows :

Urban	:	domestic, industrial, mining
Agricultural	:	irrigation and stock watering
Environmental	:	riverine and estuarine
Inter-basin transfers	:	

In addition, land-use practices influence water availability and runoff, the most important of which are afforestation, dry land agriculture, and invasive alien vegetation.

5.2 Urban and industrial

The urban communities identified within the basin are shown in **Table 5.1** which provides information on estimated populations, current water requirements and water source.

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4 For more detail refer to Report PE000/00/0289, "Physical Characteristics and Land Use", and Report PE000/00/0498, "Soils and Irrigation Potential".

Table 5.1: Urban water supply data

TOWN	POPULATION[1]	WATER REQUIREMENTS (million m³/a)	WATER SOURCE
Bitterfontein	1 010		South Namaqualand GWS [3]
Calvinia	8 000	44	Municipal [2] dams + boreholes
Citrusdal	3 500	71	Olifants River
Clanwilliam	4 200	199	Clanwilliam Dam/ Jan Disselsrivier weir
Ebenhaeser	5 000	5	Olifants River GWS [4]
Klawer	4 200	84	Olifants River GWS [4] + boreholes (winter)
Loeriesfontein	4 000	75	Boreholes
Lutzville	3 820		Olifants River GWS [4]
Nieuwoudtville	1 400		Boreholes
Nuwerus	790		South Namaqualand GWS [3]
Vanrhynsdorp	4 000	20	Olifants River GWS [4] + boreholes
Vredendal	13 000	30	Olifants River GWS [4]
Wuppertal	2 250		Tra-Tra River Weir [5]

NOTE : 1. Source : Northern and Western Cape Provinces Water Supply and Sanitation Studies : Demographic Database

2. The Municipal dams supplying Calvinia are the Akeren and Karee Dams situated on the Oorlogskloof River, a tributary of the Doring River

3. The Southern Namaqualand Government Water Scheme comprises six boreholes supplying water to a reverse osmosis desalination plant from which water is distributed to Bitterfontein and Nuwerus.

4. The main elements of the Olifants River Government Water Scheme comprise Clanwilliam Dam, Bulshoek Dam and a distribution canal (concrete lined). The canal starts at Bulshoek Dam and runs down the left bank of the river to a point below the Olifants/Doring confluence where it splits into left and right bank canals.

5. The community around Wuppertal also draw water from several springs and small streams in the area.

The urban requirements above which are inclusive of domestic, commercial and industrial components are relatively insignificant in a regional water planning context. Several of these communities have severe water problems, or pay high costs for their water, and for these communities such as Calvinia, Bitterfontein and Nuwerus, the water issue is high on the agenda.

The basic water and sanitation needs of rural communities have been assessed recently during studies undertaken by the Directorate for Community Water Supplies and Sanitation of the Department of Water Affairs and Forestry. Separate studies undertaken for the Northern Cape and Western Cape Provinces, provide complete coverage of the Olifants/ Doring River Basin.

A number of RDP projects have been initiated which are addressing these and other problems in the area. These projects are in various stages of completion ranging from initial planning to construction.

In addition to the above requirements, the Namakwa Sands mining operation draws approximately 1 million m^3/year from the Olifants River GWS.

5.3 Agricultural

The water requirements for irrigation are, by far, the largest sectoral use in the basin. The basin is an important agricultural production area based largely on intensive irrigation, mainly for export purposes. The most important areas are the Koue Bokkeveld (9 000 hectares predominantly deciduous fruit), the Witzenberg and Bo-Boskloof areas (2 700 hectares mostly deciduous fruit), the Citrusdal area (5 400 hectares mainly citrus and wine grapes) and the Vredendal area (11 500 hectares mainly of wine grapes and table grapes). Some irrigation also occurs in the Ceres-Karoo near the confluence of the Doring and Tankwa rivers and further downstream adjacent to the Doring River.

The irrigation requirements for the various (incremental) sub-catchments are summarised in **Table 5.2** below. The sub-catchment localities are shown in **Figure 5.1.**

Table 5.2: Irrigation requirements

SUB-CATCHMENT NO.	DESCRIPTION OF CATCHMENT AREA	ESTIMATED IRRIGATION REQUIREMENTS (million m³)		
		AREA (ha)	DEMAND	SUPPLIED
1	Upstream Keerom Dam site	2 700	25	14
2	Upstream Clanwilliam Dam	5 400	64	47
3	Upstream Bulshoek Dam	1 650	23	23
4	Downstream Bulshoek Dam (ORGWS)	11 500	158	117
5	Upstream Aspoort Dam site	9 500	89	79
6	Tankwa River catchment	300	6	6
7	Middle and lower Doring	1 150	21	23
TOTAL		32 200	386	309

The irrigation water shown as "supplied" in **Table 5.2** is derived from the results of the hydrological modelling. It shows that the needs of the irrigated areas cannot be met every year and, as often occurs in practice, the farmers consider it worthwhile to accept some risk of shortfall. The water shown as supplied are those volumes which can be supplied at high assurance from surface water supplies - mainly from farm dams (about 35 %), the Clanwilliam/Bulshoek Dam system (44 %) and from run of river abstractions (21 %). In addition to surface water, groundwater is also utilised for irrigation and it is estimated (DWAF, 1997) that about 8 million m³/year are currently being abstracted in the Citrusdal valley for this purpose.

The future agricultural usage within the basin will be limited by the availability of water and will thus be determined by the economics of further irrigation development and policy decisions on the amount of water to be set aside to sustain the riverine and estuarine ecologies and for potential inter-basin transfer.

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Sub-catchments used to summarize irrigation demands

Fig 5.1

5.4 Environmental water requirements

Chapter 4 of this report summarises the findings of the studies carried out into the natural environment as part of the Olifants/Doring River basin Study. These studies included investigations into the freshwater requirements of the estuary.

Unfortunately the limited previous knowledge of the basin, coupled to the time and budget constraints of the present study, preclude conclusive findings in this regard.

The conclusions which may be drawn from the investigations into the estuarine freshwater requirements in which a range of future runoff scenarios were evaluated by a team of the estuarine and scientific specialists in terms of impact on the estuary are summarised in **Table 5.3**.

Table 5.3: Findings regarding estuarine freshwater requirements

DEVELOPMENT [1] SCENARIOS	ESTUARINE INFLOW		COMMENT
	(million m^3/a)	% of MAR	
Natural conditions	1 040	100	Ideal
Present day conditions	690	66	Acceptable
Moderate further development	580	56	May not be acceptable
Maximum further development	490	47	Probably unacceptable

NOTE 1 : See Section 4.4 for more detailed information on the meaning of the development scenarios.

The scenarios were developed soon after the study commenced and these are not identical to the scenarios described in **Chapter 8**. Similarly, the hydrology used was subsequently refined during the study.

The water requirements of the rivers themselves were not determined during the course of this study and should be determined as part of the next phase of any investigation for any of the proposed major schemes. Given the high ecological conservation status and importance attached, especially to the Doring River but also to the upper Olifants River, the proportion of natural MAR for ecological maintenance is likely to be large. For example, after the IFR investigation for Rosendaal Dam the IFR suggested was between

50 % and 85 % of the naturalised MAR (DWAF, 1994). Similarly for the Doring River the IFR required downstream of dams is also expected to be large (pers. comment : Dr J King).

5.5 Inter-basin transfer

At present water is exported from the catchment to support the mining operations at Namakwa Sands. There are two imports. Desalinated groundwater is supplied to Nuwerus as part of the South Namaqualand Government Water Scheme and water is imported to the upper reaches of the Doring River from the catchment of the Lakenvallei Dam to supply irrigation.

These inter-basin transfers are relatively small. During the Western Cape System Analysis (DWAF, 1994) the possibility of using the Olifants River as a source for the Cape Metropolitan area and surrounds was considered, and a subsequent public evaluation of all the known options for the Cape carried out. Although it was considered feasible to transfer 90 million m^3/year from a diversion on the Olifants River at Keerom, the scheme was an expensive option and not favoured on financial and environmental grounds. It appeared that the scheme might be required at earliest by 2025.

If the Atlantis/Saldanha/Vredendal Strategic Development Initiative results in a major growth in the demand for water along that axis, it would be necessary to revisit the Western Cape System Analysis investigation, especially as it appears that the yield of the Lower Berg River aquifers may be less than previously indicated.

6. POTENTIAL FOR IRRIGATED AGRICULTURE [5]

6.1 General

Irrigated agriculture is by far the largest user of water in the predominantly agricultural society of the Study Area. The soils, climate and potentially the human resources required for considerable expansion and sustaining of irrigation development are available, limited only by the availability of water.

Climate and soil suitability are critical factors determining the potential expansion of sustainable, economic viable irrigation development in the Olifants/Doring River basin. The availability of water, as elsewhere in South Africa, is the limiting factor determining the extent of potential irrigation development. The availability of human resources with the required managerial skills and expertise, and the growing market for products will determine the rate at which such developments would be implemented. The existence of physical infrastructure such as roads, electricity, nearby towns, although not a prerequisite, would facilitate development and contribute to contain the cost of implementation.

6.2 Soils

Since about 1920, soil surveys in the Olifants/Doring River basin were conducted on request of various authorities each for a specific purpose and within a particular area. Soil maps were compiled of the areas surveyed, but since areas surveyed were not always linked, not all suitable soils for irrigation were necessarily identified. However, the potentially suitable soils not identified are believed to be insignificant.

In recent years soil surveys were conducted in the following areas:

- Olifants River Valley around Citrusdal, 1989.
- Olifants River from Bulshoek to Lutzville and the area from the coast to Vanrhynsdorp including Urionskraal, Aties Karoo and Knersvlakte, 1978.

[5] For more detail refer to Report PE000/00/0498, "Soils and Irrigation Potential".

- Middle Doring River (Doringbos), 1978.

- Ceres Karoo (several surveys), 1961 to 1996.

- Koue Bokkeveld, including the Witzenberg Valley. These were detailed soil surveys of most farms as well as a land type survey, but were never integrated to a workable scale.

Along many tributaries of both the Olifants and Doring Rivers no soil surveys were conducted, although some irrigation does occur in some of those areas.

Since mapping legends of soil surveys differed, soils were reclassified during the study to facilitate comparison of the soils of the various regions.

The Soils Report of this study distinguishes between not recommended, suitable and most suitable soils for irrigation in each designated region. For the purpose of formulating alternative irrigation development options both categories of suitable and most suitable soils were assumed to be equally suitable for irrigation.

A summary of the areas of identified suitable soil for irrigation in the various regions of the study area is presented in **Table 6.1**. These areas include existing irrigation development.

The largest areas of undeveloped irrigable land were identified in the Coastal Region and the Aties Karoo. About 25 % of the extensive irrigable land in the Koue Bokkeveld has already been developed.

Despite the fact that large areas of suitable soil has been identified, the soil in all cases has certain properties which to some extent restrict plant roots to absorb water and nutrients. The important physical, morphological and chemical soil limitations in each region were studied and recorded in the Soils Report.

Table 6.1: Availability of irrigable soil

Region	Total identified Irrigable Soil (ha)
Olifants River:	
Witzenberg and Bo-Boskloof	5 500
Citrusdal	10 000
Clanwilliam	1 900
Olifants River GWS	11 500
Aties Karoo	31 000
Knersvlakte	6 000
Urionskraal	10 000
Coastal Region	37 000
Sub total	**112 900**
Doring River:	
Koue Bokkeveld	36 500
Rietvallei	500
Tankwa	4 250
Elandsvlei	700
Aspoort	4 800
De Bos	5 000
Mid-Doring	1 500
Sub total	**53 250**
TOTAL	**166 150**

Most soil limitations can be improved or even eliminated. Amelioration methods to achieve this are described in great detail in the Soils Report. The cost of amelioration measures for the dominant soils of the Olifants Doring River Basin were determined and used in the financial viability evaluation of development options.

6.3 Climate

Data from fifteen long-term weather stations in the study area were used to evaluate in each region the climate suitability for the cultivation of certain crops on available suitable soil. Data recorded were average, maximum and minimum temperatures, rainfall, evaporation maximum and minimum humidity, sunshine and wind speeds. Cold units at weather stations were calculated, and were used as indicator of climatic suitability for individual crops, cultivars and varieties. Heat units at weather stations were determined and compared to heat units for ideal production patterns of wine grapes.

A workshop, attended by experienced farmers, technical advisors, academics and consultants was held to qualitatively evaluate both climatic and soil suitability. The evaluation was done for various citrus and grape cultivars and several varieties of pome and stone fruit. White and red wine grapes, table grapes and raisin grapes were also considered.

In general it was found that in all regions climatic conditions were favourable for more than one high production crop.

In all regions except the Koue Bokkeveld and Witzenberg Valley climatic conditions are suitable for most citrus cultivars, but nowhere for pomelos.

Only in the Koue Bokkeveld and Witzenberg Valley are climatic conditions favourable for the cultivation of pome fruit (apples and pears) and stone fruit (plum, peaches and apricots).

White wine grapes can be grown in all regions including the Koue Bokkeveld and Witzenberg Valley, but red wine grapes only in the Coastal Region, Olifants River Valley south of Clanwilliam and in the Koue Bokkeveld and Witzenberg Valley.

Climatic conditions are suitable for table grapes and raisin grapes in all regions except Koue Bokkeveld and Witzenberg Valley. Field data is, however, required to verify certain production characteristics, such as ripening dates, for some of the regions.

6.4 Crops

At present the following crops are cultivated under irrigation in the different regions of the study area:

- Koue Bokkeveld and Witzenberg Valley - predominantly deciduous fruit and also vegetables.

- Olifants River Valley south of Clanwilliam - primarily citrus (about 80 %), but also deciduous fruit, grapes, vegetables and lucerne.

- harvest dates may vary depending on climatic conditions;

- although there is a measure of uncertainty with respect to the harvest date at any particular location, it was estimated during workshops that the Ceres Karoo would be the earliest in the region (weeks 48 to 1). The prices used in the analyses were based on the expected favourable realisation for grapes on export markets during these early weeks in the season when competitive production is low;

- favourable climatic conditions, in particular no rain during the harvesting season and the absence of frost, are a prerequisite for the expected output of table grapes in the Ceres Karoo;

- certain management practices can be applied during establishment to advance or delay the harvest date;

- the potential income can be strongly influenced by the harvest date.

Notice of these concerns has been taken in the financial viability evaluation process by not completely relying on specific harvest dates and maximum production and prices.

6.5 Water requirements

Based on climatic data of temperature, evaporation, rainfall etc. the nett average annual irrigation water requirements for deciduous fruit, citrus and grapes, using eight crop factor suites, were estimated at thirteen weather stations in the study area. The same exercise was followed to determine peak nett monthly irrigation water requirements.

These net water requirements were converted to gross requirements in each region where future irrigation development could be expected.

At the workshop the results of water requirement estimates were found to compare fairly well with the quantity of irrigation water currently applied in the Olifants/Doring River basin.

Assuming an irrigation efficiency factor of 90 %, gross requirements at field edge were calculated, the results of which are given in **Table 6.2**. These water requirements do not include evaporation and other losses from storage dams or transmission losses from the dam to the field edge.

Losses through evaporation and transmission depend on the characteristics of storage dams, the mode, size and length of conveyances and the efficiency of operation. In addition to yielding a sufficient quantity of water for an irrigation scheme any dam would also be required to release a certain flow of water for the riverine ecology, the quantification of which has not yet been established.

Table 6.2: Recommended gross annual water requirements

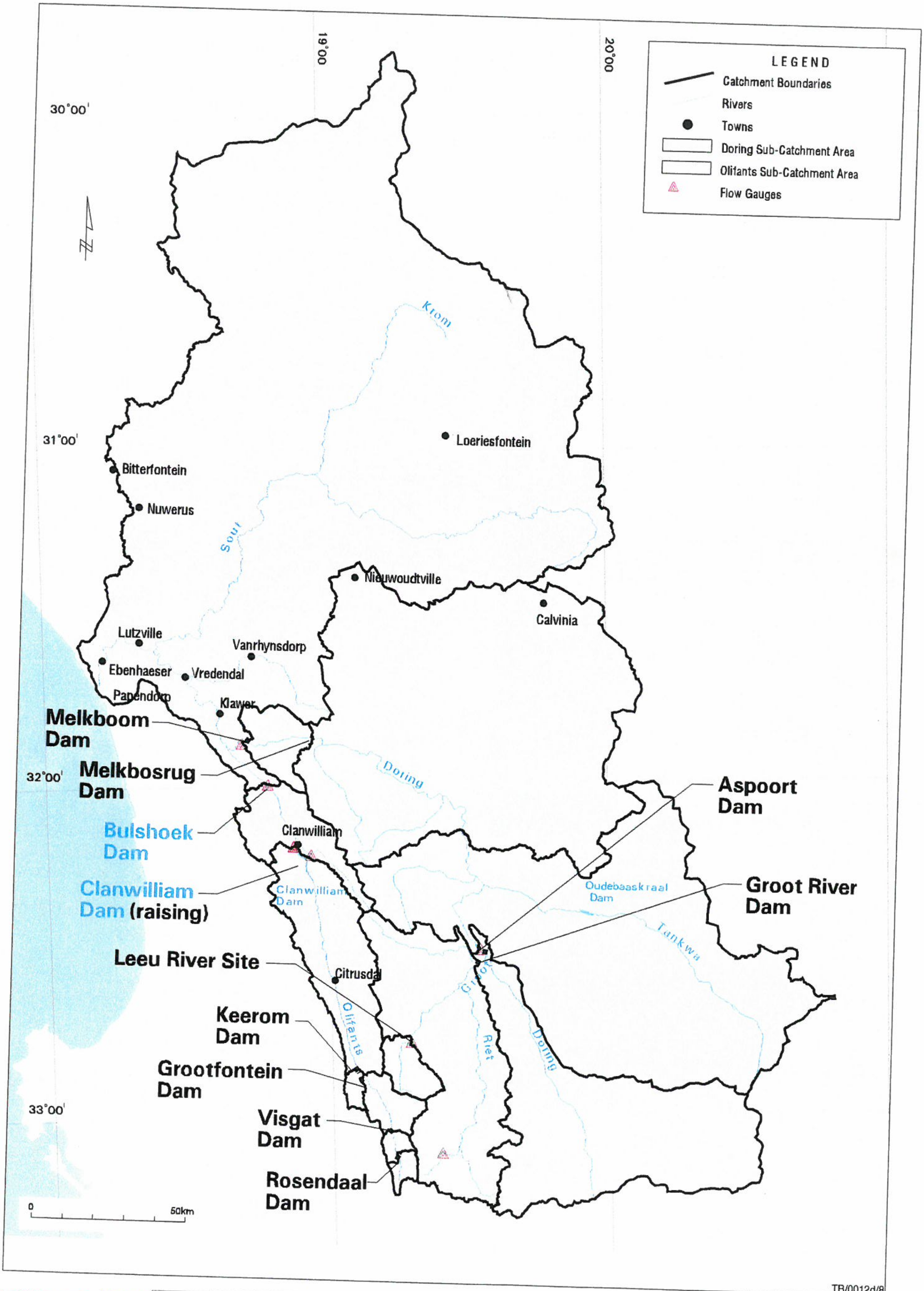
Locality	Recommended gross water (million m^3/ha/a)		
	Annual volume (no leaching)	Annual volume with leaching	Peak monthly volume
Koue Bokkeveld	7 500		2 100
Upper Olifants River	9 500		2 250
Lower Olifants River	11 000	12 000	2 500
Middle Doring River	13 000	14 500	2 800
Ceres Karoo	14 500	16 000	3 100

6.6 Summarised findings

At all existing irrigation developments in the study area a considerable potential for expansion exists, the extent of which would probably only be limited by the availability of water for that particular purpose.

Sufficient suitable soil is available among existing developments, the climate is suitable as proven in the past by the successes achieved with high income crops.

There is a market for the recommended products and a momentum of ongoing development. Human resources at all levels are potentially available and there are potential new farmers in search of land in the study area. Sufficient infrastructure for



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Location of proposed dam sites

Fig 7.1

Both the Olifants and Doring rivers rise in the winter rainfall area in the Western Cape and their runoff patterns have a strong seasonal character. Large parts of the Doring River catchment, especially the large Tankwa River catchment are located in the Karoo and these experience more summer rainfall, but this rainfall is more erratic. This factor, coupled to the higher evaporation rates experienced in this area, tends to reduce the efficiency of dams in this part of the basin.

7.2 Groundwater

The stratigraphic units of hydrogeological significance are the Table Mountain Group (TMG) and to a lesser extent the Bokkeveld and Witteberg Groups, the fractured sandstone formations of the Ecca and Beaufort Groups and various Karoo dolerite intrusions, and the alluvial formations of the Sandveld Group.

The TMG provides high quality water and is already exploited to some extent, for example about 8 million m^3/year is abstracted annually in the Citrusdal valley. The TMG is believed to have significant potential for further exploitation.

Groundwater is abstracted from the Karoo aquifers for supplementary supply to municipalities (e.g. Calvinia) and for stock watering and domestic use. Water quality is generally very poor due to the high salinity of water derived from the Karoo Supergroup. Better quality water is obtained from the fractured rock aquifers associated with dolerite and other magmatic intrusions.

Large scale, sustainable development of the TMG aquifers may be possible by exploiting large fault systems which cross the Olifants River valley could provide preferred flow paths and/or barriers to groundwater movement. Yields of 80 million m^3/a or more are postulated. Recharge of this aquifer occurs mainly in the Kouebokkeveld mountains and evidence for the very deep flow of groundwater is provided by the natural hot springs which occur in the area, of which those at The Baths are most well known. It is postulated that a significant volume of this groundwater may be discharging outside of the Olifants/Doring basin.

Conjunctive use of this resource, together with surface water, may be of significant benefit and it is recommended that this be further investigated.

7.3 Water quality

The water quality data available from the Department of Water Affairs and Forestry permitted an acceptable evaluation of the water quality situation to be made for the possible development scenarios. Specific proposals would require more detailed examination before they proceed, however.

The natural quality of waters draining into rivers from the Table Mountain Sandstone areas, namely the Olifants River and Groot River tributary of the Doring River is excellent. The quality of water draining in the upper part of the Doring River above its confluence with the Groot River, and from tributaries draining from the east and north into the Doring River are significantly poorer and is problematic (unfit for domestic use and irrigation) on occasions.

The dominant influence of the Groot River on the flow means that the water which could be yielded to consumers from the proposed dams on the Doring River, i.e. at Aspoort, Melkboom or Melkbosrug, may be expected to be suitable for the users proposed.

7.4 Sedimentation

Sediment washed from the catchments will accumulate in large dams and lead to loss of storage capacity and hence yield of these dams. Inspection of the catchment areas showed that this is potentially a serious problem in the more arid eastern catchments of the Doring River.

It was estimated that catchment sediment yields would range from 140 to 250 $t/km^2.a$ in the upper Olifants River valley (i.e. above the confluence with the Doring River) but could reach a maximum 600 $t/km^2.a$ in large parts of the Doring River catchment, for example the Tankwa River catchment. Such high yields would have major implications for dam costs as extremely large provision of excess storage capacity would be required and a set of revised sediment yields were prepared for preliminary planning purposes.

This led to reconsideration of the sediment yields.

The projected sediment volumes for the various reservoirs under consideration are shown in **Table 7.2**.

A number of development scenarios were drawn up by the project team which are described in greater detail in **Chapter 8**. In **Table 7.3** the water mass balances for those potential development scenarios are summarised.

The yields indicated are historical firm yields suitable for comparative purposes at the current level of study. Further investigation should include an assessment of the reliability of the yields and hence stochastic hydrology.

The allowance for compensation indicated in **Table 7.3** is provisional on subsequent determination of instream flow requirements which, as indicated previously, may be substantial.

7.6 Summarised findings

The principal findings in respect of the water resources evaluation are as follows :

- The water resources of the Doring River have been harnessed to a lesser extent than the Olifants River. Greater potential for further development exists on the Doring River than on the Olifants River, which is closer to the limits of financially viable utilisation.

- Opportunities for further development in the lower part of the Doring River may be undermined by the high sediment yields of the catchments in the Karoo. There is uncertainty on this point which needs further investigation before it can be resolved.

- Whilst water quality in large parts of the Doring River is poor on occasions, especially in summer, the strong flows of high quality (low TDS) water from the Groot River catchment should be sufficient to obviate any problems in respect of water in and drawn from the dams. Concerns have been identified in respect of the likely increase in TDS of river flows downstream of the dams.

- Groundwater drawn from deep boreholes in the upper Olifants River valley and operated in conjunction with surface water resources could provide a substantial additional resource. It is recommended that this be further investigated.

Table 7.3

Water Balances for Potential Development Scenarios

Scenario	Scheme	Dam	Capacity mcm	Present MAR mcm/a	New u/s not noted above mcm/a	Irrigation requirement mcm/a	Compen-sation mcm/a	Total yield mcm/a	Inflow mcm/a	Evap mcm/a	Spill mcm/a
1(a)	Aspoort	Grootrivier	235	162	0	63	13	76	162	10	76
	Klawer	Melkboom	300	404	2	51	20	71	322	15	236
	Olifants	Clanwilliam	183	370	Municipal 0	158	0	158	370	17	195
1(b)	Aspoort	Aspoort	395	177	0	63	13	76	177	43	58
	Klawer	Melkboom	313	404	2	51	20	71	290	15	204
	Olifants	Clanwilliam	183	370	0	158	0	158	370	17	195
1(c)	Tanqua	Grootrivier	235	162	0	59	17	76	162	10	76
	Klawer	Melkboom	300	404	2	50	20	70	322	15	237
	Olifants	Clanwilliam	183	370	0	158	0	158	370	17	195
2(a)	Aspoort	Grootrivier	232	162	15	54	13	67	147	10	70
	Klawer	Melkboom	312	404	6	50	20	70	312	15	227
	Olifants	Clanwilliam	208	370	10	165	0	165	360	19	176
2(b)	Aspoort	Aspoort	430	177	15	54	13	67	162	44	51
	Klawer	Melkboom	395	404	6	50	20	70	291	18	203
	Olifants	Clanwilliam	208	370	10	165	0	165	360	19	176
2(c)	Tanqua	Grootrivier	232	162	15	51	16	67	147	10	70
	Klawer	Melkboom	312	404	6	50	20	70	312	15	227
	Olifants	Clanwilliam	208	370	10	165	0	165	360	19	176

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Table 7.3 (continued) Water Balances for Potential Development Scenarios

Scenario	Scheme	Dam	Capacity mcm	Present MAR mcm/a	New u/s not noted above mcm/a	Irrigation requirement mcm/a	Compen-sation mcm/a	Total yield mcm/a	Inflow mcm/a	Evap mcm/a	Spill mcm/a
3(a)	Atieskaroo	Melkboom	430	404	52	93	18	111	352	19	222
	Exist Irrigation	Grootfontein	50	139	4	33	12	45	135	2	88
	Olifants	Clanwilliam	365	370	0	172	0	172	347	27	148
3(b)	Coastal Region	Melkboom	430	404	52	93	18	111	352	19	222
	Exist Irrigation	Grootfontein	50	139	4	33	12	45	135	2	88
	Olifants	Clanwilliam	365	370	0	172	0	172	347	27	148
3(c)	Urionskraal	Melkbosrug	463	397	52	93	18	111	345	25	209
	Exist Irrigation	Grootfontein	50	139	4	33	12	45	135	2	88
	Olifants	Clanwilliam	365	370	0	172	0	172	347	27	148
4(a)	Transfer to Cape Town	Grootfontein	200	139	3	*99	0	99	136	4	33
	Olifants	Clanwilliam	210	370	0	**145	0	145	319	20	154
	Klawer	Melkboom	550	404	22	***125	20	145	382	20	217
5(c)	Coastal Region	Melkboom	280	404	23	53	20	73	381	14	294
	Olifants	Clanwilliam	208	370	10	165	0	165	360	19	176
7(a)	Coastal Region	Melkboom	407	404	23	93	20	113	381	17	251
	Olifants	Clanwilliam	208	370	10	165	0	165	360	19	176

* 90 TO CAPE TOWN, 9 NEW IRRIGATION
** 35 EXCISTING IRRIGATION UPSTREAM
20 COMPENSATION DOWNSTREAM OF GROOTFONTEIN
90 DOWNSTREAM REQUIREMENTS
*** 75 TRANSFER TO OLIFANTS RIVER SCHEME
50 NEW SCHEME AT KLAWER OR COASTAL REGION

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The third group of development scenarios allowed for "maximum conceivable" expansion of existing irrigation development, together with those options for new schemes which were not eliminated by the larger allocation of water for the expansion of existing irrigation.

A fourth scenario was based on the possibility that water would be transferred to Cape Town, but also allowed further irrigation development.

No expansion of the existing ORGWS was assumed, but in each scenario provision was made to stabilise water supply to the scheme (should it be financially viable).

b) ***Possible new schemes***

The options for possible new schemes can broadly be classified on a regional basis, being those in the Ceres Karoo and the others along the Lower Olifants River.

The options considered in the Ceres Karoo were:

- The Aspoort Scheme as proposed by the Northern Cape Government and
- the Tankwa Scheme along the Tankwa River downstream of the Oudebaaskraal Dam.

For both these options Groot River Dam and Aspoort Dam were considered as storage dams.

Options considered along the Lower Olifants River were:

- Urionskraal near Vanrhynsdorp supplied from Melkbosrug Dam;
- Aties Karoo (including Klawer) between Klawer, Vredendal and Vanrhynsdorp supplied from Melkboom Dam; and
- Coastal Scheme between the Olifants River and the coast near the estuary, also with Melkboom as storage dam.

c) ***Development scenarios***

Having identified the various development options and possible new schemes, the following irrigation development scenarios were defined; with different sizes for the respective combinations of options.

Scenario 1:

- No expansion of existing irrigation.
- A 3 650 ha new scheme in the Ceres Karoo with a storage dam at Aspoort or Groot River.
- A 4 000 ha new scheme along the Lower Olifants River with a dam at Melkboom.
- Raising of Clanwilliam Dam for stabilisation of supply to the ORGWS.

Scenario 2:

- Limited expansion of existing irrigation of 3 180 ha or about 10 %.
- A 3 050 ha new scheme in the Ceres Karoo with Aspoort or Groot River Dam.
- A 4 000 ha new scheme along the Lower Olifants River with Melkboom Dam.
- Raising of Clanwilliam Dam.

Scenario 3:

- Maximum expansion of existing irrigation of 7 200 ha or about 22 %.
- No new scheme in the Ceres Karoo.
- A 7 500 ha new scheme along the Lower Olifants River with Melkboom or Melkbosrug Dam.
- Raising of Clanwilliam Dam.

Scenario 4:

- Transfer of 90 million m^3/a to Cape Town from a dam at Grootfontein.
- Limited (10 %) expansion of existing irrigation.
- New 4 000 ha scheme along the Lower Olifants River with Melkboom Dam.
- Raising of Clanwilliam Dam.

A number of other scenarios were also analysed, to assess the impact of changes in upstream water allocation on downstream developments, as well as to assess the financial viability of smaller schemes. Although some analyses were to lesser detail, the results indicated that schemes smaller than the selected sizes of schemes as for the main development scenarios, were less viable.

The results of analyses of two of the additional scenarios were important for further considerations. They are :

Scenario 5 :

- Limited expansion of existing irrigation of 3 180 ha (as for Scenario 2).
- A new 4 000 ha scheme, along the Lower Olifants River supplied from Melkboom Dam.
- Raising of Clanwilliam Dam.

Scenario 6 :

- Limited expansion of existing irrigation of 3 180 ha (as for Scenario 2).
- A new 7 500 ha scheme along the Lower Olifants River, with Melkboom Dam or Melkbosrug Dam.

8.4 Financial viability evaluation

a) *Input*

The basic input to the financial viability analyses was the total capital and annual cost of engineering works, physical infrastructure, in-field development, farm infrastructure, purchase of land etc as well as the expected income of the development.

b) *Evaluation criteria*

A number of financial criteria were used to evaluate the performance of proposed development options from different points of view. They were:

- the financial benefit/cost ratio (FBCR) and the internal rate of return (IRR) which are the true economic performance indicators;

- the net present value (NPV) of income as financial indicator of the economically efficient utilisation of available land;
- the net benefit per m^3 total water used as indicator of the economically efficient utilisation of available water;
- jobs per million m^3 water used as indicator of the creation of employment opportunities per unit water used; and
- jobs per hectare as indicator of the creation of employment opportunities per hectare of land for the cultivation of a particular crop.

Although Scenario 1 was included in the analyses, it became clear during the study that immediate termination of expansion of existing irrigation would not be acceptable, and need not be further considered.

c) ***Results of financial evaluation***

Studying the results of the financial viability evaluation, the following important conclusions can be drawn:

- In the Ceres Karoo the Aspoort Scheme is more viable than the Tankwa Scheme.
- Judged by financial indicators, Aspoort Dam appears to be more attractive than Groot River Dam if the financial and economic effects of evaporation losses are ignored. As a result of excessive evaporation losses from the Aspoort Reservoir, however, Groot River Dam, despite its higher cost, performs better with regard to the efficient utilisation of available water.
- Among the Lower Olifants Scheme options the Coastal Scheme proved to be the most viable. It must however be noted that the Aties Karoo Scheme may be equally viable, or even better, if the long conveyances from Melkboom Dam were to be replaced by using the river as conveyance to a point near the scheme from where water could be pumped into the canal distribution system.
- The larger 7 500 ha Coastal Scheme, from a financial point of view, would be a better option than the 4 000 ha scheme.
- The expansion of existing irrigation development, both in the Koue Bokkeveld and Citrusdal Region, according to the financial and other indicators, would be the best development options.

d) **Comparison of scenarios**

Based on the evaluation criteria as described under paragraph (b) above and considering different approaches in the selection process, the following scenarios were identified as the best options:

- In the interest of sustained socio-economic development Scenario 1 should not be considered.
- The best general option, which would allow limited expansion of existing irrigation development as well as new medium size irrigation schemes in both the Ceres Karoo and along the Lower Olifants River was Scenario 2.
- Scenario 4 would not be considered for development in the short to medium term. Should the transfer of Olifants River water to Cape Town by about the year 2025 be seriously considered, this scenario would require further attention.
- The best option for only one new medium size scheme and limited expansion of existing irrigation, would be Scenario 5.
- The best option allowing for maximum expansion of existing irrigation together with a new large scheme was Scenario 3.
- Scenario 7 was the best option for a new large scheme with limited additional upstream development.

A summary of the financial performances of the most promising development scenarios is presented in **Table 8.1**.

Important information not shown in **Table 8.1** is that the employment opportunities per 1 000 ha with respect to the most likely crops, are:

2 400 for table grapes;
350 for wine grapes;
410 for citrus; and
720 for deciduous fruit.

Concerning the efficient use of water, cultivation of citrus shows good results on all development options except Aspoort, mainly as a result of high evaporation from Aspoort Dam.

Table 8.1: Financial performance of most viable development scenarios

Scenario	Option	Crops	FBCR	IRR %	Break even year	NPV/ha (R1 000)	Benefit (R/m³)	Jobs per million m³
All	Citrusdal	Citrus	4,03	13,47	15	89,5	0,62	34
All	Koue Bokkeveld	Deciduous fruit	3,92	11,46	17	67,4	0,60	77
2(a)	Coast	Citrus	1,93	11,40	18	90,6	0,46	25
	4 000ha	Wine grapes	1,53	10,45	19	51,3	0,25	21
2(b)	Aspoort (Aspoort Dam)	Table grapes	2,05	11,30	16	114,9	0,31	77
	3 050ha	Citrus	1,39	9,60	22	43,4	0,12	13
2(a)	Aspoort(Groot River Dam)	Table grapes	1,53	10,05	19	79,0	0,33	118
	3 050ha	Citrus	1,05	8,25	37	7,5	0,03	20
3(b)	Coast	Citrus	2,67	13,04	16	117,2	0,64	27
	7 500ha	Wine grapes	2,11	12,23	16	77,9	0,42	23
5(c)	Coast	Citrus	2,12	11,97	17	100,7	0,51	25
	4 000ha	Wine grapes	1,69	11,05	18	62,0	0,32	21
7(a)	Coast	Citrus	2,77	13,20	16	119,4	0,65	27
	7 500ha	Wine grapes	2,20	12,45	16	80,8	0,44	23

It should be noted here that the cost of collector drains was not included in the cost estimates of either the engineering works or land preparation. This resulted in a 5 % to 7 % under-estimation of the capital cost of engineering works, which means that all irrigation options would be slightly less viable than the figures given in **Tables 8.1** and **8.2**.

e) **Effect of evaporation losses on the financial viability of schemes**

For the purpose of this analysis, the potential monetary value of water from the Olifants/Doring River was taken as the nett benefit that could be realised on the financially most viable new scheme option investigated. The best benefit achievable was R0,65/m^3 from the cultivation of citrus on a 7 500 ha Coastal Scheme, with limited upstream irrigation development.

A value of R0,65/m^3 was therefore assumed for evaporation losses from storage for the schemes listed in Table 8.1. The recalculated FBCR together with the original values are given in **Table 8.2**, and show a considerable decrease in the financial viability of most schemes. Citrus will not be viable any more at an

Aspoort Scheme with Aspoort Dam, while the cultivation of table grapes will become marginal. Groot River Dam, which has been found more acceptable from an environmental point of view, now also becomes financially preferable to an Aspoort Dam, although feasible for one crop only.

Table 8.2: Effect of Evaporation Losses on the FBCR of Development Options

Scenario	Development Option	Crops	FBCR* with evaporation losses valued at	
			R0,00/m³	R0,65/m³
All	Citrusdal	Citrus	4,03	3,53
All	Koue Bokkeveld	Deciduous fruit	3,92	3,42
2(a)	Coastal scheme 4 000ha	Citrus Wine grapes	1,93 1,53	1,54 1,14
2(b)	Aspoort (Aspoort Dam) 3 050ha	Table grapes Citrus	2,05 1,39	1,03 0,37
2(a)	Aspoort (Groot River Dam) 3 050ha	Table grapes Citrus	1,53 1,05	1,37 0,89
3(b)	Coastal scheme 7 500ha	Citrus Wine grapes	2,67 2,11	2,39 1,83
5(c)	Coastal scheme 4 000ha	Citrus Wine grapes	2,12 1,69	1,82 1,39
7(a)	Coastal scheme 7 500ha	Citrus Wine grapes	2,77 2,20	2,51 1,94

* Actual financial performance slightly lower, due to cost of engineering works to be increased

8.5 Technical considerations

On the outcome of the financial evaluation certain questions arose which need to be clarified.

a) ***Financial viability of private farmer development***

The very positive financial performance of expansion of existing irrigation development in the Olifants River Valley and the Koue Bokkeveld raised the question on how assumptions compare to those for new schemes, with particular reference to input costs and production levels.

The in-field development costs and production of both development categories were based on the same assumptions. The better performance of own development options may be ascribed to the following:

- No need for additional infrastructure;
- no purchase of land for development;
- farm dams do not need expensive spillways to pass large floods;
- distribution systems are relatively inexpensive due to the proximity of the farm dams;
- normally development of water resources in upper reaches of catchments are less complicated, since diversion of small tributaries is easier and less upstream interference in the river flow can be expected; and
- the quality of water is better and farm dams are less affected by sedimentation, particularly for off-channel storage.

b) ***Expansion of existing irrigation development in the Olifants River Valley***

The estimated water supply to existing irrigation development in the Olifants River Valley upstream of Clanwilliam is currently only about 75 % of the actual irrigation requirements. In some instances this is due to the restriction of 6 000 m^3/ha on the allowable storage capacities of farm dams. Existing irrigation development could, in fact, be extended by about 750 ha should more storage be allowed. The expansion of upstream irrigation, however, also impacts on the availability of sufficient water for the requirements of downstream users.

For 1 500 ha expansion of existing irrigation development a storage dam would be required in the Olifants River at either Rosendaal or Grootfontein. Rosendaal Dam is more acceptable than Grootfontein Dam from an environmental point of view, but is more expensive and does not have sufficient yield potential.

A dam at Grootfontein for 1 500 ha expansion, which would also sustain existing irrigation downstream and supply a provisional 12 million m^3 compensation water for environmental requirements, would require an estimated capital investment of R160 million. This would reduce the financial benefit cost ratio for the cultivation of citrus in the Olifants Valley from 4,03 to 1,05.

On the basis of these findings it must be concluded that any expansion of existing irrigation development in the Olifants River Valley that would require a dam on the main river, would be considerably less favourable than private development with off-channel farm dams. The environmental advantages of better river flow regulation afforded by a new dam have, however, not been taken into account in this argument.

More detailed studies are required to establish the extent to which existing irrigation development in the Olifants River Valley may be extended, either by means of new off-channel farm dams or through a new dam on the Olifants River.

c) ***Clanwilliam Dam raising***

Even with no further expansion of existing irrigation in the Olifants River Valley, stabilisation of water supply to the Olifants River Irrigation Scheme is required. This can be achieved by the raising of Clanwilliam Dam by 5 m to increase the present yield by about 35 million m^3/a to approximately 160 million m^3/a.

Another option would be to recover the losses through leakage at Bulshoek Dam as well as from the first few kilometres of the main canal below Bulshoek, which amounts to about 25 million m^3/a.

Should allowance be made for a scenario with "limited" expansion of existing irrigation, Clanwilliam Dam would have to be raised by 7 m.

For the "maximum" expansion of existing irrigation, and with a dam at Grootfontein, Clanwilliam Dam would have to be raised by 16 m. Such a major raising of the dam would seriously disrupt infrastructure around the town, and would cost about R168 m, including the relocation of infrastructure.

Should Melkboom Dam be built for a new Lower Olifants River scheme, increasing the size of the dam to supplement the supply to the Olifants River GWS would in all probability be more cost effective than the raising of Clanwilliam Dam.

8.6 Key assumptions

The investigation and evaluation of irrigation development options in the Olifants Doring River Basin were based on various assumptions, some of which should be highlighted as having a crucial influence on the outcome of the evaluation of individual options.

Instream flow requirements (IFR)

Since the IFR has not been determined, provisional IFR releases have been assumed for each dam. Should the IFR eventually be increased, the financial viability of new scheme options would be negatively affected. Own development need not necessarily be affected, depending on what release requirements may be imposed.

Cost of infrastructure

The cost of all new or upgraded infrastructure required for the efficient functioning of a new scheme, such as roads and powerlines was included in the cost estimates and financial evaluation of those schemes. Should it be decided to exclude the cost of some infrastructure from the total cost of a scheme (such as the cost of the road with respect to any Ceres Karoo scheme), the financial viability would be influenced positively. The economic feasibility from a national perspective, however, will not be affected.

Water for Municipalities

The water requirements of municipalities are small compared to the overall resource capacity, and sufficient water is available to serve all municipal needs.

In all water allocation scenarios the future water requirements of municipalities and other small towns were recognised as a priority. The assumption was that municipalities would always have access to surface water resources in the catchment, but should themselves be responsible for the development of the resources, individually or in co-operation with other users of water. Water can be taken from the nearest source, whether it is a tributary or the main river.

Table grapes ripening dates and perpetuation of high market prices

Based on limited observations, certain assumptions have been made regarding harvest dates in the various regions. The Ceres Karoo was assumed to have the earliest harvest date, 7 days or up to 14 days later than Blouputs in the Orange River Valley. (Blouputs is considered as one of the earliest table grape production areas in South Africa.) The financial evaluation was, however, carried out with only 80 % of the target price and an average production rate of 2 800 cartons per hectare ("pack-out" rate of 65 %) in an attempt to allow for the possibility of a later harvest date and resultant lower prices, as well as for somewhat less than optimal production.

Similar to the Middle Doring River (as discussed in a following paragraph) no commercial production of table grapes (or citrus) currrently takes place in the Ceres Karoo. No field data therefore exists for the verification of production assumptions.

Size of market for table grapes

It should be realised that a change in the market for table grapes would be unpredictable and could be influenced negatively by the additional production of 1 000 ha or more of early grapes in the Ceres Karoo. Large new production areas elsewhere in the world could also influence the European market, and would require further market development. (Refer "Finansies en Tegniek" of 10 April 1998.)

Management capacity

A high level of management capability and technical expertise is fundamental to the success of sophisticated irrigation farming as assumed in the financial evaluation. To what extent this could be met, especially during the crucial initial years, needs to be determined.

Irrigation along the Middle Doring River

The Doring River Valley between the confluence of the Bos- and the Brandewyn Rivers with the Doring River, is referred to as the Middle Doring River. Most of the irrigable soil along this part of the river occurs at Doringbos where the Biedouw River joins the Doring River. According to the Soils Report, both soil and climate characteristics of the Middle Doring River were found suitable for the cultivation of some of the high income crops such as grapes and citrus. The financial viability of expansion of irrigation development in the region was, however, not evaluated since none of these crops are at present being cultivated on a commercial basis in this area. In view of these uncertainties further investigations would be required, should the cultivation of high income crops under irrigation be considered along the Middle Doring River.

8.7 Summarised findings

The relative benefits of the proposed development options are based firstly on a comparison of competing options in the same region, and secondly on a comparison between the best options in each region. These comparisons are only based on the engineering feasibility and financial viability of the options.

Expansion of existing irrigation development in the Olifants Valley (Citrusdal), and the Koue Bokkeveld (including Witzenberg Valley) were found to be financially viable using the key assumptions. Development in the Koue Bokkeveld marginally failed the financial viability sensitivity test which evaluated the effect of changes in the discount rate. Maximum expansion could be considered in the Koue Bokkeveld, because of the incremental manner in which development will occur.

In the Olifants River Valley the cultivation of citrus passed the financial sensitivity test. Future development in the upper valley would be limited both by the feasibility of construction of new farm dams and the availability of sufficient water for existing development along the river. With present available information it would appear that further development which would require a dam in the main river would not be financially viable.

Of the two development options investigated in the Ceres Karoo, the Aspoort Scheme with an Aspoort Dam is financially the more attractive option if the large loss of water from reservoir evaporation is not taken into account. The maximum size of the scheme allowing for moderate upstream development is about 3 050 ha and the best crops to be cultivated are citrus and table grapes. A smaller scheme would be less viable. Should the valaue of water losses due to reservoir evaporation be taken into account, a Groot River Dam becomes the better option, although only viable with the production of table grapes.

The Coastal Scheme and probably also the Aties Karoo Scheme, were found financially viable options with both wine grapes and citrus. Depending on upstream water allocations, the size of development could vary between 4 000 ha and 7 500 ha. The financial benefit increases with the size of the scheme. Both citrus and wine grapes passed the financial viability sensitivity test.

9. FINDINGS AND RECOMMENDATIONS

9.1 General

Potential still exists for further development of the resources of the Olifants/Doring River basin, especially along the Doring River branch. There is also a great need for socio-economic development in the region which can, amongst others, be alleviated through the large scale development of new irrigation. Attributable to some unique natural characteristics of the Doring River and the fact that the river has been little developed, it is one of the rivers with the highest conservation status in the country and supports eight fish species which are endemic to, or occur only in the Olifants/Doring River system. The construction of further impoundments and the additional abstraction of large quantities of water are expected to significantly impact on the river ecosystems. Great care should therefore be exercised to achieve an appropriate balance between development and conservation.

Due to the relatively broad level of detail at which this study was performed, much further work remains before that balance can judiciously and with confidence be decided upon.

It will also be the task of a Catchment Management Agency which is to be established in terms of the new Water Law, to draft a catchment management plan which should guide further development of the Olifants/Doring River basin. Such a plan should, among others, contain details of the "Reserve", other water allocations, management goals for addressing critical issues and potential management strategies.

The main findings and recommendations at this stage are summarised below.

9.2 Social aspects

Unemployment in the Olifants/Doring River basin is high and is perceived to be particularly high in the northern and north eastern (North Cape) part of the basin. Poor socio-economic conditions and social neglect are evident in many areas.

From the needs and preferences assessment, undertaken against the background of the Reconstruction and Development Programme (RDP) and the Growth, Employment and Redistribution policy (GEAR), a no-development scenario is considered the least favourable option. The need for employment (supported by infrastructure development, training, etc) as a means to socio-economic upliftment, is a common thread which can be deduced.

In general, a strong desire to farm was expressed by many of those interviewed. Small scale and commercial farming were indicated, however, the study was not conclusive on the type of farming preferred. Some responses point to a rather extensive type of irrigation farming while strong interest in stock farming was also expressed. Similar trends were also experienced at the Koekedouw development near Ceres, where emerging farmers are being settled.

A need exists for people to be properly informed about the possible options and be exposed to sophisticated irrigation farming. Further work is evidently required to ascertain what the real interest in intensive, high technology irrigation farming may be, or to determine what other farming models may rather have to be considered to ensure the sustainability of the enterprise. It is also not conclusive at this stage, as to what extent people are prepared to relocate to where opportunities may be created (within and possibly outside the basin).

Crucial to any development option aimed at the provision of opportunities and upliftment of people, many of whom are unemployed and with limited skills, is a comprehensive training and implementation programme which should be considered as part of the investment. In the event of intensive irrigation farming with high income crops, as required for the financial and economic viability of the schemes considered, extensive technical, managerial and marketing training as well as access to credit facilities are some of the basic requirements. Partnerships or collective efforts between the established commercial farmers and new entrants to farming is seen as a possible solution. Furthermore, consideration should be given to developing a number of smaller irrigation schemes for emerging farmers throughout the basin.

9.3 Environmental

The Olifants/Doring River system, and in particular the Doring River branch, is of considerable conservation importance. This mainly relates to the occurrence of endangered and critically endangered fish species, together with the fact that most of the

Doring River still remains unaffected by humans. Great concern therefore exists that the construction of dams and the abstraction of large quantities of water may significantly impact on the salinity regime in the rivers and have a detrimental effect on the aquatic ecosystems. The most important in this respect is cutting off of migration routes between the lower Olifants River and the spawning grounds in the upper reaches of the Doring (Groot, Leeu) River, which would result from the construction of large dams at Melkboom and/or Aspoort.

Although some of the potential negative impacts can probably be alleviated, it is considered likely that impacts on the riverine system will still be significant. Due to a paucity of data and limited knowledge of the ecosystem in the Doring River, much uncertainty exists with respect to the determination of an environmental reserve. No final judgement on any of the schemes can therefore be given from an environmental point of view, before substantial additional work has been done, especially with respect to the determination of the Instream Flow Requirements (IFR).

Spectacular natural scenery and valuable archeological heritage sites also occur along the river and in some of the proposed reservoir basins. In this respect a dam at Melkboom will inundate part of the gorge used for white water rafting, while some unique rock art occurs at Aspoort. Classifying the Doring River by determining the desired Conservation State of the river through appropriate stakeholder participation as well as a full heritage survey, will be required prior to any final decisions being taken with respect to development.

The Olifants River estuary is still in a relatively pristine condition and is considered of national as well as of international importance. Findings to date indicate that moderate further development and abstraction of water may not have unacceptable environmental consequences. However, a maximum development scenario would significantly change the flooding regime, with resulting negative impacts on the estuary.

Due to the large areas of irrigable soils available, any new development could be sited so as to minimise impacts on the terrestrial environment.

9.4 Water resources

The limiting factor on any further irrigation development in the Olifants/Doring River basin, is the availability of water. Although from a technical perspective much potential for development of the resource still exists, especially along the Doring River, the availability of water for commercial irrigation will depend on what needs to be allowed for as an environmental reserve. Based on the environmental and compensation releases as provisionally allowed in this study, it was found that sufficient water may be available for new irrigation development of up to about 14 500 ha.

Domestic, industrial and mining use of water in the basin is very small in relation to the overall resource capability, and no limitation is foreseen in meeting the current and future requirements in these sectors.

The Olifants River part of the basin has been largely developed, although, additional utility from the resource can be achieved through a dam at Grootfontein, the raising of Clanwilliam Dam and possible construction of farm dams in tributary streams. However, the requirements from Clanwilliam Dam are already in excess of the yield and raising of the dam will essentially only firm up on the supply to current users and improve the IFR releases from the dam. The construction of a dam at Grootfontein in particular, will have significant environmental impacts and will require specific compensatory measures to be taken, should it be found acceptable.

Of the options for new dams considered on the Doring River, where significant potential for regulation of the river still exists, the Aspoort and Melkboom sites were found to be the best from a technical and financial perspective. A particular negative characteristic with respect to the Aspoort Dam, however, is the very high evaporation which would occur from the reservoir basin and which constitutes a consumptive loss of a valuable and limited natural resource. A dam on the Groot River would have better evaporation characteristics and would be less destructive of cultural heritage sites. At the large storage volumes considered in this report the dam would, however, have a significantly higher construction cost than the Aspoort Dam. A dam at Melkboom would need to be designed for sediment inflow from virtually the whole of the Doring River basin, especially should Aspoort not be built. Should a further review of sedimentation rates suggest higher quantities than used in this study, this may have a major impact on the cost and long-term sustainability of the scheme.

9.5 Irrigation potential

Climate and suitable soils are critical determinants with respect to sustainable, financially viable irrigation development. The sufficient availability of water is an inherent pre-requisite, while the proximity of soils to the water source directly impacts on the cost-efficiency.

The climate in several parts of the Olifants/Doring River basin is conducive to the production of high income crops under irrigation, with indications from analysis of climatic data that the Ceres Karoo may be particularly well suited to grow early ripening table grapes.

Large areas of potentially suitable soils have been identified, which are also favourably located with respect to the rivers. Extensive soil preparation in the sense of ripping, chemical treatment, provision of drainage facilities and pre-leaching is, however, required for several of the areas and was allowed for in the analyses. The location and characteristics of some of the soils are also such that specific measures will have to be taken to prevent any excessive leaching of salts to the river.

Limitations are foreseen in the availability of suitably qualified human resources for the development of large new schemes within the limited span of time required to ensure financial viability.

9.6 Development and utilisation scenarios

Scenarios were considered which include possible further development in existing irrigation areas as well as completely new irrigation schemes. The potentially most viable options were found to be further development of existing irrigation (with the Citrusdal and Koue Bokkeveld areas taken as representative examples), as well as a Ceres Karoo scheme supplied from a dam at Aspoort and a Coastal Zone or Aties Karoo scheme supplied from a dam at Melkboom. Should the value of water lost through reservoir evaporation be taken into account, a dam at Aspoort will not be viable and may be replaced by a dam on the Groot River. With table grapes as the only remaining viable crop, this is financially a less attractive option.

No further development in the existing areas will allow the largest availability of water for the development of new schemes which, due to the benefits of scale, will result in the financially and economically most viable schemes. As the existing irrigation areas are located upstream from the potential new schemes, the large scale further development in the former areas will render the new schemes less viable. In particular, a scheme at Aspoort would not be viable should maximum further development occur in the Koue Bokkeveld area.

It was considered as probably unrealistic not to allow any further development of the existing irrigation, and moderate development in these areas is therefore suggested as a base for comparison purposes. Under this scenario expansion of 1 930 ha can take place in the Koue Bokkeveld and Witzenberg, 950 ha in the Citrusdal-Clanwilliam area and 300 ha along the Middle Doring River. Subject to the environmental water requirements still to be reviewed, this will allow for a scheme of about 3 000 ha in the Ceres Karoo as well as about 4 000 ha in the Coastal Zone or Aties Karoo. (Should there be no development in the Ceres Karoo, then the Coastal Zone or Aties Karoo scheme may be enlarged to about 7 500 ha.) The total associated employment opportunities would be for about 2 150 permanent and 3 000 temporary positions. This would require a capital investment of about R1 080 million, or roughly R375 000 per permanent employment opportunity and R92 000 per temporary opportunity. The maximum debt/input ratio varies between 1,3 and 1,6.

A future possibility would be for water from the Olifants/Doring River basin to be used for the augmentation of supplies to Saldanha and Cape Town. This will have a direct impact on the water available for irrigation and will require some trade-offs to be made at the time.

9.7 Financial and economic evaluation

Of several scenarios analysed, expansion of the existing developments of the Koue Bokkeveld/Witzenberg and Citrusdal as well as possible new schemes in the Ceres Karoo and Coastal Zone/Aties Karoo were found to be financially and economically viable, based on the assumptions used. Of these four, only the Coastal Zone fully passed the sensitivity tests for two crops. Citrusdal was tested for citrus only and passed all of the sensitivity tests. Both the Koue Bokkeveld area as well as the Ceres Karoo/Aspoort scheme were shown to be very price sensitive as well as sensitive to higher discount rates, the non-viability at higher discount rates being an indicator of risk sensitivity with respect to large capital investments.

There are several key factors, assumptions and uncertainties underlying the work to this stage, which should be recognised in the interpretation of the results from the financial and economic analyses:

- The environmental releases allowed for in the yield analysis of the dams, were based on provisional assumptions of what may be required. Recognising the high conservation importance of the Olifants/Doring River and estuary which became apparent during the study, indications are that a full assessment of the in-stream flow requirements may result in substantially higher releases being required. (Assuming that a compromise can be reached on the construction of new dams). This will result in less water being available for irrigation, with accompanying higher unit costs for water and primary infrastructure.

- Financial and economic viability could only be achieved for high income crops. This requires large capital investments, sophisticated farming practices and a high level of managerial and marketing skills. Uncertainty exists on whether this type of farming would conform to the needs and preferences of the people in whose interest the development is to be undertaken.

- Due to the extensive capital requirements for the development of large new schemes, full development must be reached within a relatively short period of time (5 years) to limit the capitalisation of interest on non-productive capital. It needs to be verified whether this would be achievable in practice and whether the required managerial and technical expertise would be available.

- Some of the prices used in the financial analysis, are based on the assumption of the products reaching the markets at the very beginning of the production season. Although derived from good climatic data, this is a key assumption which needs to be proven in practice before large investments are made.

Should it be decided to proceed with the development of a large new scheme, clarity should be gained in advance on issues such as the financial accountability for the project, the rights and privileges/support to be afforded the new farmers, as well as the commitment and liabilities expected of them.

9.8 Interim recommendations

Considering the dire social needs in the area, a decision not to proceed with or not to allow any development, is foreseen as not being acceptable.

The lowest risk and potentially lowest impact scenario, apart from the no-development option, would be to allow incremental further development in existing irrigation areas. This would also best facilitate the concept of partnerships between established farmers and new entrants to the sector. Models will have to be developed and applied, to ensure that such development would be to the benefit, direct or otherwise, of previously disadvantaged individuals. In the event of developments upstream of Clanwilliam Dam, further investigations would first need to be done to ensure that the impacts on the yield of the dam are not unacceptable.

There are still many uncertainties with respect to the large new schemes and a decision at this stage to proceed with any of these will hold unacceptably high risks. Much further work is required to ascertain the acceptability and viability of these schemes.

As a temporary measure, it is proposed that the moderate development scenario as described under paragraph 9.6 be used in the interim as the basis for the issuing of water use permits. Due to the many uncertainties which still exist with respect to the environmental impacts and flow requirements, as well as the practical, social and financial feasibility of the possible new schemes, some flexibility for future adjustment of the allocations needs to be retained. It is therefore suggested that a maximum of 50 % of the respective developments referred to in that paragraph provisionally be allowed, subject to all the environmental, social and other requirements stated in the report; being met. This interim arrangement should be in place for a maximum of seven years, to allow time for further work aimed at providing an acceptable basis for decision making.

The maximum developments for which further permits may be issued during this period, will thus be:

Koue Bokkeveld/Witsenberg	950 ha
Citrusdal/Clanwilliam area	475 ha
Middel Doring River	150 ha
Ceres Karoo	1 500 ha
Coastal Zone	2 000 ha

9.9 Further work

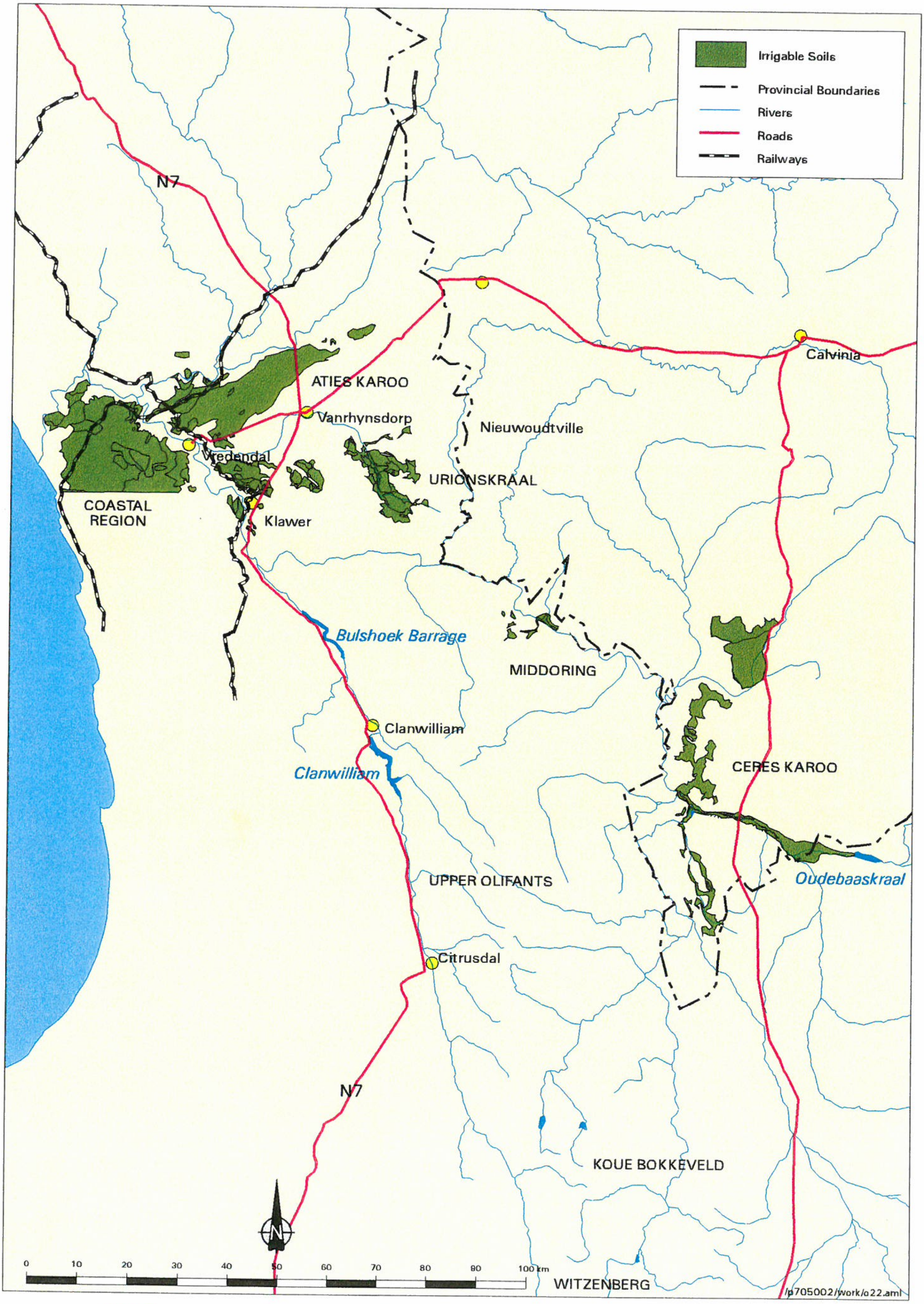
The following further work is recommended :

- Establish a Catchment Management Agency (CMA) to develop an overall plan for the management and development of the basin.
- Classification of the rivers in terms of the latest legislation.
- Detailed assessment of the in-stream flow requirements (IFR) and determination of the Reserve, for representative points in the river and estuarine systems. Due to the impact which this may have on the possible new schemes envisaged, determination of the IFR should precede any further engineering and financial investigations.
- Detailed investigation of estuarine freshwater requirements.
- The interests and preferences of the people who are to benefit from the developments need to be more specifically addressed. A data base containing all relevant information, should be established with respect to prospective farmers.
- Development of appropriate farmer settlement models and training programmes.
- Investigation of the potential for farm dam development upstream of Clanwilliam Dam, as well as of options to stabilise the water supply to users from the dam.
- Investigation of the possible combined use of surface and ground water.
- Pilot projects should be established to verify the key assumptions with respect to cultivation requirements and crop performance, specifically in the Ceres Karoo.
- Re-assessment of the viability of the potential new irrigation schemes as new information and insights become available.

A draft programme of activities and proposed responsibilities are given in **Table 9.1**.

Table 9.1 : Draft programme for further work

Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Responsibility
Catchment Management									
Create advisory committee									DWAF
Establish Catchment Management Agency									DWAF
Develop Catchment Management Plan									Catchment Management Agency
Riverine Ecology									
Classification of rivers									DWAF
Biological data collection									DWAF
Chemical data collection									DWAF
Hydrological measurement									DWAF
Prepare information for IFR determination									DWAF
Initial IFR determination									DWAF
Review of IFR									DWAF
Estuary									
Data collection									DWAF
Background documentation									DWAF
Determination of flow requirements									DWAF
Social									
Detailed needs and preferences assessment									Provinces (and district councils)
Data base on prospective farmers									Provinces (and district councils)
Training needs and programmes									Provinces
Requirements for successful settlement									Provinces
Develop farmer settlement models									Provinces
Agricultural									
Establish pilot projects									Provinces
Verify production requirements and yields									Provinces
Review markets and prices									Provinces
Engineering/Financial									
Investigate groundwater combined use									DWAF
Resource potential upstream of Clanwilliam									DWAF(W.Cape)
Review water availability									DWAF
Review viability of developments									DWAF/Provinces



OLIFANTS / DORING RIVER BASIN STUDY

Irrigable Soils **A-1**

APPENDIX A

OLIFANTS/DORING RIVER BASIN STUDY REPORTS

Report number	Title
PE000/00/0298	Physical Characteristics and Land Use
PE000/00/0398	Water Resources Evaluation : Hydrology
PE000/00/0498	Soils and Irrigation Potential Investigation
PE000/00/0598	Water Resources Development Options
PE000/00/0698	Financial Viability of Irrigation Schemes
PE000/00/0798	Water Quality Assessment
PE000/00/0898	Hydrology and Groundwater Resources
PE000/00/0998	Reservoir Sedimentation
PE000/00/1098	Social Impact Study
PE000/00/1198	Public Participation
PE000/00/1298	Synthesis of Environmental Studies

APPENDIX B

KEY MEMBERS OF THE PROJECT TEAM:

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Mr P Huizinga	CSIR Stellenbosch	Estuary
Dr Prof J King	Southern Waters	Natural environment

Department of Water Affairs and Forestry
Directorate of Project Planning

PE000/00/0898

OLIFANTS / DORING RIVER BASIN STUDY

Hydrogeology and Groundwater Resource Report

March 1998

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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

DIRECTORATE OF PROJECT PLANNING

OLIFANTS/DORING RIVER BASIN STUDY

HYDROGEOLOGY AND GROUNDWATER RESOURCE POTENTIAL OF THE OLIFANTS/DORING RIVER BASIN, WESTERN & NORTHERN CAPE PROVINCES

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OLIFANTS/DORING RIVER BASIN STUDY

HYDROGEOLOGY AND GROUNDWATER RESOURCE REPORT

EXECUTIVE SUMMARY

Umvoto Africa cc was appointed by Ninham Shand (Pty) Ltd as a sub-consultant to BKS (Pty) Ltd) in order to undertake a desk-top hydrogeological investigation for the Olifants/Doring River Basin Study, which had been commissioned by the Department of Water Affairs and Forestry (DWAF) in order to quantify aspects of water resource development in the catchment. The terms of reference to Umvoto Africa specified that the initial step in the groundwater study should involve a "brief review of the resource in terms of :

(a) present level of exploitation;
(b) potential for further exploitation;
(c) .. restraints on use on account of water quality".

The study area covers the E100, E200 and E400 catchments, which have a total area of 48500 km^2.

Following an outline of the geological history and stratigraphy (Section 5 and Table 5.1.1), the stratigraphic units of hydrogeological significance are identified, *viz.*, the Table Mountain Group (TMG), and to a lesser extent the Bokkeveld and Witteberg Groups, within the Cape Supergroup, the fractured sandstone formations of the Ecca Group and Beaufort Group within the Karoo Supergroup, the Karoo dolerite intrusions, and the alluvial formations of the Sandveld Group. Each aquifer is later (Section 8) systematically discussed with regard to the level of abstraction, water quality and potential for further exploitation.

Groundwater is currently abstracted from the TMG in reasonably large volumes from high-yielding thermal artesian boreholes (confined aquifers) and also from moderate to low yielding subartesian boreholes of ambient ground temperature. In the Citrusdal valley (E100) the volume abstracted is on average 8 million cubic meters per annum in the summer months (November-April), and in some areas between September and May. Abstraction in the E200 basin is not well quantified and figures obtainable from large scale irrigation farmers in the Agter Witzenberg area (E200) were not made available in time for this study. The TMG water quality is of relatively low pH (unbuffered character), and contains very low total dissolved solids (TDS). There are no inhibiting factors as regards water quality for either irrigation or domestic use.

Groundwater is abstracted from the Bokkeveld Group (Witteberg Group information is lacking in the study area) where the water has an electrical conductance (EC) below 360 mS/m, generally from fractured zones which also intersect the underlying TMG aquifer (hydraulic connection inferred). Bokkeveld groundwater is otherwise potentially problematic due to higher salinity.

Groundwater is abstracted in the Karoo aquifers for supplementary supply to municipalities (e.g., Calvinia), and also for general stock watering and domestic use. Other than for the municipal supply the abstraction figures are not well documented. The groundwater is variable in quality, depending upon whether it is derived from the fractured Ecca and Beaufort sandstones, the Karoo dolerites, or the superficial (alluvial/weathered zone) aquifers. The best quality water, characterised as fresh, is obtained from the fractured-rock aquifers associated with dolerite and other magmatic intrusions. In general, however, the quality of groundwater derived from various aquifers in the Karoo Supergroup, covering the eastern E200 and the whole E400 catchment, is poor or very poor due to a high salinity. The groundwater potential of the Tankwa Dolerite Dyke (*cf.* Figure 5.1.2), and its role in the regional flow patterns should be assessed further.

In the Olifants/Doring River basin any *large-scale, environmentally sustainable* development of the groundwater resource must necessarily concentrate on the TMG fractured-rock aquifers, which are a dominant element in the mountainous topography of the E100 and western E200 catchments, and therefore exert significant orographic control over rainfall and groundwater recharge patterns. Major tectonic features within the TMG, such as fold axes (Olifants River Syncline and Cedarberg Anticline), kinematically related large-scale fault structures (NW/SE-striking Ceres-Verlore Vlei and Twee Riviere-Liepoldtville "megafault" [CVM and TLM] systems, extending laterally over distances of the order of 100 km), and other structural features (NW/SE-, NE/SW and E/W-trending master-joint sets identified from photogeological interpretation, localized intrusive dykes), provide possible preferred flow paths and/or barriers to the movement of groundwater. In order to understand their significance for the groundwater potential, a summary of the abovementioned main structural features is presented (Section 6 and Figure 5.1.2).

Evidence for the very deep flow of groundwater in the main TMG aquifers, closely linked to major structural features, is provided by natural hot springs in the area (E100 catchment particularly) and borehole occurrences of thermal waters (*cf.* Section 7). The geological observations are interpreted in terms of a (long-established but neglected) *confined artesian basin model* for the TMG in the Olifants River Syncline, which is supported by recent oxygen and hydrogen isotope studies in the Cape Fold Belt, including the Citrusdal valley. The main recharge area for the artesian reservoir is in the higher reaches of the Koue Bokkeveld mountain range, straddling the E100-E200 catchment divide. A possible natural ("bypass") discharge across parts of the western E100 divide with the adjacent G drainage basin is postulated.

The groundwater potential available for sustainable abstraction is estimated (Section 9) using mean annual recharge maps of the Water Research Commission (WRC), the WRC Groundwater Component of River Flow (Base Flow) map, and reference material from other studies in the TMG aquifers. The sustainable yield in the E100 basin is estimated to be between 80 (very conservative) and 260 million cubic meters per annum, depending upon the recharge figure used and the base flow component. Using published theoretical values for fractured rock, as well as an idealised empirical model of groundwater flow between and within the E100 and E200 basins, the hydraulic conductivity (K) of the major fracture zones is estimated to be between 1 - 10 m/day. The storativity coefficient of the confined TMG aquifer is assumed to be about 0.001.

Among the main conclusions (Section 10) and recommendations (Section 11) are the following :

(1) The existing pattern of groundwater exploitation is best known in parts of the E100 basin, but usage is fragmented among individual landowners, unsystematic and unevenly monitored. Groundwater is a supplementary supply in the peak irrigation period (November to April inclusive) without which the farmer is unable to sustain the trees through the summer, or as a reserve or emergency supply. The contribution of groundwater to economic development is large;

(2) The main potential for future large-scale exploitation is found in the headwaters part of the E100 catchment, also the south-western part of the E201 catchment, where the groundwater target is the zone of "rejected recharge" or overflow, expressed by cold springs around the upper contact of the main TMG aquifer;

(3) The opportunity exists to exploit the confined artesian, high-yielding character of the main TMG aquifer by careful hydrogeological exploration aimed at specific fracture zones of demonstrably high hydraulic conductivity, close to intersections with the upper confining (Cedarberg shale) layer;

(4) The most important groundwater restraint, common to most of the Doring River basin (E200 and E400 areas), is provided by the high salinity (TDS) in groundwaters from shale-bearing Bokkeveld, Witteberg and Karoo aquifers;

(5) A preferred exploitation of the water resource in the study area (as well as in the greater Western Cape) is a management strategy which optimises the conjunctive use of both surface water and groundwater, but further well-planned hydrogeological studies, based particularly around (a) the quantification of the base-flow contribution, (b) the mapping of structural controls on the TMG fractured rock aquifers, and (c) the hydrogeochemical (isotopic) characterization of groundwater reservoirs and recharge sources, are needed.

(6) For Integrated Catchment Management strategy and planning, as well as for Water Conservation planning, it is necessary to quantitatively determine, in terms of volume and cost, the implications of conjunctive water usage. This also needs to be determined for a scenario of only surface water usage. It will involve, determining the evaporation losses on a mean annual as well as a cyclical climatic basis, the evapotranspiration rates of the local flora, and the comparative environmental and potential financial costs and risks associated with different approaches to the use of the water resource. At present 500×10^6 m^3/a excluding surface runoff is unsatisfactorily accounted for.

(7) It is traditionally assumed in the Western Cape, but never satisfactorily quantified, either in general or for specific areas, that abstracting groundwater produces either, no net gain to the water resource, or an undetermined nominal gain, due to evaporation losses in surface water storage. It would appear that if the periodicity of the rainfall pattern, local climate, and the usage patterns are taken into account, there is a minimum net gain (arguably up to 30 and 50% due to evaporation loss and a variable, but generally high, percentage due to dam siltation) in the study area, as well as a longer term water conservation and potential capital gain.

(8) Groundwater is primarily used when the surface water is either routinely insufficient or the supply fails due to drought conditions. What is a certainty is that extreme drought conditions are experienced in this country. It would clearly be of benefit to consider an Integrated Catchment Management strategy which accounts and plans, as appropriate, for conjunctive water resource management for the E100 basin as well as for the Western Cape.

OLIFANTS/DORING RIVER BASIN STUDY

HYDROGEOLOGY AND GROUNDWATER RESOURCE REPORT

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3. SCOPE OF WORK

The scope of work involves only a desk study and brief review of available information. The following report thus includes a concise summary of

1) Geology and Hydrogeology

2) Aquifers
   - location
   - nature
   - quality

3) Existing boreholes and groundwater use (where information is available)
4) Potential target areas for optimum groundwater resource development.

4. LOCATION, PHYSIOGRAPHY AND CLIMATE

The study area is centred around latitude 32,5°S, longitude 19,5°E. It includes the towns of Citrusdal and Clanwilliam. Nieuwoudtville and Calvinia are located close to its northern boundary, and Klawer is close to its north-western corner (Figure 4.1.1). It is bounded by the Winterhoek and the Olifantsrivierberge ranges along the western divide, and the Great Escarpment along the eastern boundary. The area incorporates the Koue Bokkeveld and Cedarberg mountain ranges along the internal divide between the Upper Olifants River (E100) and Doring River (E200) drainage basins.

4.1 CATCHMENT AREAS

The Olifants and Doring River catchments form the major part of the E drainage region (Figure 4.1.2). The total E catchment area is variously given as 46 625 km^2 or 46 084 km^2 (different sources cited by Morant, 1984) and 48 500 km^2 (Kovacs, 1980), and its mean annual run-off (MAR) is 122 x 10^6 m^3 (Midgeley & Pitman, 1969, cited in Morant, 1984) . It is subdivided into four secondary drainage basins (E100-E400). The E300 area (Krom-Hantams-Doring-Sout-Hol system; Figure 4.1.1), which has a catchment area of 17 167 km^2 above the gauging station at the Olifants confluence near Lutzville (Kovacs, 1980), was omitted from the terms of reference of this study as no significant development options were located in this region. The remaining three secondary catchments, namely, the E100 (Upper Olifants), E200 (Doring), and E400 (Oorlogskloof), having a combined area of about 31 333 km^2 (after Kovacs, 1980), are further considered here.

4.1.1 Upper Olifants (E100) Catchment

The E100 catchment has an area of 2 659 km^2 above the gauging station near the Bulshoek Dam (E1M01; Kovacs, 1980). It has no further internal subdivision (Figure 4.1.2). Proclaimed mountain catchment areas exist in the Winterhoek (81 427 ha) and the Cold Bokkeveld (96 348 ha) (Morant, 1984, p. 10). Along the E200 divide it includes State Forest areas and the Cedarberg Wilderness area. The E100 catchment lies within the winter rainfall area which has a Mediterranean climate. The average annual rainfall at Citrusdal in the central part is 365 mm (Weather Bureau records, cited in Diamond, 1997). It contains two major dams, at Clanwilliam and Bulshoek (Figure 4.1.1) with capacities of 127 x 10^6 m^3 and 7,5 x 10^6 m^3, respectively (Morant, 1984, p. 11).

4.1.2 Doring (E200) Catchment

The total area of the E200 and E400 catchments upstream from the gauging station near the confluence (E2M03; 31°51'S 18°41'E) is given as 24 044 km^2 (Kovacs, 1980). The E200 region is further subdivided into four quaternary drainage regions (E201-E204; Figure 4.1.2) The E201 catchment includes the upper Doring, Riet and Groot rivers (Figure 4.1.1) and has an area of 6 903 km^2 (Kovacs, 1980) above the Aspoort gauging station (E2M02; 32°30'S 19°32'E). The E202 catchment covers the Tankwa River and its tributaries (Figure 4.1.1), and has an area of 6 426 km^2 (*op. cit.*) above the gauging station near its confluence with the

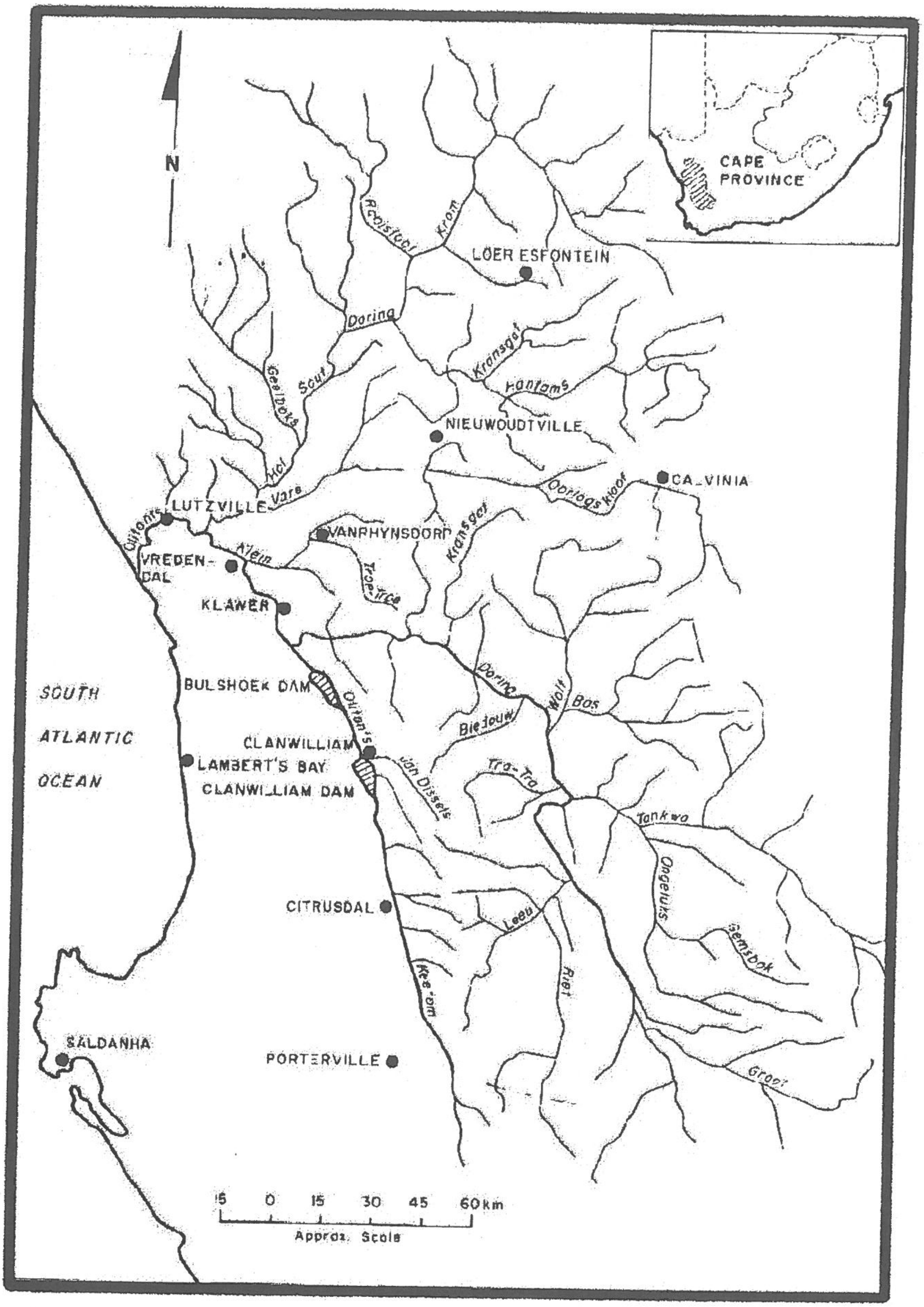

Figure 4.1.1 : Location and drainage pattern of the Olifants River system (from Morant, 1984)

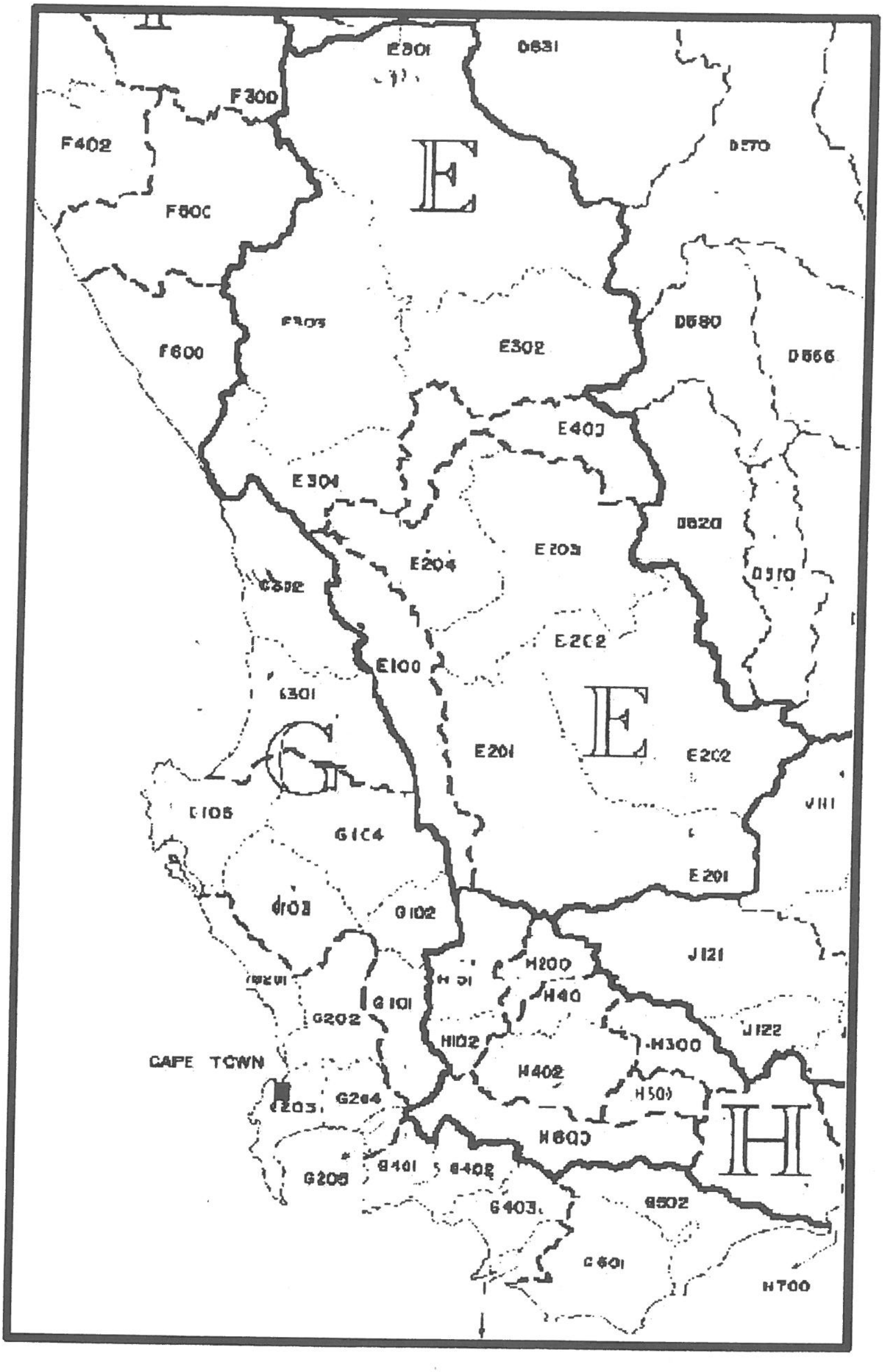

Figure 4.1.2 : Quaternary drainage regions of parts of the Western Cape and Northern Cape Provinces (after Department of Water Affairs and Forestry)

upper Doring (E2M04; 32°19'S 19°35'E). The E203 catchment covers the middle reach of the Doring, and its west bank (Tra-Tra, Biedouw) and east bank (Bos-Wolf) tributaries. The E204 catchment covers the lower reach of the Doring and one north bank tributary (Kransgat River), the other major north bank tributary being the Oorlogskloof River (E400; Figure 4.1.1 and Figure 4.1.2). The combined E203-E204-E400 area is about 10 715 km^2 (after Kovacs, 1980).

The E region has a semi-desert or poor steppe climate in which rainfall is unreliable and rarely exceeds 250 mm per annum (Schulze, 1965). Monthly run-off figures show an extreme variability; 1922-1960 records from Aspoort reveal minima as low as one-tenth and maxima of up to 4,5 times the mean monthly flow rate in winter (Morant, 1984, Figure 5.1.2). On 1925 June 17 the Aspoort measuring station recorded a peak flow rate of 2 124 m^3/s (Kovacs, 1980, Appendix 1), during the major winter flood which shaped the present estuary mouth (Morant, 1984). Summer floods also occur because of thunderstorms arising along the Karoo border region. A Doring River flood event in 1981 was the result of the same extreme rainfall conditions that concurrently devastated the Karoo town of Laingsburg in the adjacent J drainage region (Morant, 1984, p. 11-12).

Because it mainly drains easily-eroded Dwyka Formation tillites and Ecca Group shales and sandstones (see Section 5.2.3 below), the E200 sub-catchment is the primary source of silt to the lower Olifants River and its estuary (Morant, 1984).

4.1.3 Oorlogskloof (E400) Catchment

The Oorlogskloof (and Koebee) River is a significant northern tributary of the Doring River, hence its incorporation into the present study. The town of Calvinia is located in the eastern part of this catchment, and provides a case study in the potential of groundwater as a municipal supply (Woodford, 1994). Area statistics and rainfall statistics have not been obtained for this region.

5. STRATIGRAPHY AND HYDROGEOLOGY

5.1 OUTLINE OF GEOLOGICAL HISTORY

The geology of the Olifants/Doring Basin (Figure 5.1.1) is dominated by sedimentary rocks of the Cape Supergroup and the lower part of the Karoo Supergroup (Table 5.1.1). Small exposures of pre-Cape metamorphic rock (Vanrhynsdorp Group) occur in the north-western corner, along the lower part of the Oorlogskloof (Koebee) River and around the Doring-Olifants confluence. The north-eastern corner of the area contains exposures of intrusive Karoo dolerite dykes and sills. Alluvial deposits correlated with the Sandveld Group occur along certain stretches of the Olifants and Doring Rivers.

The geological history of this area (Table 5.1.2) begins with the rifting of a former supercontinent, and the opening of the Adamastor Ocean basin about 750 million years ago (750 Ma). It continues today with the current episode of seafloor spreading in the South Atlantic ocean. The Great Escarpment still evolves by processes of margin-normal scarp retreat and margin-parallel flexural warping. The Olifants/Doring River drainage basin has developed between the coastline and the Escarpment under strong bedrock-compositional and -structural controls imposed by the tectonic grain of the N/S-trending Cedarberg folds (Table 5.1.2).

5.2 LITHOSTRATIGRAPHY AND AQUIFER CLASSIFICATION

The nature and composition (lithology) of each of the different stratigraphic units (Table 5.1.1) is here considered from a purely hydrogeological viewpoint, with regard to the relative permeability of the unit, and its corresponding classification either as aquifer, aquitard, or aquiclude.

TABLE 5.1.1a : STRATIGRAPHY AND LITHOLOGY OF THE KAROO AND POST-KAROO SEQUENCES IN THE OLIFANTS-DORING BASIN

LITHOSTRATIGRAPHY			LITHOLOGY	THICKNESS (M)
GROUP	SUBGROUP	FORMATION		
Sandveld		various	alluvium, gravel, sand	?
major erosional unconformity				
Drakensberg		Lesotho (?)	dolerite	?
higher units of Karoo not represented here				
Beaufort	Adelaide	Abrahamskraal	reddish-purple mudstone, siltstone, sandstone	100?
Ecca		Koedoesberg	sandstone	180
		Kookfontein	shale	350
		Skoorsteenberg	sandstone	<100
		Tierberg	shale	460
		Whitehill	Mic. sandstone, siltstone	65
		Prince Albert	Fossiliferous shale, siltstone	<120
		Dwyka	Sandstone, siltstone	120
major regional unconformity				
Cape Supergroup and pre-Cape formations (see Table 5.1.1b)				

TABLE 5.1.1b : STRATIGRAPHY AND LITHOLOGY OF THE CAPE AND PRE-CAPE SEQUENCES IN THE OLIFANTS-DORING BASIN

LITHOSTRATIGRAPHY			LITHOLOGY	THICKNESS (m)
GROUP	SUBGROUP	FORMATION		
Witteberg	Lake Mentz (Dl)	Waaipoort	shale, silstone, mudstone	80
		Floriskraal	quartzitic sandstone	60
		Kweekvlei	shale , siltstone	100
	Weltevrede (Dw)	Wittepoort	massive quartzitic sandstone	310
		Swartruggens	sandstone, siltstone	280
		Blinkberg	sandstone	140
		Wagendrift	sandstone, shale	140
Bokkeveld	Bidouw (Dbi)	Karoopoort	shale	50
		Osberg	sandstone	50
		Klipbokkop	shale	170
		Wuppertal (C2Q4)	Mic. sandstone, siltstone	65
		Waboomberg (C2S4)	Fossiliferous shale, siltstone	200
	Ceres (Dc)	Boplaas (C2Q3)	Feldsp. sandstone, siltstone	30
		Tra-Tra (C2S3)	Micaceous shale, mudstone	85
		Hexrivier (C2Q2)	Feldsp. sandstone, siltstone	100
		Voorstehoek (C2S2)	Shale, siltstone, mudstone	115
		Gamka (C2Q1)	Sandstone, siltstone	135
		Gydo (C2S1)	Fossiliferous shale, siltstone	160
Table Mountain	Nardouw (Sn)	Rietvlei (C1Q2)	Sandstone, siltstone	120
		Skurweberg (C1Q2)	Sandstone	120
		Goudini (C1Q2)	Sandstone, siltstone	160
	(Ope)	Cedarberg (C1S2G)	Shale	120
		Pakhuis (C1S2G)	Diamictite, sandstone	40
		Peninsula (C1Q1)	Sandstone	1150
	(Op)	Graafwater (C1S1)	Siltstone, shale	100?
		Piekeniers (C1Q1R)	Conglomerate, sandstone	100+?
major regional unconformity				
Vanrhynsdorp	Kwanous (Nkn)	various	mixed clastic	?
	Gifberg (Ngi)	various	mixed clastic & carbonate	?
Malmesbury	Boland (Npo)	Porterville (MaS)	Slate, phyllite, greywacke	?

TABLE 5.1 2 : OUTLINE OF GEOLOGICAL HISTORY

AGE (Ma)	EPISODE	DESCRIPTION
0 to ~130	seafloor spreading in the **South Atlantic ocean**	erosion and land-surface development along south-western African continental margin
135 ~175	**Palmer Land Orogeny**	major normal and oblique strike slip faults (Worcester and Cango megafaults), possibly also the N/S Cedarberg folds and "syntaxis", complex microplate rotations, extensional opening of narrow back-arc oceanic basins, compressional deformation of surrounding terranes in between Africa, South America and West Antarctica;
~180	**Gondwanaland breakup** (onset)	eruption of the Drakensberg flood basalts; concurrent intrusion of Karoo dolerite dykes and sills
~220 ~250 ~251 ~260	**Gondwanide Orogeny**	compressional tectonics, major E/W fold and thrust-fault structures of the **Cape Fold Belt;** fluviatile strata deposited in lower Beaufort Group from meandering continental river systems arising in the Gondwanide mountains to the south; rapid deposition of sandstones from turbidity-current flows into the deep-marine Ecca basin resurgence of subduction-related tectonism; appearance of thin, wind-blown, volcanic ash beds within the lower Ecca shales (from extensive areas of volcano-plutonism in parts of Patagonia);
~300	**Dwyka Ice Sheet**	deposition of a major tillite
	Mild uplift and erosion	significant regional pre-Karoo conformity; hiatus in subduction/orogeny
~350	**Famatinian Orogeny** ("Chanic phase")	deposition of Bokkeveld and Witteberg groups; subduction-related tectonism along active margin of Gondwanaland
~440	("Ocloyic phase")	deposition of the Table Mountain Group; accretion of "suspect" Occidentalia Terrane to western South America ends **Gondwanaland** assembly
~480	Uplift and erosion	peneplanation of Vanrhynsdorp rocks
~540 -520	**Saldanian Orogeny**	subduction, collision, mountain-building between the Southern African crustal block and island arcs of southern South America
750	**Adamastor Ocean** opening	rifting of a former ("Rodinia") supercontinent

Olifants/Doring Basin Geology

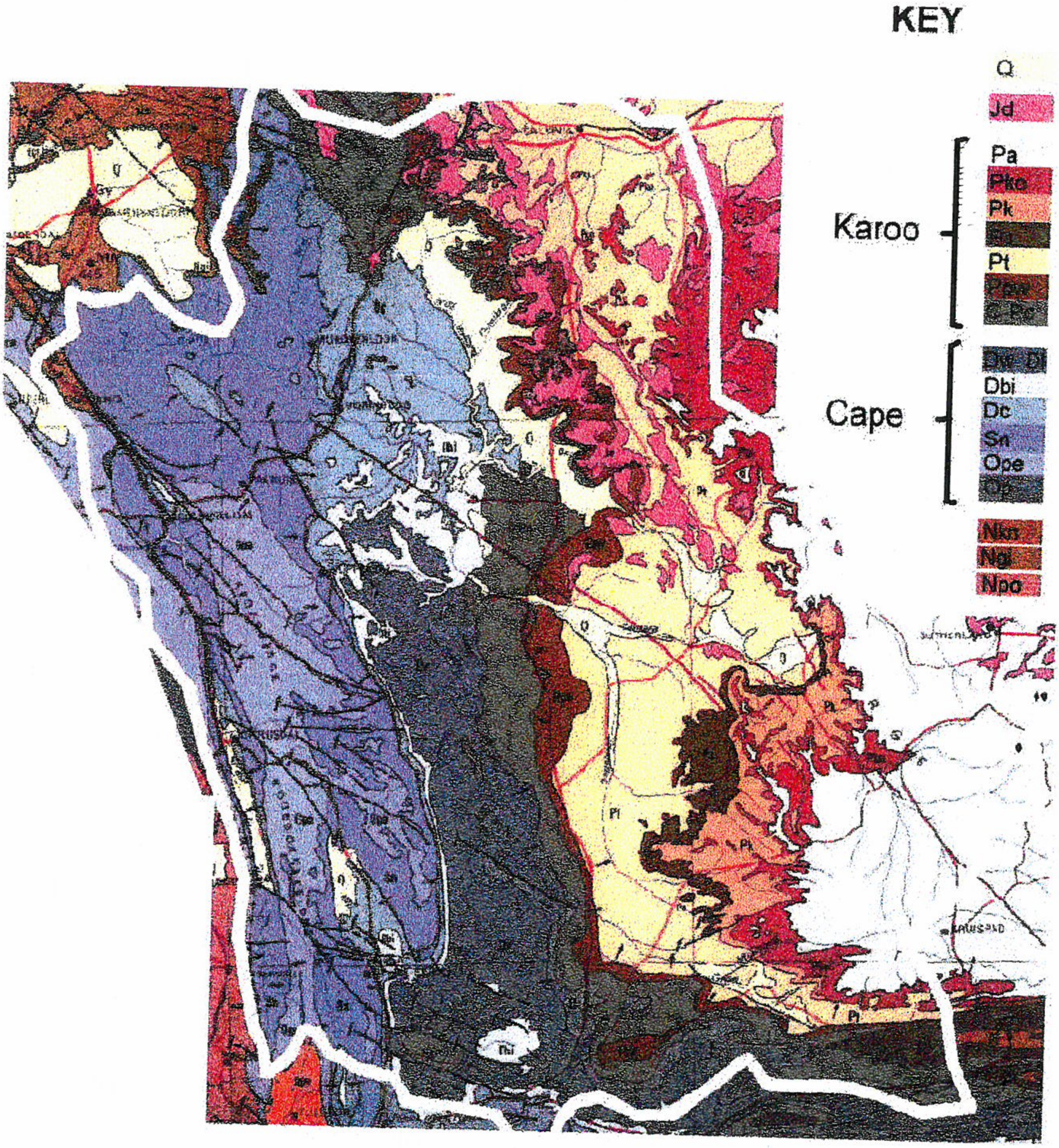

Figure 5.1.1 : Geology of the Olifants/Doring River Basin (after 1:1 million scale Geological Map of the Republic of South Africa, 1984 edition)

Olifants/Doring Basin Geology

Main Structural Features

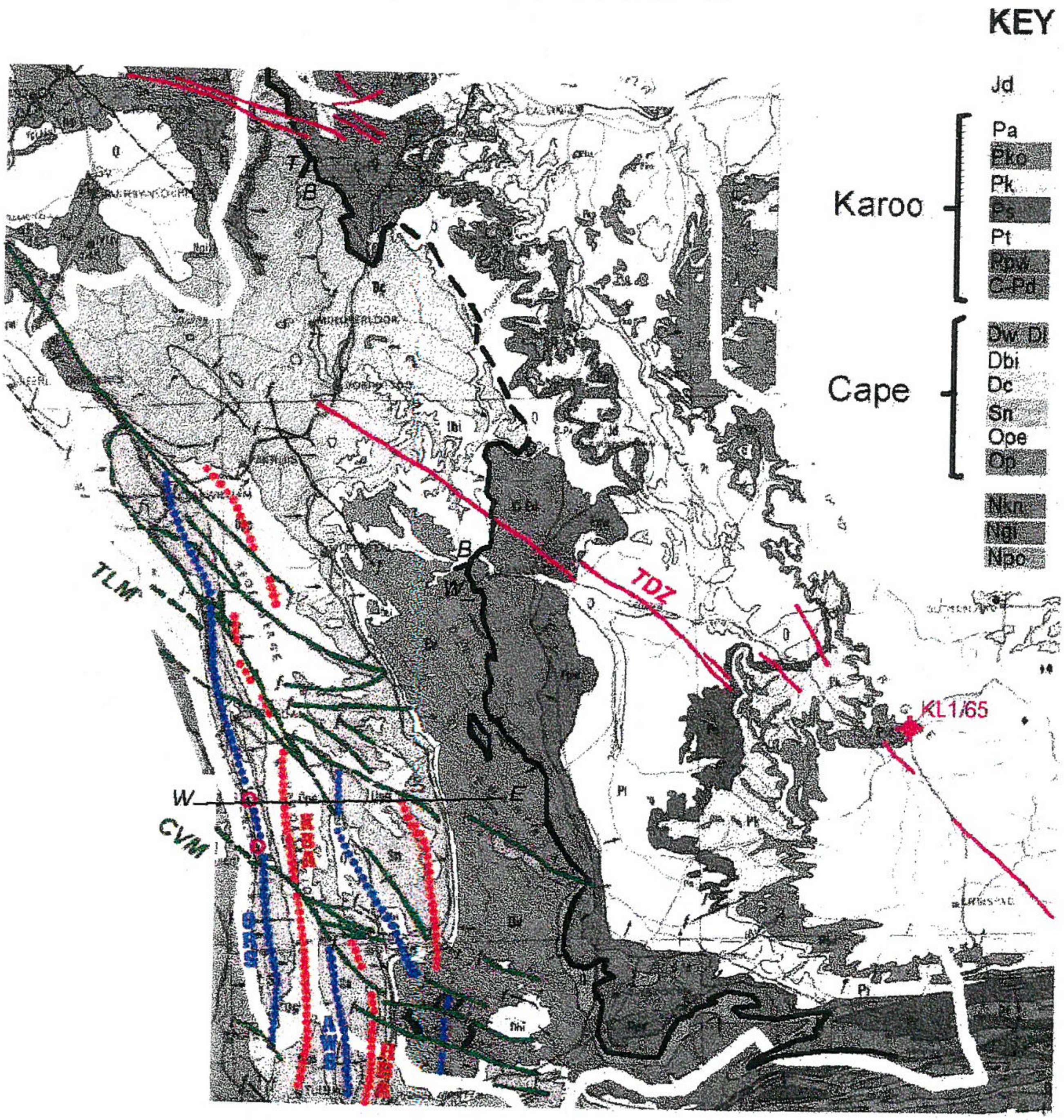

Figure 5.1.2 : Main structural features of the Olifants/Doring River Basin (adapted from the 1:1 million scale Geological Map of the Republic of South Africa, 1984 edition)

5.2.1 Vanrhynsdorp Group and Malmesbury Group

In the north-western part of the basin, the Gifberg Subgroup (Ngi on Figure 5.1.1) is separated from the Kwanous Subgroup (Nkn; Figure 5.1.1) by the south-eastern extension of the Arizona Fault (Gresse, 1992). Beyond the south-western border of the Olifants River basin, the Porterville Formation (Npo; Figure 5.1.1) underlies the Table Mountain Group. None of these units has any hydrogeological significance for the present investigation. They are generally impermeable aquicludes.

5.2.2 Cape Supergroup

This major unit is comprised of three principal stratigraphic groups.

Table Mountain Group
The eight formations of the Table Mountain Group (TMG; Table 5.1.1) include three major fractured-rock ("secondary") sandstone aquifers, separated by two shale-bearing units which locally act as confining layers for groundwater flow. The Piekeniers Formation (Op; Figure 5.1.1) is the basal aquifer unit (TMG-0), overlain by the Graafwater Formation (too thin for representation on Figure 5.1.1, shown only as upper boundary of Op).

The Peninsula Formation and overlying Pakhuis Formation (together shown as Ope on Figure 5.1.1) constitute the middle aquifer unit (TMG-1), confined above by the Cedarberg Formation. The Peninsula Formation is the topographically dominant unit, building most of the high mountain ranges, and is hydrogeologically most important in having

(1) the *widest areal extent* in the areas of maximum precipitation and recharge potential;
(2) the *greatest sub-surface volume* of permeable fractured rock.

The Nardouw Subgroup (Sn; Figure 5.1.1) is the top aquifer (TMG-2), confined above by the lowermost shale unit in the overlying Bokkeveld Group.

Bokkeveld Group
Subdivided into a lower Ceres Subgroup (Dc; Figure 5.1.1) and upper Bidouw Subgroup (Dbi; Figure 5.1.1), this major unit of eleven formations (Table 5.1.1) is dominated by shaly strata, and has little significance as an aquifer, except where the intercalated sandstone formations have become fractured and relatively porous in the near-surface (generally <50 m depth) weathered zone or "regolith".

Witteberg Group
The seven formations of the Witteberg Group (Table 5.1.1) are divided between a lower Weltevrede Subgroup (Dw; Figure 5.1.1) and an upper Lake Mentz Subgroup (Dl; Figure 5.1.1). Although the Wittepoort Formation and the Floriskraal Formation are dominant fractured sandstone units in the lower and upper parts of the sequence (Table 5.1.1), the group as a whole has marginal hydrogeological significance.

5.2.3 Karoo Supergroup

The Karoo strata dip gently towards the east above a regional unconformity (*thicker black line* in Figure 5.1.2) that cuts downward through the Cape stratigraphic sequence in a northerly direction, crossing the Witteberg-Bokkeveld contact (marked B/W) and the Bokkeveld-TMG contact (marked T/B) (Figure 5.1.2).

Dwyka Formation

The Dwyka tillite (C-Pd; Figure 5.1.1) is compact with a very low permeability. It is regarded as an efficient aquiclude, sealing the aquifers of the Cape Supergroup at the top, and thus forming a stratigraphic trap against the deeper regional migration of fluids northward into the main Karoo basin from the southern mountain recharge areas of the Cape Fold Belt.

Ecca Group

The lower three formations of the Ecca Group (Table 5.1.1) are easily weathered and erodible shale units of very low hydrogeological significance. The Prince Albert Formation and Whitehill Formation (Ppw; Figure 5.1.1) in particular are characterised by black carbonaceous shales with a high pyrite content. The Whitehill Formation decomposes to a gypsum-bearing regolith (Visser & Theron, 1973), with deleterious implications for groundwater quality. Confined within a localised area in the E202 drainage region, along the Roggeveld escarpment mainly south of the Tankwa River, the Skoorsteenberg Formation (Ps; Figure 5.1.1) and Kookfontein Formation (Pk; Figure 5.1.1), contain thin sandstone strata which may have greater hydrogeological potential as a shallow fractured-rock aquifer. The overlying Koedoesberg Formation (Pko; Figure 5.1.1) is a more extensive, thicker-bedded sandstone unit forming the higher cliff topography along the escarpment top in the eastern E201 and E202 drainage regions.

Beaufort Group

The reddish-weathering sandstones and siltstones of the Abrahamskraal Formation (Adelaide Subgroup; Pa in Figure 5.1.1) are confined to the higher eastern areas of the E201 (Groot River headwaters) and E202 (Tankwa) drainage regions. Hydrogeologically they are of only localized significance.

5.2.4 Karoo Dolerites

North of the Tankwa River, in drainage regions E202, E203 and the eastern part of E400, dolerite sills (Jd; Figure 5.1.1) have been emplaced subhorizontally within the Prince Albert and Whitehill formations, and in the lower part of the Tierberg Formation. The main magma feeder systems for these sills occur as long NW/SE- to WNW/ESE-trending dykes along the Tankwa River, and in the Nieuwoudtville-Calvinia area (Figure 5.1.2). The fractured contact zones and narrow metamorphic aureoles of the dolerite dykes or sills often serve as aquifers in the Karoo.

5.2.5 Sandveld Group

The deposits consist of alluvial sands and gravels around the main drainage channels (yellow-toned areas in Figure 5.1.1).

6. STRUCTURAL GEOLOGY AND HYDROTECTONICS

Because the hydrogeology is dominated by "secondary" or fractured-rock aquifers, an understanding of structural controls on groundwater movement is fundamental to appreciating the groundwater potential of the area, in particular the E100 basin and E200 basin. Major tectonic features, such as fold axes, fault structures, and intrusive dykes form possible preferred flow paths (hydrotects) and/or barriers for water (cf. Figure 5.1.2).

[A hydrotect - a term coined, as far as we are aware, by a Scandinavian hydrogeologist - is here (re)defined as a distinct planar or linear tectonic feature - such as a fracture, a fault, a line of intersection between planar structures, or a fold closure - which is characterised by a hydraulic permeability that is greater by orders of magnitude relative to the surrounding country-rock matrix.].

6.1 HEX RIVER SYNTAXIS STRUCTURES

A convergent bundle of folds in the Ceres District swings from N/S trends in the Kouebokkeveld ranges in the south-western part to ENE/WSW trends in the Hex River Mountains at the far southern end of the E drainage region. The structurally controlled high topography of the syntaxis zone forms the southern boundary divide between the Olifants/Doring Basin and the Breede River catchment.

6.2 CEDARBERG FOLDING

The Kouebokkeveld and Olifantsrivierberge ranges form part of the N/S-trending Cedarberg fold belt, the structurally controlled topography of which forms the south-western boundary divide of the E drainage region.

6.2.1 Olifants River Syncline

The major N/S-striking fold structure is the Olifants River Syncline (blue dotted line marked ORS; Figure 5.1.2), divided by a hinge-zone culmination around Kriedouwkrans, ~35 km north of Citrusdal, into two distinct axial troughs, the Citrusdal Trough and the Clanwilliam Trough, both floored by rocks of the Bokkeveld Group. The profile shape of the ORS (cf. the slightly exaggerated cross-section in Figure 6.2.1) and its sense of asymmetry change where it is obliquely transected by NW/SE-trending faults, which implies a close kinematic relation between the faulting and at least the later phases of fold development.

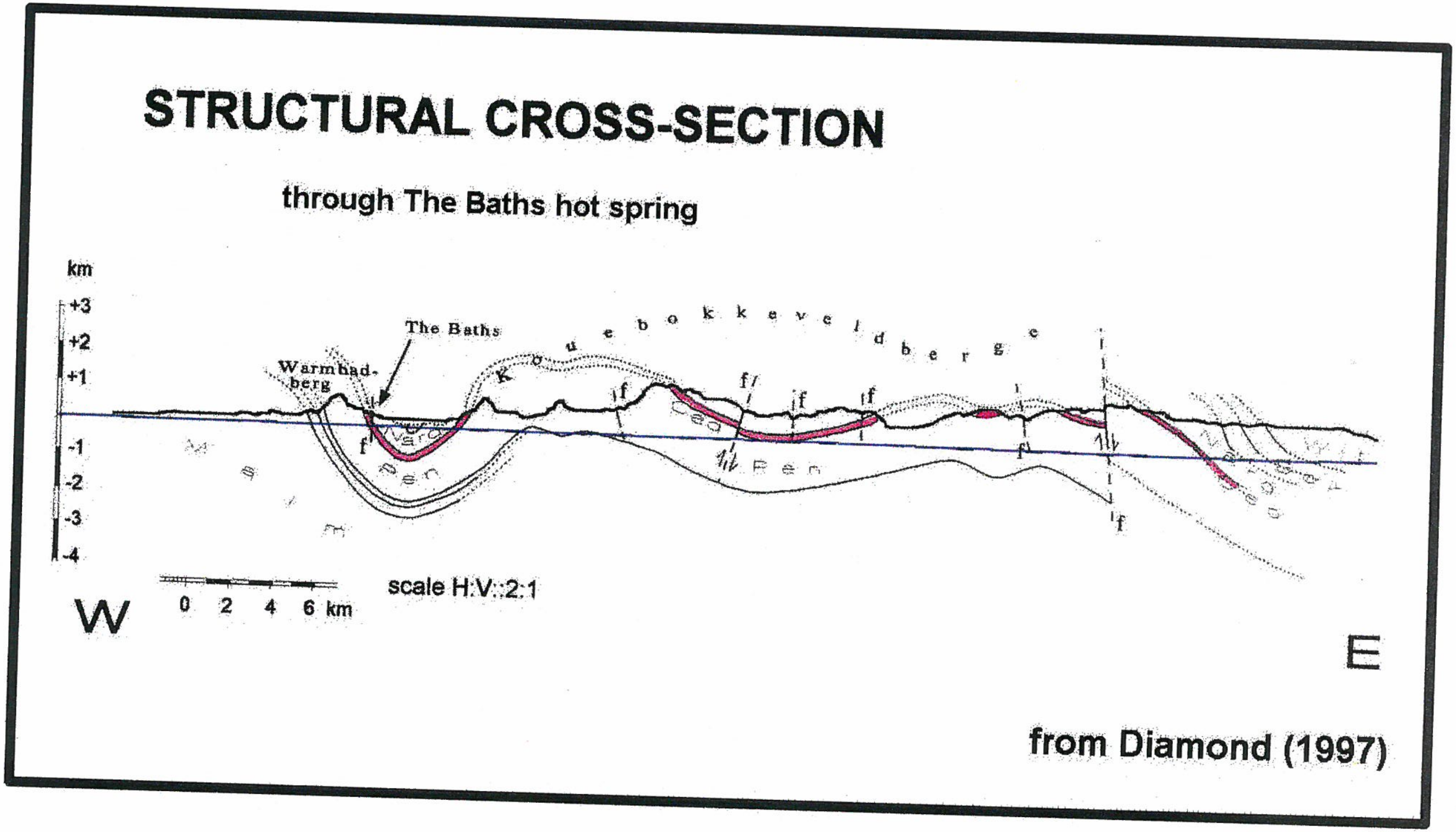

Figure 6.2.1 : Structural cross-section drawn west to east through The Baths hot spring location from the Olifantsrivierberge to the Tankwa Karoo (from Diamond, 1997).

6.2.2 Other Major Folds

East of the ORS, there are less continuous fold structures (Figure 5.1.2). Only a broad open anticline forms the backbone of the Cedarberg Range alongside the Clanwilliam Trough. East of the Citrusdal Trough, three major folds terminate or change shape northwards along a NW/SE-striking fault system. From east to west, these are :

(a) the Hansiesberg Anticline (orange dotted line marked HBA);

(b) the Agter-Witzenberg Syncline (blue dotted line marked AWS);

(c) the Kouebokkeveld Anticline (orange dotted line marked KBA) (cf. Figure 5.1.2).

The zone of generally west-dipping strata between structures (1) and (2) above is no longer evident on the northern side of the fracture system. The three fold structures are thus replaced by the single anticlinal structure along the axis of the Cedarberg range. The Kouebokkeveld Anticline apparently terminates near or along a parallel NW/SE-striking fault which crosses the eastern limb of the Citrusdal Trough in the Boschkloof area.

6.3 MAJOR FAULT SYSTEMS

NW/SE-striking faults in the south-western part of the Olifants/Doring basin form a sub-parallel, possibly continuous, interconnected system, extending over distances of more than 100 km.

6.3.1 Ceres-Verlore Vlei Megafault Zone

The Ceres-Verlore Vlei Megafault (belt of green solid lines marked CVM; Figure 5.1.2) extends between Op-die-Berg in the northern part of the the Ceres district and Verlore Vlei near Elands Bay (Umvoto Africa, 1995a, p. 5), and crosses the ORS in the Thara Kamma (Keerom) area. Its westerly extension across the broad anticlinorium of Malmesbury Group basement rocks is problematic because of poor exposure.

6.3.2 Twee Riviere-Liepoldtville Megafault Zone

At the Kriedouwkrans culmination, the ORS hinge zone is locally offset by intersecting NNW/SSE- and WNW/ESE-striking faults which apparently form part of a much larger NW/SE-striking fault system, suggested to be continuous over a total length of ~100 km, between Twee Riviere and Leipoldtville (Umvoto Africa, 1995c, p. 8). This Twee Riviere-Liepoldtville Megafault (belt of green solid lines marked TLM; Figure 5.1.2) possibly extends farther north-westward to the coast near Lamberts Bay. It is partially linked to the southern CVM fracture belt by the Middelberg Fault zone in the mountains east of Citrusdal (Figure 5.1.2).

6.4 MAJOR JOINT SETS

NW/SE-, NE/SW and E/W-trending joint sets are identified in air-photogeological interpretation (API) studies along the E100 and E200 catchment boundary, undertaken for borehole siting purposes (unpublished Umvoto Africa cc reports, 1994-1997).

6.5 TANKWA DOLERITE DYKE ZONE

Dolerite intrusions that cut through the Karoo and pre-Karoo basement rocks over long distances (of the order of 100+ km) are possible crust- or lithosphere-penetrating feeder dykes to the abundant sill complexes in the Karoo basin. Such major vertical feeders are actually rarely encountered. The Tankwa Dyke Zone (solid red line marked TDZ in Figure 5.1.2) is one such noteworthy structure.

Hydrogeologically the TDZ could act as a lateral barrier to the horizontal groundwater migration of deep thermal waters in the TMG and other sub-Karoo aquifers. Its marginal fracture systems could also provide vertical migration channels of relatively high hydraulic conductivity, that may locally breach the basal Karoo (Dwyka) aquiclude, and promote a substantial leakage of deep artesian water across the Cape Karoo stratigraphic boundary.

7. DEEP GROUNDWATER FLOW IN THE TMG AQUIFERS

Evidence for deep regional flow of groundwater in TMG aquifers is widespread in the Cape Fold Belt. Notable instances occur within the E100 and E200 drainage sub-regions.

7.1. NATURAL THERMAL SPRINGS

7.1.1 The Baths Hot Spring Resort

At The Baths hot spring near Citrusdal (northern red circle along the ORS structure on Figure 5.1.2), groundwater emerges in large volumes (~105 000 l/hr or ~30 l/s) at a temperature of 42,9°C.

The spring location is structurally controlled at the intersection of the basal Cedarberg shale contact with a ENE/WSW-striking transverse fault, extending in an easterly direction towards and probably linking with the TLM fracture zone. There is also a conspicuous belt of E/W-striking sub-vertical master joints and fractures in the mountains on the opposite (eastern) side of the Olifants River. The recharge area for The Baths hot spring is clearly in the Kouebokkeveld mountains on the eastern side of the ORS (cf. Figures 6.2.1 and 7.2.1), for no other feasible explanation exists for the high temperature of its waters.

Geopressured artesian conditions exist in the TMG-1 "fractured-rock" aquifer beneath the confining aquiclude of the Cedarberg Formation, forcing a deep (>2 km) transverse circulation of groundwater beneath the synclinal axis (Figure 7.2.1). This occurs obliquely to the N/S-trending ORS fold axis, along discrete pathways or "hydrotects" of greatly enhanced hydraulic conductivity, generally associated with the major megafault (CVM and TLM) zones.

7.1.2 Warmwaterkloof

In Warmwaterkloof (southern red circle on Figure 5.1.2), well south of The Baths, the stream is warmed to a temperature of at least 27°C by the concealed emergence of unknown quantities of hotter water near the basal contact of the Cedarberg Formation, where the latter is transected by a small, roughly E/W-striking fault. The Warmwaterkloof hot spring lies close to the main trace of the NW/SE-striking CVM fracture zone (Figure 5.1.2).

7.2 BOREHOLE OCCURRENCES OF THERMAL WATERS

Further pertinent cases of thermal artesian waters are provided from the E100 drainage region by the Kingston 1 and DK5 boreholes, and in the eastern part of the E210 drainage sub-region by the KL1/65 oil-exploration well.

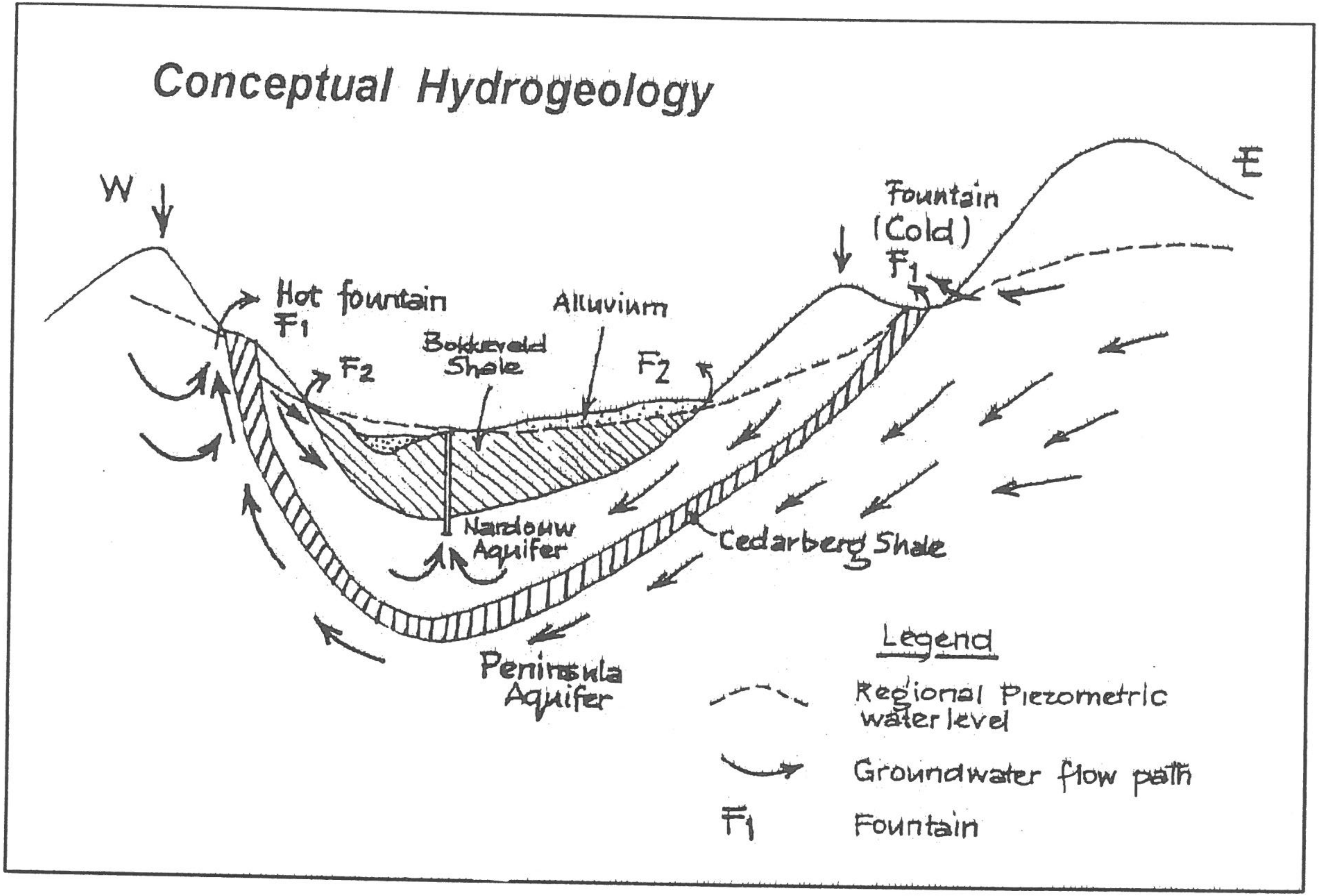

Figure 7.2.1 : Conceptual hydrogeology of the Table Mountain Group (TMG) aquifers in the Olifants River Syncline

7.2.1 Kingston 1 and Satellite Wells

Kingston 1 was sited (~1995) by persons unknown on the farm Koornlandskloof , ~10 km south of Citrusdal, in footwall fault-breccia outcrops along an E/W striking fault near the top of the TMG-1 aquifer. Drilled to a depth of only 85 m, it has an artesian flow of 3,8 ℓ/s at a temperature of 29°C (pH = 5,5; TDS = 70 mg/ℓ), and supplies a commercial bottling plant with water (Murray & Rosewarne, 1996)

Further artesian boreholes were subsequently drilled (November 1995) into the TMG-1 aquifer along the fault zone in the neighbourhood of the Kingston 1 well. The SRK 5 borehole, drilled close to the Kingston 1 site to a depth of 108 m yields an artesian flow of 1,2 ℓ/s from the deepest strike (93 m) at a temperature of 26°C (*op cit.*; 28°C measured during an Umvoto Africa cc reconnaissance on 1996 November 26).

7.2.2 DK5 Borehole

The DK5 borehole site was indicated as a groundwater target in the Die Kom area on the western side of the valley during a groundwater investigation commissioned by the Citrusdal Municipality (Umvoto Africa cc, 1995a,b). It was collared in the lower part of the Cedarberg Formation, and drilled through that unit into the underlying Pakhuis/Peninsula Formation (TMG-1) to a depth of ~150 m. It now produces an artesian flow (~5 ℓ/s) of warm (23,7°C) groundwater.

The elevated temperature, and stable (hydrogen and oxygen) isotope characteristics of the DK5 groundwater (E R Hay, C J H Hartnady and C Harris, unpublished data, 1997) which are comparable to those of the hot (42,9°C) groundwater from The Baths spring (Diamond, 1997), indicate that the borehole is in (probably imperfect or partial) connection with the deep confined aquifer. Improved siting of a deeper (>250 m) well, with due regard to the local structural controls provided by fault and joint systems, has a strong probability of producing a high (>10 - 20 ℓ/s) artesian yield of warm to hot (>25°C) groundwater from the Die Kom area.

7.2.3 KL1/65 Soekor Well

Within the E200 drainage basin, the KL1/65 borehole, drilled in 1965 by Soekor (Pty) Ltd at Klipdrift near Sutherland (red crossed circle on Figure 5.1.2), struck an artesian flow (1,2 ℓ/s) of highly saline thermal water (76,7°C; TDS = 10 010 mg/ℓ) in jointed TMG quartzitic sandstone at depths between 2 347 m and 3 184 m below surface (Kent, 1969). The borehole is close to the south-eastern end of the Tankwa dyke zone (TDZ in Figure 5.1.2), which may be a controlling structural factor in the occurrence, migration, and trapping of thermal waters at this locality.

The KL1/65 thermal-water strikes recall a similar historical accident to the deep borehole at Zwartkops, near Port Elizabeth. It was drilled in the Bokkeveld Group in a speculative 1920s oil exploration venture, when - at a depth of 1 036 m - a large artesian flow (13,1 ℓ/s) of hot water (54,5 °C) was struck and subsequently developed into a leading spa resort (Kent, 1949, p. 248).

7.3 HYDROGEOLOGICAL INTERPRETATION

The hydrogeological significance of the deep, artesian, thermal water strikes in the Zwartkops and KL1/65 boreholes is the same as that provided by the natural hot springs in the Western Cape region, of which Brandvlei (126 ℓ/s or 3,7 x 10^6 m^3 per annum at 64 °C) and Goudini Spa, near Worcester, and The Baths, near Citrusdal, are outstanding examples :

(1) The groundwater in the TMG aquifers circulates freely to great depths in the upper crust of the Cape Fold Belt;

(2) It can be tapped to surface in large volumes from depths at which conventional hydrogeological theory declares the hydraulic conductivity of fractured rock to be reduced due to lithostatic (i.e., rock overburden) pressure by 3-4 orders of magnitude, from ca. 10^{-5} m/s to 10^{-8}-10^{-9} m/s (Banks et al., 1996, Figure 3(b)).

Clearly other extrinsic factors in the Cape Fold Belt play a role in overwhelming the usual rock pressure effect. These geological factors are probably related to either or both of the contemporary ("neotectonic") crustal stress regime and the modern geothermal gradient. Neither of these aspects of Western Cape geology is well studied and thoroughly understood.

Near Citrusdal, the Kingston 1 and DK 5 strikes of tepid groundwater are important because they extend the potential for larger strikes of deeply circulating artesian water by a considerable distance northwards along the western side of the Olifants River valley, effectively most of the Citrusdal Trough segment of the ORS. They constitute a preliminary experimental demonstration of a long-established hydrogeological concept to explain the occurrence The Baths hot spring (Kent, 1949, Figure 2 and Figure 7.2.1).

The Kingston 1 and DK5 artesian wells can be contrasted with the artesian E1 well, sunk earlier to a depth of 250 m at the Thara Kamma property (Umvoto Africa cc, 1995c). In the latter case, the target was in the footwall of the main strand of the CVM fracture structure (Figure 5.1.2), where it crosses the eastern limb of the ORS fold structure. The E1 well yields an artesian flow of ~5 ℓ/s at a normal temperature of 21 °C, because it intercepts water recharged in the Kouebokkeveld mountains on the descending leg of its flow-path beneath the ORS. A proportion of this descending groundwater overflows as "rejected recharge" from a nearby cold spring along the top of the Cedarberg aquiclude in the hangingwall of the CVM structure.

The emergence of voluminous quantities of deep geothermal (i.e., hot to scalding) water at several natural springs in the Western Cape region (Kent, 1949) is the most remarkable aspect of the hydrogeology of the TMG fractured-rock aquifers. Joubert (1970, p. CV1) remarked that the "underground water reserve (in the TMG aquifer) of the southern Cape Province is its single most important natural resource ... (which) should be properly exploited." He provided the following general guidelines for hydrogeological exploration :

> "Regional fracture systems serve as high permeability zones, along which almost unlimited supplies of high quality water may be expected. ... Boreholes should be sited on fault structures, and should be drilled at least several hundred feet deep for optimum results. ... With increase in depth boreholes increase in yield, and many ultimately become artesian."

In spite of this optimistic early assessment, the TMG aquifer has not recently received due and adequate attention to research and exploration. The Western Cape System Analysis (Ninham Shand, 1994), a "comprehensive study ... to ascertain a basis for the development of future water supplies", disregarded it after an initial review.

7.4 CONFIRMATORY ISOTOPE STUDIES

Recent stable-isotope ($^{18}O/^{16}O$ and D/H) investigations of several thermal springs in the Cape Fold Belt (Diamond, 1997) indicates that the precipitation of the recharge water for the springs is "occurring from a more fractionated water and vapour mass, under colder and possibly more humid conditions, such as at high altitude" (*op. cit.*, p. 75). Samples taken during an earlier study (1971/1972 collection) are isotopically indistinguishable from the 1995 data fields, indicating that the "underground spring reservoirs are well mixed" and are "large relative to the outflow at the springs". The groundwater circulates deeply (up to 3 km below sea-level) as indicated by the outflow temperatures, probably through discrete fractures.

Another recent stable-isotope study of the hydrometeorology and hydro(geo)logy of the Jonkershoek area - where the surrounding TMG terrain constitutes the recharge area - establishes that, even under storm-flow conditions, the contribution of direct rainwater runoff to surface-water stream-flow is less than 5 per cent, the vast bulk being derived from a groundwater reservoir (Midgeley & Scott, 1994). The exact location of this reservoir and the hydraulic process or "push-through mechanism" (New & Schulze, 1996) is uncertain. The concept is, however, radically at odds with conventional hydrology, in which Hortonian overland flow is thought to account for storm-flow. Its implications for the quantitative understanding of TMG aquifer behaviour, in terms of transmissivity and storage properties, have yet to be clearly elaborated.

7.5 SIGNIFICANCE OF REGIONAL FAULT SYSTEMS IN REGIONAL FLOW PATTERNS

The Twee Riviere-Leipoldtville Megafault Zone (TLM) is hydrogeologically significant because, where it transects the TMG aquifer systems, it constitutes a potential subterranean by-pass to the coastal plain for deeply circulating groundwaters supplied by the Kouebokkeveld mountain recharge area. This hypothesis implies that a significant percentage of the deep (thermal artesian) groundwater from the E100 catchment - particularly that which may enter the lowest (TMG-0) aquifer along sections of the fold-axial crest of the Koue Bokkeveld Anticline (KBA) structure - migrates north-westward along a TML fracture-zone channel, a natural inter-basin transfer route which takes it through the G302 quaternary drainage region (Figure 4.1.2) to the lower reaches of the Jakkals River near Lamberts Bay, and thence to the Atlantic Ocean.

8. ABSTRACTION AND QUALITY

8.1 TABLE MOUNTAIN GROUP AQUIFERS

8.1.1 Groundwater Abstraction

In the course of earlier work by Umvoto Africa cc (1995-1997) a comprehensive hydrocensus was conducted over an extensive area of the Olifants River. A summary of the hydrogeological observations pertinent to the brief is as follows :

(1) Reported borehole yields are highly variable, ranging from dry to up to 35 ℓ/s. The distribution of borehole yields has a binomial character, i.e, boreholes are either particularly high yielding and strongly artesian, or relatively low to moderate yielding but still often weakly artesian. There appears to be a definite pattern in the spatial distribution of the higher yielding boreholes;

(2) A large proportion of the deeper boreholes (>100 m) are weakly artesian. In some instances this artesian nature is reported as diminishing in the summer months, the water table then falling to between 0.5 m and 6 m below surface. This probably depends on the pumping regime as well as on the borehole location and depth. In general the weakly artesian nature of a borehole is not indicative of a good yield, and many artesian boreholes have reported yields of less than 5 ℓ/s. Conversely, all high yielding boreholes (> 20 ℓ/s) are relatively strongly artesian in nature and deeper than 150 m. There are limited exceptions to this;

(3) Springs or seeps occur under two distinct hydrogeological settings :

(a) Springs occur at the contact between the Peninsula and Cedarberg Formations, especially in conjunction with major linear structures;

(b) Seeps occur throughout the area at the contact between the Nardouw sandstone and Bokkeveld shale. The confining nature of the Bokkeveld Shales is further reflected by the presence of weakly artesian boreholes drilled into the Bokkeveld near this contact. Such boreholes appear to have penetrated the underlying Nardouw. The evidence of structural control on these seeps is not conclusive;

(4) Temperature of the borehole water in the Nardouw and the Peninsula sandstones varies between 21°C and 28°C. Above 25°C is considered to be a high temperature for groundwater, particularly given the relatively shallow depths of the boreholes concerned. This is an indication that certain boreholes have intercepted major features which act as conduits for deeper flowing groundwater;

(5) Farmers are abstracting a minimum of 4 million m^3 of water per annum and up to 12 million m^3 per annum, primarily between November and April but in some areas from September to May. It is estimated that approximately 120 000 cubic meters of

groundwater is used per annum at a bottling plant. The Baths is not quantified since no information exists as to the runoff after use;

(6) While groundwater has traditionally been used as a reserve supply, it is increasingly being used as a supplementary source and as a source for extending the area under cultivation. It is used in areas where either the river allocation is too little or it is used where the cost of piping from the river is not competitive.

8.1.2 Groundwater Quality

In terms of water quality the previous hydrocensus results from the Citrusdal district indicated the following :

(1) Electrical conductivity (EC), which is an indication of the total dissolved solids (TDS) in groundwater, is generally very low and of an acceptable nature in samples obtained from boreholes drilled in the TMG-1 and TMG-2 aquifers. It varies slightly between 9 mS/m and 16 mS/m;

(2) EC obtained from springs arising in the Peninsula Formation is generally higher than the borehole water, i.e., 23 mS/m or more.

The TMG groundwater thus has a low to very low TDS, but also a low pH because of its unbuffered character.

8.1.3 Potential Restraints

There is mixing of the waters between the TMG-2 aquifer and aquifer zones in the overlying Bokkeveld shale. This results in poorer quality water in the TMG-2 aquifer along the contact zone. Given the inferred hydraulic gradient along this contact, it is expected that the water quality will improve with depth.

The low pH of TMG groundwater renders it prone to chemical reaction with iron-bearing formations, soils, or piping around boreholes. This can lead to the onset of the growth of iron bacteria, which needs to be managed through appropriate pump cycles.

8.2 BOKKEVELD AND WITTEBERG GROUP AQUIFERS

8.2.1 Groundwater Abstraction

The Bokkeveld and Witteberg strata are considered to be aquifers of lesser importance, both in terms of groundwater quality and quantity. The main groundwater potential is generally in the shallow weathered or regolith zone. Groundwater occurrence within the Bokkeveld is variable, and there does not appear to be a clear correlation between the depth of groundwater interception and the recorded yield. The higher yields are probably obtained on discrete, steeply dipping, and easily observed fracture structures The relatively narrow nature of the target results in highly variable depths of intersection. The orientation of these structures is also important, an E/W strike apparently being optimal.

8.2.2 Groundwater Quality

EC measurements obtained from groundwater in the Bokkeveld shales are high and very variable. Measured values vary between 40 mS/m and 84 mS/m, but some farmers report the water as being unacceptable for human or animal consumption which generally implies an EC greater than 200 mS/m.

Salinity and the danger of salinization of soil is the main restraint on usage of groundwater from boreholes which penetrate the Bokkeveld shales. Where fracture systems in the Bokkeveld formations appear to be continuous in the underlying TMG aquifer the groundwater quality improves (e.g. Ceres area).

8.3 KAROO AQUIFERS

Groundwater is intercepted in three distinct geological situations (Seward 1981 and Woodford 1994):

1) alluvium
2) fractured sedimentary rocks on the margins of dolerite and other intrusions
3) within intrusions.

The character of intrusions varies. In the Calvinia area municipal well points are sited on relatively small diameter circular intrusions with particularly subtle surface expression (Woodford 1996, personal communication in the field). The geological context of the Tankwa dyke and geological variations along strike merit further attention, given the artesian nature of the KL1/65 borehole at its eastern end.

8.3.1 Groundwater Abstraction

In 1994 (Woodford, 1994) it was recommended, based on pump test results, that production boreholes would be capable of "delivering approximately 266 000 cubic meters of groundwater per annum, of which only 122 000 cubic meters/annum is fit for domestic consumption without treatment /blending to Calvinia " Fresh water production would be as high as 135 000 cubic meters. The municipal supply is a successful conjunctive system using water from the Karee Dam supplemented by groundwater. Abstraction from the alluvial aquifers is dealt with below.

8.3.2 Groundwater Quality

In the Calvinia area of the E400 drainage region it is found that approximately half of the available groundwater resources are unfit for direct human consumption (Woodford, 1994), on account of salinity problems (TDS >2000 mg/ℓ). No samples in the database have a TDS of less than 400 mg/ℓ (*op.cit.*, Appendix C). Locally there is a further complication of a high fluoride content (>1,5 mg/ℓ). As the Karoo geology around Calvinia is continued southwards through the E203, E202, and E201 areas, it is anticipated that poor groundwater quality is common to the whole of the eastern part of the Doring River drainage area.

Analyses of surface water in the Doring catchment (E200) indicate a TDS generally in the range of 401 mg/ℓ to 800 mg/ℓ, prompting an irrigation classification for this basin in terms of "increasing problems" (Geldenhuys et al., 1991, Figure B5). The surface water chemistry of this arid drainage region is probably affected by a base flow dominantly from the areally extensive, near-surface, groundwater compartments in weathered and fractured Karoo host-rocks. The poor surface water quality in the E200 area probably indicates that the groundwater quality is substantially worse, bearing out the inference drawn above from the Calvinia database.

8.4 ALLUVIAL AQUIFERS

Groundwater is commonly stored at shallow depths in semi- to unconsolidated alluvial sands and gravels. Borehole yields are variable, depending on grain size and thickness of the deposits, and adequate well development (i.e., removal of fines from the formation adjacent to the borehole).

8.4.1 Groundwater Abstraction

In the E100 region, alluvial deposits along the middle reaches of the Olifants River vary between 6 m and 20 m in thickness. Some boreholes in the valley-floor setting have intercepted partially saturated alluvial deposits along the banks of the Olifants River but the water yielding capacity of this potential aquifer remains uncertain because it is a common practice to case off such sections of the borehole.

In the E201 subregion, alluvial deposits occur around the upper reaches of the Leeu River, overlying a major syncline of Bokkeveld strata, but no specific information has been obtainable.

In the E202 subregion, alluvial deposits along the lower reaches of the Tankwa River are schematically shown to be “exploited” for groundwater (Vegter & Seymour, 1995, Sheet 1). The 1:250 000 geological map (Visser & Theron, 1973) shows numerous "waterpoints" (waterbronne) around the ephemeral watercourses draining into the Tankwa from its south (left) bank. Others occur in the Springbokvlakte on the north bank (e.g., one even named "Brakbosfontein"). These are all assumed to be shallow boreholes and wells into alluvium or highly weathered regolith on Dwyka tillite and lower Ecca shale. This groundwater source is presumably vital to the practice of low density sheep grazing in this area. No available source of further quantitative information has been located during the present study.

In the E203 sub-region, similar "waterpoints" are shown within and around alluvial deposits along the Bos and Wolf Rivers (Visser & Theron, 1973). No further information on these occurrences is available.

Information on alluvial abstraction from the E204 and E400 regions is still lacking.

8.4.2 Groundwater Quality

The alluvial aquifers lie between the surface-water channels and the shallow Karoo aquifers and therefore are characterised by the same chemical features of high TDS and low pH.

9. GROUNDWATER RESOURCE POTENTIAL

Consideration of future large-scale development of the hydrogeological resource potential in the Olifants-Doring basin must necessarily focus on the TMG aquifers to the virtual exclusion of the others. The reason is best illustrated in those parts of the recently published Water Research Commission (WRC) maps of "Groundwater Resources of the Republic of South Africa" (Vegter & Seymour, 1995) covering the Olifants/Doring River Basin.

The key map of "Borehole Prospects" (*op. cit.*, Sheet 1) classifies the resource in terms of its "Accessibility" (probability of drilling a successful borehole) and its "Exploitability" (probability of a successful borehole yielding >2 ℓ/s). The TMG aquifers in the E100 catchment and along the south-western boundary of the E200 catchment receive the highest ratings in South Africa, >60% in terms of accessibility and >50% in terms of exploitability (Figure 9.1). Furthermore the E100 basin is an ideal case study area for the entire TMG aquifer.

9.1 WATER BALANCE AND RECHARGE

The WRC "Mean Annual Recharge" map indicates recharge in the range 25-37 mm for the northern part of the E100 catchment (north of Citrusdal) and in the range 37-75 mm for the southern part. If a figure of 40 mm per annum is conservatively assumed to apply over a catchment area of approximately 2 000 km^2 upstream from the gauging station near Clanwilliam, then the corresponding annual recharge volume within the entire E100 area is approximately 80 x 10^6 m^3. In the E100 area upstream from Citrusdal the WRC "Groundwater Component of River Flow (Base Flow)" map (Vegter & Seymour, 1995, Sheet 2) indicates a range of 25-50 mm for the annual mean groundwater component.

The mean annual rainfall measured at Citrusdal over a 23-year period is 365 mm (Diamond, 1997, Table 3.1, p. 18). If this is assumed to be representative of the entire ~2000 km^2 catchment area, then it indicates a mean annual precipitation volume of 730 x 10^6 m^3. The mean annual run-off for this part of the catchment, calculated from the record at the E1H011-Q01 gauging station (Clanwilliam Dam,) is 212 x 10^6 m^3 (Swart et al., 1991). On the basis of these figures, the maximum potential recharge is ~520 x 10^6 m^3.

If evapotranspiration from the unsaturated zone, the soil moisture deficit, and other unspecified losses remove 50% of this potential, one is still left with a recharge of 260 x 10^6 m^3, which is equal to 28% of the precipitation figure. Experience in similar parts of the Cape Fold Belt recharge is expected to vary between 10% and 30% of the rainfall depending upon its intensity (e.g., the Klein Karoo; Kotze, 1995). The winter rainfall pattern in the E100 basin is such that one would expect a recharge in the upper part of the range given.

Borehole Prospects over part of the E Drainage Region

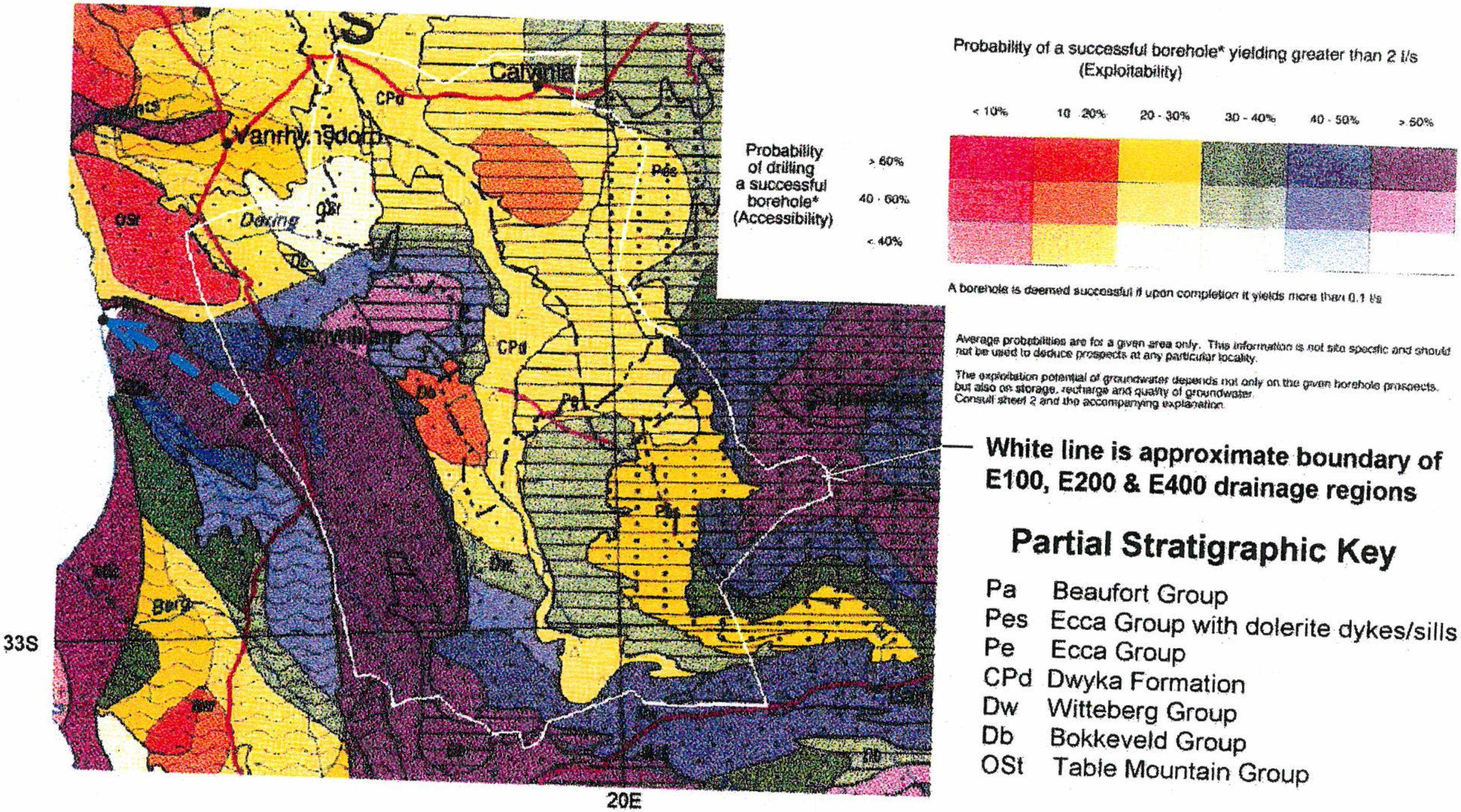

Figure 9.1 : Borehole prospects over part of the E drainage region (adapted from Vegter and Seymour, 1995)

9.2 AQUIFER PARAMETERS

9.2.1 Storativity

A storativity (S) of <0,001 is estimated for TMG aquifers on the WRC "Saturated Interstices" map (Vegter & Seymour, 1995, Sheet 2). An S value of 10^{-3} is assumed here as being a reasonable estimation for the confined TMG-1 aquifer, being at the upper end of the 10^{-5} to 10^{-3} range usually given (e.g., Driscoll, 1986, p. 737). This is equivalent to regarding the whole TMG aquifer as an "effective porous medium" of clean- coarse-sandstone character on the 1000-m thickness scale. On this basis, a 1-km thick aquifer folded into a 10-km-wide, 90 km long syncline, would contain a water volume of about 900 million cubic metres in confined storage.

9.2.2 Hydraulic Conductivity

Theoretical Range

The range of hydraulic conductivity in "fractured igneous and metamorphic rocks" is generally given as 10-10^{-3} m/day (Driscoll, 1986, Figure 5.14, p. 75). The TMG quartzitic sandstones are actually fractured low-grade metamorphic rocks of brittle, highly siliceous, un- or hardly weatherable character. Thus the fractures are likely to be open and unclogged. The hydraulic conductivity (K) value for the TMG-1 aquifer may accordingly be taken to be in the higher part of this range, say 1-10 m/day.

Empirical estimate

An order-of-magnitude calculation based on an idealised Darcian-flow model for The Baths hot spring can be used to cross-check the above K-value estimation. The spring is at an elevation of ~300 m on the western side of the Olifants River valley and is observed to have a flow rate (Q) of 30 ℓ/s. The potentiometric surface in the Kouebokkeveld Mountains recharge area, about 10 km distant on the eastern side of the valley, is in the 700-900 m elevation range, so that the hydraulic gradient (i) driving the east-to-west deep flow is at least ~0.04 (40 m/km).

Applying Darcy's law ($Q = Kbwi$) involves making idealistic assumptions about the effective thickness (b; vertical depth range) and the effective width (w) of the fracture network (treated as an effective porous medium) that supplies the hot spring. The thickness may range up to the total thickness of the TMG-1 aquifer, i.e., 1 150 m (Table 5.1.1), between the Graafwater and Cedarberg aquicludes. The effective width (w) of the "hydrotect" structure, considered as a Darcian conduit, is simply taken to be in the 1-10 m range. Solving the Darcy equation for K with the above variables yields a range of 56 m/day ($w = 1$ m and $b = 1\ 150$ m) to 5,6 m/day ($w \rightarrow 10$ m or $b \rightarrow 115$ m). This range brackets the higher end of the theoretical or textbook range given in the paragraph above.

10. CONCLUSIONS

The brief for the present desk-top study was to provide information on

- the present level of exploitation
- the potential for further exploitation
- the restraints on use on account of water quality
- preliminary estimates or inferred values of basic hydraulic parameters for those aquifers considered suitable for further exploitation.

These are key aspects for future planning of both groundwater exploration, abstraction and management in the context of sustainable water resource planning and development in an Integrated Catchment Management (ICM) context. The relevant conclusions from available information and data are summarised below. Recommendations as how to proceed with further quantification of these key aspects are outlined in the following section.

10.1 PRESENT LEVEL OF EXPLOITATION

- The pattern of exploitation is best known in parts of the E100 basin. Based on all recorded borehole data and assuming that the boreholes are only used in the peak irrigation period it is estimated that an average of at least 8×10^6 m^3 per annum are currently being abstracted from the TMG aquifers in the E100 basin.

- Groundwater usage is fragmented among individual landowners and therefore often unsystematic and unevenly monitored. Current abstraction figures, which are incomplete, indicate that where groundwater is integrated into the farming and irrigation planning as much as 434 484 m^3/yr of groundwater is used by one property owner who owns several farms in the Citrusdal valley and as little as 77 760 m^3/yr by another.

- There are two main aspects to the usage pattern. These show some variation depending upon the situation of the farm with respect to the Olifants River and with respect to the situation along the river course of tributaries to the Olifants River.

- *The primary pattern in the E100 basin is to use groundwater as a supplementary water supply in the peak irrigation period from November to April inclusive*, (in some areas this time period may be mid-January to mid-April or November to March end). In general, without this supply the farmer is unable to sustain the trees through the summer. It has been stated that "a good borehole can replace a dam" (Mr Dirk Visser, Hexrivier Citrus (Pty) Ltd. pers. comm; August 1997).

- *The secondary pattern is to use groundwater as a reserve or emergency supply.* The abstraction figures are very variable and incomplete in that it is not routinely measured.

- *A new pattern has emerged in the last two years : farmers are now exploiting groundwater as a long term water resource for extending the area of land under cultivation, either because they do not have the river allocation or because the land is too far from the river. Boreholes have been drilled solely for this purpose.* The hydrocensus figures in this regard are incomplete.

- Karoo aquifers are used for stock water, domestic supply and to supplement municipal supplies. The regional data and the results of the Soekor borehole KL1/65 suggest that the Tankwa Dolerite Dyke Zone extending across the entire E200 catchment warrants detailed attention as a potential supplementary or emergency water supply.

10.2 POTENTIAL FOR FURTHER EXPLOITATION

- The main area for future large-scale exploitation is in the headwaters part of the E100 catchment and also the south-western part of the E201 catchment.

- The groundwater target in this area is the zone of "rejected recharge" or overflow, expressed by cold springs around the upper contact of the TMG-1 aquifer on the eastern (Kouebokkeveld) side and by warm to hot springs on the western (Olifantsrivierberge) side of the E100 area.

- The opportunity exists to exploit the confined, artesian, high-yielding character of the TMG-1 aquifer by careful hydrogeological exploration aimed at specific fracture zones of demonstrably high hydraulic conductivity, close to intersections with the upper confining (Cedarberg shale) layer.

- Evaporation losses used for planning purposes by commercial farmers in this area are very high, minimum of 30% with some farmers using a 50% value. The advantage of water storage without such loss is self evident.

- There is debate amongst professionals as to the evaporation losses from dams in this area, some placing it as low as 10%, while putting evapotranspiration losses as high as 80%. This discrepancy is anomalous given the climate of the area and the nature of the indigenous plant kingdom (fynbos).

- The minimum net gain to the basin's water resource by accessing groundwater would be that amount lost by evaporation of surface water. This does not take into consideration the sustainable recharge to the TMG aquifer potentially available if conjunctive usage is carefully managed on an annual basis, in particular in times of drought.

- The volume of sustainable recharge is currently under debate. However what is known is that annually, of the order of 500 million cubic meters of rainfall is presently unaccounted for, and is proportioned between the sustainable recharge volume of groundwater and that lost to evapotranspiration.

- In order to realise the potential in the TMG aquifer throughout the Western Cape, it is necessary to establish well planned studies in a number of ideal type areas. In order to meet the growing water demand of the urban and rural areas, as well as the job creation demands of the rural areas, the financial resources must be made available to begin scientific efforts toward the process of resource quantification.

- Environmentally sound approaches to conjunctive surface and groundwater usage in the E100 and E201 catchments should be developed at "grass-roots" level, through an ongoing outreach programme of community and professional education and cooperation with associated studies in the area.

10.3 WATER QUALITY RESTRAINTS

- The most important restraint, common to most of the Doring River basin (E200 and E400 areas), is provided by the high salinity (TDS) in groundwaters from shale-bearing Bokkeveld, Witteberg and Karoo aquifers. There is an acceptable EC value of 360 mS/m limit for groundwater used for irrigation purpose, although irrigation practice can to some extent overcome this.

- The low pH in TMG aquifers can lead to corrosion of piping and equipment necessitating stainless pumps and piping or layflat piping. This is not an inhibiting factor with respect to large scale exploitation for irrigation or municipal purposes.

- The usually high iron content in TMG water requires management. It does not pose a serious problem for either irrigation usage or domestic usage.

10.4 AQUIFER HYDRAULIC PROPERTIES

- The storativity, S, of the confined TMG-1 aquifer is estimated at 10^{-3}.

- The hydraulic conductivity, K, of major fracture zones in the TMG-1 aquifer is estimated around 1-10 m/day, although the host-rock conductivity in un- or little-fractured domains may be more than three orders of magnitude lower ($<10^{-3}$ m/day).

11. DISCUSSION AND RECOMMENDATIONS

The main inhibiting factor to further, large-scale groundwater exploitation in the E100 and E201 basins is the presently limited experimental base of quantitative hydrogeological data on aquifer properties. This is compounded by a perception amongst some professionals that the invisible resource is being mined, that abstraction will invariably adversely affect surface water supplies and that it is inherently unquantifiable, and therefore unreliable.

The commonly perceived, but as yet unquantified risk, is the reduction of the base flow contribution to surface flow, consequent upon falling water tables in the zone of abstraction. In the E100 and the E200 basin the base flow contribution to the rivers is not directly from the (semi-) confined artesian TMG-1 aquifer except in the uppermost head water reaches, but from the unconfined TMG-2 and Bokkeveld aquifers. This is important in terms of management stategies and planning.

11.1 ALTERNATIVE WATER RESOURCE MANAGEMENT STRATEGY

- The optimal exploitation strategy in the target area is to create a substantial drawdown of the piezometric surface ("overdraft") in the (semi-) confined portions of the TMG-1 aquifer during the dry summer season, when the groundwater is needed for large-scale irrigation or municipal consumption. This will create unsaturated storage space (with zero evaporation loss) and thus minimize the rejection of the recharge in the high lying areas during the wet winter season.

- It is suggested that close attention be paid to the relationship between surface flood waters and natural discharge of groundwater under pressure during flood conditions in future water resource management strategies.

- The conjunctive management of surface water and groundwater implicit in this strategy requires further quantification of the groundwater contribution to surface flow (base flow). This entails a commitment to make the necessary resources available.

- When one considers that, in parts of the E100 drainage region alone, there are approximately 4 900 ha of arable land unused due to limitations in the surface water supply, there is a considerable cost (estimated to be minimum of R450M/annum to the Citrusdal Valley alone) of not capitalising on a major, if generally unrecognised, resource.

11.2 FURTHER HYDROGEOLOGICAL STUDIES

The purposes of an ongoing hydrogeological investigation should be :

- to undertake a detailed study of the interaction and balance between surface and ground water components in carefully selected parts of the E100 and E201 groundwater recharge and discharge areas;

- to undertake a systematic groundwater hydrocensus and a concurrent programme of rain-, surface-, spring-, and groundwater sampling for stable hydrogen ($^2H/^1H$) and oxygen ($^{18}O/^{16}O$) isotope investigations within the E100 and western E201 drainage subregions, with the ultimate aim of hydrogeochemically characterising the deep artesian thermal groundwater component, which appears to arise from a convectively well-mixed reservoir with relatively high-altitude, mountain-divide origins;

- to define accurately and quantitatively the geological boundaries and internal structures of the deep TMG fractured-rock aquifer that supplies a strong, locally focussed, groundwater flow to thermal and hypothermal springs and boreholes along the Olifants River valley flanks. In order to do this the following is required :

- locate and map the principal tectonic structures or "hydrotects" along which the deep artesian flow is channelled or preferentially conducted, on a regional scale within the E100, E201, and also the down-gradient G302 drainage subregion;

- undertake localised structural mapping to determine quantitatively the patterns of fracture orientation and fracture spatial density over a range of characteristic length scales;

- [Fracture spatial density d is defined as $d = 1/l_0^2 \, {}_{i=1}\Sigma^n a_i^2$, where l_0 is the side-length of a square sampling area and a_i is the half-length of fracture i from a sample of n fractures within the area. A minimum d of 1.5 is required to ensure that an entire fracture network percolates. Many natural networks have d over the percolation threshold, such that the "hydrogeology of many fractured sites is controlled by a finite number of major conductors" (Renshaw, 1996, p. 1526).]

11.3 WATER BALANCE STUDIES

Given that conjunctive groundwater and surface water usage is already being practised, and that this pattern will probably be reinforced if a dry period ensues, it is in the long term interests of Integrated Catchment Management and primarily water conservation that we, as water management professionals :

- determine the real evaporation losses in surface water storage facilities of different shape and sizes on a cyclical basis in the study area

- determine the evapotranspiration rate of the local flora and any spatial variations thereof

- determine on a basin scale the net sustainable and exploitable recharge to the TMG aquifer on an mean annual as well as best case and worst case climatic basis to the E100 catchment

- determine the cost implications of both the surface water losses by evaporation and the gradual siltation of dams and the capital losses potentially incurred by not integrating groundwater supply, i.e. when surface water supply is insufficient in times of drought.

- undertake a comparative cost study and initial risk analysis using both the insights of (agricultural) economists, hydrologists as well as geologists and hydrogeologists between surface water and of groundwater and the cost and risk implications of conjunctive surface and groundwater usage.

- undertake a water conservation study of the implications of optimising the periodicity of the rainfall and the abstraction cycles in an Integrated Catchment Management scenario where conjunctive water use is considered over short, medium, long and very long time periods as against an only surface water development and management with ad hoc groundwater development and uncoordinated aquifer management scenario.

- undertake a cost study of the implications of optimising the periodicity of the rainfall and the abstraction cycles in an Integrated Catchment Management scenario where conjunctive water use is considered over short, medium, long and very long time periods as against only surface water development and management with ad hoc groundwater development scenario.

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