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Conceptual Overview of the Olifants River Basin's Groundwater, South Africa.

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1. Introduction

This paper, commissioned by the International Water Management Institute (IWMI), presents an overview of the state of knowledge of groundwater issues in the Olifants River Basin in South Africa. It traces work, completed or ongoing, that has a direct or circumstantial relevance to the Olifants River Basin and presents a summary of the known state of existence of groundwater in the basin.

The paper examines both the physical presence of the underground water and, though to a lesser extent, the social exploitation of this resource. The examination of the availability of groundwater will include a general description of the aquifer types, the recharge of water to these host aquifers and the flow of groundwater through and availability for extraction from the aquifers. The study goes on to look at the quality of this water, its present use, and the extent to which there are institutional bodies managing this water. By the end of this paper the reader should have a broad overview of the extent of the importance of this valuable natural resource to the development of the Olifants river basin together with an insight into the future potential to more fully yet sustainably utilise this resource.

Overall the structure and content of the paper has been kept to a level that gives a good introduction to some of the themes relevant to the basin's groundwater reserve and acts as a platform from which to successfully manage future work.

1.1 Physical Setting

The Olifants River Basin is situated in the north east of South Africa spanning the Northern Province and Mpumalanga. Its upper streams drain the Witbank and Middelburg Highveld regions, then passes over the Springbok Flats and ends up meandering through the Lowveld to the Kruger National Park and onwards to Mozambique. In all, it covers a surface area of 54 575 km^2, receives a mean annual rainfall varying from 500 to 1000mm, has a sub-tropical climate with an average evaporation of 1682 mm/year and would produce, if unexploited, an overall surface runoff at the Mozambique border of some 1950 million cubic meters (DWAF, 1996). In 1990 the catchment supported a population of 2.5 million inhabitants (RSA Department of Water Affairs, 1991).

2. Literature Review

A great deal of work has already been carried out on the Olifants river basin. The following is a summary.

2.1 Department of Water Affairs, RSA, (1991), "Water Resources Planning of the Olifants River Basin - Study of Development Potential and Management of the Water Resources".

This publication is the culmination of a Department of Water Affairs project to create a river basin management plan for the Olifants river basin. The study was initiated in 1985, with its steering committee being established in 1987. The findings of the study were published in 1991. The main aspects addressed in the study were:

- "Quantification of the impact of catchment characteristics on the available water resources;
- Estimates of the past, present and future water requirements at the appropriate levels of security of supply;
- The availability of water supplies in the past, at present and for future development scenarios;
- Identification of shortages in water supply and of the need for future resource development;
- Aspects impacting on development opportunities;
- Proposals for meeting water requirements in the long-term; and
- Proposals for integrated water resource management."

The study resulted in a suite of reports consisting of an Executive Summary, a Main Report, eight volumes of Situation Assessments (looking at eight sub-catchments) and 28 supporting technical reports available as Annexes to the Main Report. A listing of these annexes is presented as an appendix to this paper. This 1991 report is a quite comprehensive desk study, presenting a good general understanding of the catchment's physical condition as it was known when this report was produced. It should be considered that, with groundwater moving as slow as it does and the geology with which it interacts even more so, the period of nine years since publication of this report by no means dates the knowledge presented in it.

Multiple copies of this suite of reports are available in the Library of the Department of Water Affairs and Forestry in Pretoria. The consultants involved were Theron Prinsloo Grimsehl & Pullen.

2.2 DWAF, (1999), "Pre-feasibility Study on Bulk Water Supply in the Middle Olifants and Steelpoort River Area".

This study seeks to identify and assess options available for water resource development in the southern district of the Northern Province around the Steelpoort River Valley. It has essentially five themes, namely:

1 Situation Assessment,
2 Water Demands, Land Use and Return Flows,
3 Water Resources,
4 Environmental Aspects, and
5 Planning and Development Options.

The work is ongoing and reports may be obtained from DWAF in Pretoria. The consultant involved is BKS Consultburo (Pty) Ltd.

2.3 DWAF, (1995), "Olifants-Sand Transfer Scheme - Feasibility Study".

The objective of this study was to identify the most beneficial means of developing the Olifants River for the supply of water to the town of Pietersburg and its surrounding area in the Sand River Basin. It does not focus on groundwater. However, at an integrated catchment scale, it is of interest and has chapters dealing with the following:

- Water Demands
- Environmental Considerations
- Hydrology and Yield Analysis
- Social Impact Assessment
- Effect on Infrastructure
- Engineering design (Pipeline)
- Use of Arabie Dam and Olifantspoort Treatment Works.

This report may be obtained from DWAF in Pretoria. The consultant involved was Ninham Shand Inc.

2.4 DWAF, (1995), "Middle Steelpoort River Catchment Groundwater Management Plan - Effect on Irrigation Water by Tweefontein Chrome Mine" - Draft Copy.

This is a localised study identifying potential adverse effects of the Tweefontein Mine on local groundwater, and in particular on a farm owned by JPJ Boerdery. After analysing the limited technical information available, this study established no detrimental effects.

The report is available from DWAF in Pretoria. Consultants were Wates, Meiring & Barnard Inc.

2.5 Hodgson, F.D.I.; Krantz, R.M., (1998), "Groundwater Quality Deterioration in the Olifants River Catchment above the Loskop Dam with Specialised Investigations in the Witbank Dam Sub-Catchment", WRC Report no. 291/1/98.

This extensive water quality study focuses on the uppermost portion of the Olifants river basin; from the head of the catchment to the Loskop Dam. The study was commissioned by the Water Research Commission, the Department of Water Affairs and Forestry, the Chamber of Mines of South Africa (excluding Amcoal) and Eskom in 1989 and was carried out by the Institute for Groundwater Studies at the University of the Orange Free State. The objectives of the study were:

- To "quantify the contribution of various activities which may result in a deterioration of the groundwater resources in the catchment above the Loskop Dam, with special emphasis on the Witbank Dam Sub-catchment".
- To "predict future salt loads in groundwater, based on projections of probable development in the area. Extrapolate information to other catchments that supply water to the Olifants Catchment".
- To "investigate and research improved management and precautionary measures that could be utilised to minimise groundwater quality deterioration".
- To "integrate groundwater information with other investigations in the area, including the water management programme of the DWAF, with the purpose of deriving a catchment management programme at the end of (the) project".

The study looks at the effects of Coal-Mining (both opencast and underground), Power Generation, Municipal General Waste, Sewage Effluent, the Metal Industry and Agriculture on groundwater quality and, where appropriate, quantity.

The report is available from the Water Research Commission.

2.6 Midgley, D.C.; Pitman, W.V.; Middleton (1994), "Surface Water Resources of South Africa 1990 - Book of Maps", Volume 1, WRC Report no. 298/1.2/94.

This book of maps produced for the Water Research Commission covers the Olifants river basin and gives information at a scale of 1 : 1 000 000 on:

- General Layout (Base map)
- Rainfall
- Evaporation
- Runoff
- Land cover and Water usage
- WRSM90 Model Parameters
- Geology
- Soils
- Sediment Yield
- Vegetation

The consultants who put this together were Knight Piésold (formally known as Watermeyer Legge Piésold & Uhlmann), Steffen Robertson and Kirsten Inc., and Stewart Scott Inc. This map book is available for a small fee from the Water Research Commission.

2.7 DWAF, (1997), "Overview of the Water Resources availability and utilisation in South Africa", ISBN 0 7970 3540 0.

As conveyed by its title, this is a good general summary of the water resources of South Africa. Available from the Department of Water Affairs and Forestry.

2.8 DWAF, (1995), "1:500 000 Hydrogeological Map 2326 Pietersburg".

DWAF, (1998), "1:500 000 Hydrogeological Map 2330 Phalaborwa".

DWAF, (1998) - Draft Copy, "1:500 000 Hydrogeological Map 2526 Johannesburg".

These three maps cover the hydrogeology, at a scale of 1:500 000, of the Olifants river basin. They are currently being upgraded with the Phalaborwa map being the only completed new edition. They are available from the DWAF.

2.9 DWAF, (1998), "Geohidrologie Van Die Nasionale Krugerwildtuin Gebaseer Op Die Evaluering Van Bestaanme Boorgatinlighting", Volume 1 & 2.

This report, written in Afrikaans, covers the hydrogeology of the Kruger Park in detail. It is available for reference at the DWAF.

2.10 WRC, (1995), "Groundwater Resources of the Republic of South Africa - Sheet 1: Borehole Prospects".

WRC, (1995), "Groundwater Resources of the Republic of South Africa - Sheet 2: Saturated Interstices, Mean Annual Recharge, Base flow, Depth to Groundwater, Groundwater Quality, Hydrochemical Types".

These sheets of maps cover the whole of South Africa and depict groundwater conditions on a regional scale. They are not site-specific and cannot be used for accurate borehole siting or for deducing any other site-specific condition. They do, however, provide a good regional feeling for the groundwater potential of an area. Information provided is:

- Borehole Prospects
- Saturated Interstices providing a qualitative indication of Groundwater Storage
- Depth to Groundwater
- Mean Annual Groundwater Recharge
- Groundwater Component of River Flow (Base Flow)
- Groundwater Quality
- Hydrochemical Types

They are accompanied by an explanation booklet that also provides the uninitiated person with a good basic understanding of the groundwater / hydrogeological conditions prevailing in South Africa along with the basic theory therein. Both the sheets and the booklet are available for a fee from the Water Research Commission.

2.11 DWAF, (1996), "Groundwater Harvest Potential of the Republic of South Africa".

This sheet is very similar to 2.10 above, however also provides estimates of yields that one might expect from a given surface area (m^3 / km^2 / annum).

2.12 DWAF, (1999), "Resource Directed Measure Manual", version 1.0.

This is a CD containing word documents of the soon to be issued Resource Directed Measure Manual. In its present format it is not very user friendly as one must open each file separately and there is no index as yet. The finished product is expected shortly.

3. Regional Groundwater Availability

Groundwater occurs in a geological formation known as an aquifer. To be beneficial as a water supply source an aquifer must contain sufficient permeable interconnected saturated material to yield significant[1] quantities of water to boreholes or springs. An aquifer, therefore, serves two main functions. It stores water, but also provides a conduit for the water to be transmitted to a point of exploitation.

Four distinct aquifers are present in the Olifants river basin. They are:

1 Weathered Rock Aquifers,
2 Structural or Fractured Aquifers,
3 Dolomitic or Karst Aquifers,
4 Alluvial Aquifers.

Each aquifer type has a unique range of storage capacities and yield potentials. In this paper a brief description of the whereabouts of the aquifers and their yield potential will be outlined. A more in-depth knowledge of these aquifers may be obtained from the referenced reports outlined in the literature review.

3.1 Weathered Rock Aquifers

This aquifer type occurs near the ground surface throughout the study region and is the most extensively exploited aquifer. It tends to be 5 - 12 metres deep (Hodgson & Krantz, 1998) although may be as thin as 0.2m or as thick as 50m in certain areas (RSA Department of Water Affairs, 1991). Solid unweathered rock or structural aquifers tend to form the lower boundary of this aquifer. A weathered rock aquifer is often of a perched nature (i.e. it has a more extensive aquifer beneath it). The aquifer tends to be rather low yielding because of its limited thickness, giving a typical flow of approximately one litre per second. However, when existing in conjunction with a structural aquifer, yields of up to five litres per second may occur from a borehole penetrating both the weathered aquifer and a deeper aquifer beneath (RSA Department of Water Affairs, 1991).

3.2 Structural or Fractured Aquifers

Water storage and transmission occur in what is known as secondary porosity in structural aquifers; secondary porosity being that porosity attributable to fractures, cracks and joints

[1] in the context of local water supply needs.

in the rock and not actually to the rock itself. As one gets deeper, however, more and more of these cracks are closed due to the weight exerted by the overlying formations. At depths below 30m, water-bearing fractures with significant yields tend to be rarer, being spaced 100m or more apart (Hodgson & Krantz, 1998). These fractures may be identified as linear features on air photographs or indeed may often be readily observed in the field. More scientific siting techniques, however, are required to successfully locate these fractures at greater depth (using, for instance, a magnetometer). Highly variable yields are found in these aquifers. Initially yields may be high, but then show a marked decrease with continued pumping due to the limited storage in some of the cracks. In general, there is insufficient yield from these aquifers for intense irrigation (Hodgson & Krantz, 1998).

3.3 Dolomitic or Karst Aquifers

The groundwater in dolomitic aquifers are found mostly in the underground cavities that are formed at depth in calcium rich rocks as a result of the dissolution of materials such as solid dolomite by carbonic acid present in the groundwater. Yields from successfully placed boreholes tend to be high, ranging from five to forty litres per second. This aquifer type is present in three main areas of the Olifants basin. First, along the western foothills of the Drakensberg Mountains from Pilgrim's Rest in the south to Maseseleng in the north. The other two areas are around Delmas and Marble Hall. (RSA Department of Water Affairs, 1991)

3.4 Alluvial Aquifers

Alluvial aquifers consist of unconsolidated material ranging from clayey silts to coarse gravels and boulders that occur along watercourses, in old dried up valleys and in existing or historic floodplains. Borehole yields are generally high, with 30% giving in excess of ten litres per second (DWAF, 1995c).

A visual presentation of the locations of these various aquifers is presented in the 1991 RSA Department of Water Affairs document and, more particularly, in Annex 11 of that report.

4. Groundwater Recharge

4.1 Natural Groundwater Recharge

Groundwater recharge is dependent in the first instance on rainfall. However, in South Africa, of the total amount of rainfall for a given area, only a small percentage will actually reach the aquifer and be available for extraction. The majority is lost to evaporation, evapotranspiration and runoff. The other factors affecting recharge are:

- soil and permeability and the presence of Macro Pores
- ground slope
- vegetation
- rainfall intensity and antecedent conditions
- underlying geology where have shallow soils
- man's influence.

Groundwater recharge in the basin is estimated to be 3% to 6% of the mean annual precipitation, which in turn is estimated to be between 500 to 1700 mm per year. Specific exceptions are that more than 60% of the basin receives less than 700mm precipitation per year. On the other hand recharge of up to 8% of precipitation is suspected in the north western fringes of the catchment. The range of mean annual precipitation quoted here shows that quite often recharge occurs only locally and is certainly not spatially homogenous. Total recharge for the basin per year is estimated at approximately 1800 million cubic meters (RSA Department of Water Affairs, 1991).

As a consequence of the processes listed above most of this recharge occurs during, or shortly after, heavy rain and it is suspected that the majority of water reaching the water table does so via macro pores (cracks, fissures, etc) in the soil rather than through the actual soil body.

It should be stressed that regionally stated recharge is often of little hydrogeological significance; therefore, any local implementation of a basin catchment plan requires that the plan be revised for local conditions. For example, recharge occurring at 6% of 1700mm/yr is significantly greater than recharge occurring at 3% of 631mm/yr and vice versa. The generalised numbers quoted in this paper are useful, however, as they present a simplified understanding of the complexities that are involved in estimating groundwater recharge. They also contribute to the development of an overall conceptual model for the catchment.

4.2 Artificial Groundwater Recharge

There are a number of methods of artificially enhancing groundwater recharge, some of which are:

- Inefficient irrigation - either through over irrigating or by having a leaky distribution system;
- Leaky reservoir - groundwater recharge induced by creating reservoirs of water over a relatively permeable unsaturated zone lying on top of a suitable aquifer;
- Reversed pumping - injecting clean and treated water into an aquifer via boreholes.

Obviously the use of the above methods is site specific. To a greater or lesser extent their efficiency / applicability is governed by the list of factors presented in section 4.1. All three require the presence of a suitable aquifer.

In all cases artificial recharge should only be thought of as a tool to tap excess surface runoff - something that is not always readily available when the needs of the whole region and the downstream recipients are considered. This means that in the Olifants River Basin artificial recharge may only be conducted during the height of the rainy season or from surface water reservoirs.

Looking briefly at the three possibilities mentioned above, the following may be considered:

- Reversed pumping does incur relatively high costs - both in obtaining water of sufficient quality so as not to pollute the aquifer and in setting up and running the required infrastructure.

- Leaky reservoirs are always a useful option but only works if there is sufficient excess surface water for long enough periods to justify their construction. On a smaller scale, any land management method that enhances the capture and percolation of excess rainfall into the ground should be examined and encouraged.

- Inefficient irrigation is an excellent method of storing water in areas that have extensive aquifers, deep water tables and permeable unsaturated zones. This water can be exploited during the dry season, having experienced little evaporative loss and be recharged during the following wet period. However, if only small amounts of water are leaked towards the water table, for example from very localised leaking irrigation water mains, it is very unlikely that much of this would reach the groundwater. This is because for most of the year the water absorption capacity of the unsaturated zone between the ground surface and the water table is extremely high due to high evaporation and evapotranspiration. Moreover, even if this water were to reach the water table, it would only be of benefit to boreholes close by due to its insignificance compared to the large quantity of groundwater being recharged more naturally. Further to this, the water available for irrigation with is often too precious and expensive to allow leakage for future storage. It is important to remember that in areas of high water table, relatively impermeable unsaturated zones or indeed no efficient aquifers, over-irrigation or leaky distribution mains can lead, over time, to the creation of saline soil (evaporation leaves behind any salt that may be contained in the excess water). In these situations efficient irrigation is essential.

5. Groundwater - Surface Water Interaction

The general impression from the literature and interviewing concerned people is that throughout the Olifants river basin, with the exceptions of the alluvial aquifers near rivers, the predominant groundwater movement is from the ground to the rivers.

This discharge must not be thought of, however, as a visual phenomena of groundwater gushing up into the streams but much more in keeping with groundwater's gentle and slow movement causing gradual seepage from the ground up into the stream. (This will occur when the hydraulic head in the aquifer near the stream is higher than the hydraulic head acting on the water in the stream.)

Where this does occur the relatively unpolluted groundwater being drawn towards the streams may be exploited as a source of localised water supply.

Additionally, although a river may be polluted, the groundwater nearby need not be, as it may not be receiving water from the river.

6. The Existing Use and Exploitation of Groundwater

Groundwater in the Olifants river basin is extensively used for rural domestic supplies and for stock watering. In many areas groundwater is in fact the only available water source. Due to the relatively low yield per borehole, however, it is rarely used for commercial irrigation although some groundwater irrigation does occur in the Lowveld and Eastern Highveld (RSA Department of Water Affairs, 1991). The over-riding impression received from the desk study and interviews was that full-blown commercial irrigation was much more dependent, or indeed nearly totally dependent, on the surface

water resources. Again, it is important to note, this may not be homogenous throughout the catchment. There is certainly groundwater use in the localised high-yielding aquifer areas and in the less commercially orientated farmlands where yields of the order of one litre per second are tapped.
The extraction of the water from the relatively low-yielding boreholes is done mainly using hand pumps. Due to the relatively low amount of maintenance required by these pumps they are often the better choice.

When choosing a make of pump, the choice is site specific and depends on the local community / end-users desire to take ownership of the system. UNDP and the World Bank (1987) gives an interesting comparative study of hand pumps.

Thought might also be given to the use of wind pumps if the local community would be prepared to maintain, and fully benefit from, them.

Where the relatively shallow weathered aquifers are discharging into the streams / rivers, the construction of say a one meter deep trench intercepting this water overnight would provide a reasonable daily supply of water for, among other uses, the irrigation of small scale plots. The advantage of using these trenched instead of small dams in the streams is that the better quality groundwater would be tapped before mixing with the normally lesser quality surface water.

7. Groundwater Quality

Groundwater quality is intrinsically linked to the chemical properties of the aquifer's geology through which it flows. As a result its quality varies from one aquifer to another, and even within aquifers. However, artificial pollution of groundwater by man-induced means are of course now more and more common. Further, given among other things, the slow speed that groundwater moves through the ground resulting in a very long residence time, once an aquifer is polluted it may take many generations before that aquifer can again produce unpolluted water.

In the upper weathered aquifer the groundwater can be considered to be of excellent quality when existing in its natural state. The material that it flows through has long since been flushed of its leachable minerals and hence provides a nearly inert conduit for the water. The presence of local surface pollution would of course severely adversely affect this relatively unprotected aquifer as it occurs near the surface and often has little soil cover.

Going deeper down to the fractured aquifers one finds a higher salt load due to the longer residence time and the less leached rocks that the water comes into contact with. When the groundwater has come into contact with granitic rocks there often are naturally occurring high levels of fluoride.

When considering the use of groundwater for human or agricultural consumption it is normal to measure the quantity of Total Dissolved Salts present in a given sample. RSA Department of Water Affairs (1991) Annex 19 presents the results obtained from analysing the water quality data then available. Problem areas were noted to be near the Gotwane and Elands rivers, along the Springbok Flats, and to some extent, from the confluence of the Mohlapitse River to the border with Mozambique. For the concerned reader Annex 19, as mentioned above, gives a more complete picture. Hodgson & Krantz (1998) also cover the area above the Loskop Dam.

As a general note, whenever there is a possible pollution source at ground surface, and it seems reasonable that there is a link between this source and the groundwater, then it is also reasonable to assume that some of that pollution will be in the groundwater of the underlying area to a greater or lesser extent. Whenever one hopes to exploit a groundwater source a quality assured water quality test should be carried out on the potential water first.

8. Impacts of Mining on Groundwater

The majority of the mines in the Olifants river basin occur in the Witbank area, at the head of the Olifants River. Over the years runoff from these mines have had adverse affects on the quality of the surface water. This, however, has become more and more controlled. Now the water pumped from the mines must be treated before it may be put into the river system. At present there is a pilot project underway that is using this mine water (with neutralised pH) as irrigation water. The objective of this project is to determine if the surrounding land, along with the crops being grown there, can unharmfully adsorb the high sulphur content of the mine water.

As for the mines themselves, when operational there is only movement of water from the ground into the mines because the mines are being constantly pumped to keep them dry. Therefore an operational mine's water does not go directly into the surrounding groundwater. However, as mines close and pumping stops they become filled with highly acidic mineralised water which can have a direct affect on the regional groundwater quality when there is an aquifer adjacent to a mine. Under the polluter pays policy[2] the mine operators have a vested interest to prevent this.

The closed mines eventually have a large quantity of stored water that could potentially be an attribute to the local irrigation efforts. Obviously, treatment is required to some degree, but the chances are that less treatment would be required if the water were to be used for certain irrigation rather than allowed to overflow from the mines into the natural water system.

Exploitation of groundwater from closed mines would either be through distribution from overflow points or through boreholes sunk into the old mine tunnels. The latter would provide more spatial distribution of the water over a given area, and would hence reduce transmission costs and losses. However, the need for treatment plants may necessitate centralisation.

A description of all the issues involved here is beyond the scope of this study but is covered to a large extent by Hodgson & Krantz (1998).

9. Groundwater Regulatory Framework

Overall responsibility for all groundwater within South Africa falls in the hands of the Department of Water Affairs and Forestry (DWAF). Local interest groups are involved in the exploitation of groundwater but have no legal powers other than those obtained by working through the DWAF. Groundwater exploitation by villages / local communities tends to be governed by community leaders. Localised research would be required to determine the structures present that govern this local sharing of water.

As the river basin management authorities become established, more and more of DWAF's work will be channelled through river basin management units. However, it is believed that no legislation to date has empowered the local communities, nor imposes structures nor responsibilities on them.

The new water act does require that any well producing more than five litres per second be licensed.

[2] The operation of the polluter pays principle pivots around the idea that if pollution leaves one owners property and goes on to damage that of another then the original owner is held responsible. The polluter-pays principle is entrenched in the new South African water laws currently being put through its final edits. The overall effectiveness of the new law is inherently related to how it can be policed. The extent that this law is, or will be, taken seriously is grounds for future research.

10. Conclusion

There has already been a large quantity of work completed on the understanding of the groundwater of the Olifants river basin as outlined in the literature review.

Groundwater is an important source of water supply for many small towns, villages and small-scale farms (stock watering and some irrigation especially on the Springbok Flats) within the Olifants river basin. The majority of the catchment's exploitable groundwater exists in the relatively shallow weathered aquifer that gives an average yield in the vicinity of one litre per second. Areas of higher potential (five litres per second and more) do occur in the vicinity of the Steelpoort river, while roughly half of the catchment to the west of the Drakensberg mountains may be classified as having moderate potential (one to three litres per second).

Legislative responsibility for the groundwater lies with the Department of Water Affairs and Forestry, some of whose people have an in-depth understanding of the occurrence and exploitability of groundwater for the catchment.

A hydrological-hydrogeological understanding that is correct for one section of the Olifants river basin would often require considerable revision for another. This is particularly true as the basin is so large and certainly does not act in a hydrologically homogeneous manner. Therefore each implementation of an overall catchment management plan would have to be accompanied by a localised in-the-field study.

References

1. DWAF, (1995a), "Olifants-Sand Transfer Scheme - Feasibility Study".

2. DWAF, (1995b), "Middle Steelpoort River Catchment Groundwater Management Plan - Effect on Irrigation Water by Tweefontein Chrome Mine - Draft Copy".

3. DWAF, (1995c), "1:500 000 Hydrogeological Map 2326 Pietersburg".

4. DWAF, (1996), "Groundwater Harvest Potential of the Republic of South Africa".

5. DWAF, (1997), "Overview of the Water Resources availability and utilisation in South Africa". ISBN 0 7970 3540 0.

6. DWAF, (1998a), "1:500 000 Hydrogeological Map 2330 Phalaborwa".

7. DWAF, (1998b) - DRAFT COPY, "1:500 000 Hydrogeological Map 2526 Johannesburg".

8. DWAF, (1998c), "Geohidrologie Van Die Nasionale Krugerwildtuin Gebaseer Op Die Evaluering Van Bestaanme Boorgatinlighting", Volume 1 & 2.

9. DWAF, (1999b), "Resource Directed Measure Manual", version 1.0.

10. DWAF, (1999a), "Pre-feasibility Study on Bulk Water Supply in the Middle Olifants and Steelpoort River Area".

11. Hodgson, F.D.I.; Krantz, R.M., (1998), "Groundwater Quality Deterioration in the Olifants River Catchment above the Loskop Dam with Specialised Investigations in the Witbank Dam Sub-Catchment", WRC Report no. 291/1/98.

12. Midgley, D.C.; Pitman, W.V.; Middleton, (1994), "Surface Water Resources of South Africa 1990 - Book of Maps", Volume 1, WRC Report no. 298/1.2/94.

13. RSA Department of Water Affairs, (1991), "Water Resources Planning of the Olifants River Basin - Study of Development Potential and Management of the Water Resources".

14. UNDP and the World Bank, (1987), "Community Water Supply - the hand pump option", ISBN 0-8213-0850-5.

15. WRC, (1995a), "Groundwater Resources of the Republic of South Africa - Sheet 1: Borehole Prospects".

16. WRC, (1995b), "Groundwater Resources of the Republic of South Africa - Sheet 2: Saturated Interstices, Mean Annual Recharge, Base flow, Depth to Groundwater, Groundwater Quality, Hydrochemical Types".

Appendix A

This appendix presents a listing of the suite of reports that make up the "Water Resources Planning of the Olifants River Basin - Study of Development Potential and Management of the Water Resources" published by the Department of Water Affairs, RSA (1991).

Section 1: Summary Reports

Volume 1.	Executive Summary
Volume 2.	Main Report
Volume 3.	Situation Assessment for the eight sub-catchments of the report.

Section 2: Catchment Description

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