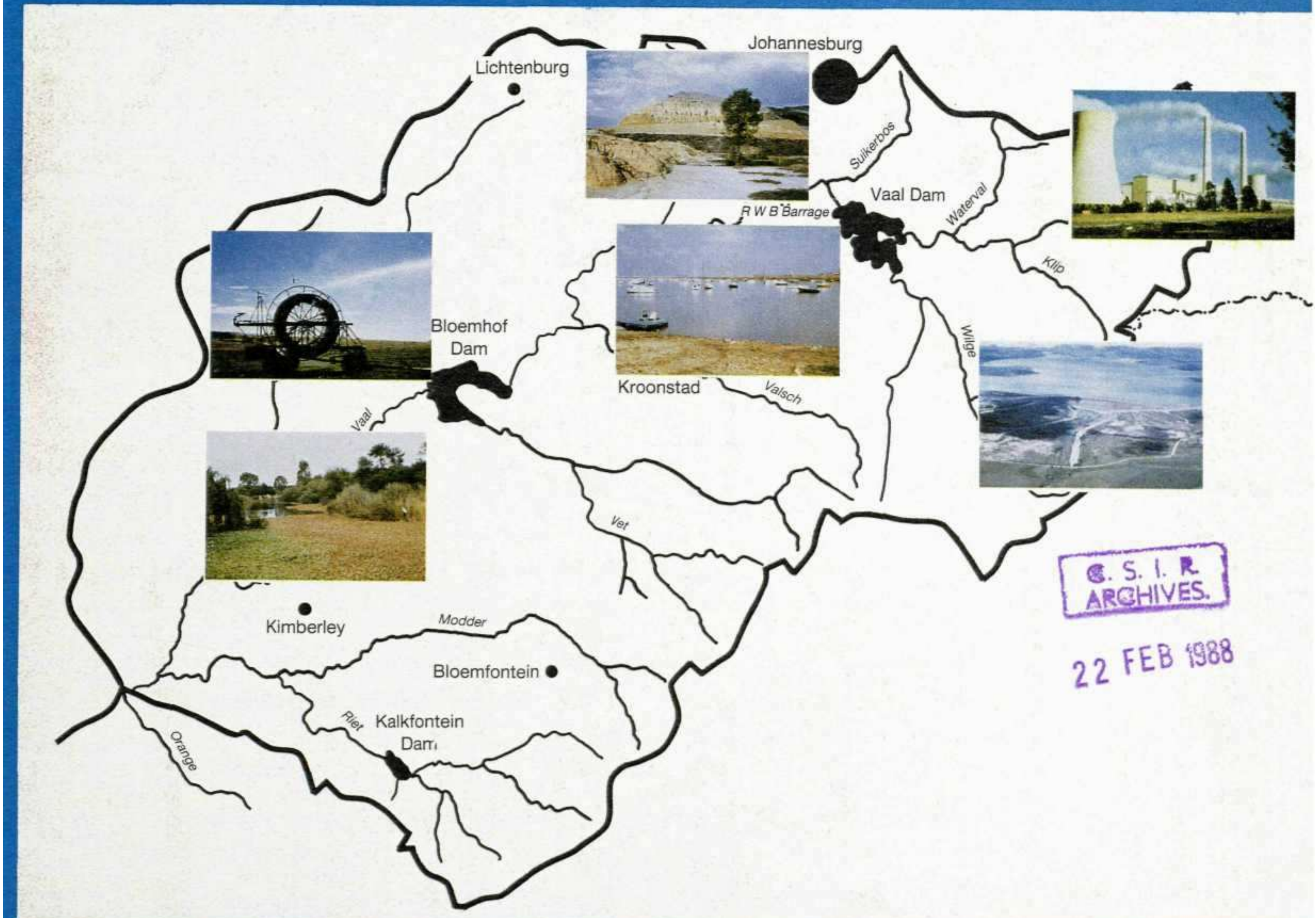

The Vaal River catchment: Problems and research needs

E Braune and K H Rogers

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A report of the Committee for Inland Water Ecosystems
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EXECUTIVE SUMMARY

The Vaal River catchment contains South Africa's economic heartland, the Pretoria-Witwatersrand-Vereeniging (PWV) complex. Although the catchment only produces eight per cent of the mean annual runoff of the country it has the highest concentration of urban, industrial, mining and power generation development in South Africa. Initial emphasis in water management was therefore on the imbalance between available supply and growing demand. Later, however, the growing water pollution problems attracted considerable attention, particularly the steady increase in total salinity of the Vaal River.

The purpose of the workshop and preceding symposium was to examine the ever increasing complexity of the Vaal River system, the much enlarged spectrum of user water quality needs and problems, and those activities in the catchment which affect water quantity and quality.

The doubling of water demand by the year 2000 will require that additional resources are imported from neighbouring catchments, the Orange, Tugela, Usutu and Komati catchments, thus altering flow regimes of the main river and its major tributaries. Large-scale development of groundwater from the catchment*s dolonitic aquifers will add a further dimension to water supply. Return flows will far outstrip the natural runoff in most catchments.

The Vaal catchment can be divided into four zones on the basis of water quality problems ie the Vaal Dam, the Barrage, the Bloemhof and the Douglas weir subcatchments. In general, the best quality water is found in the catchment of Vaal Dam and quality deteriorates downstream. This deterioration is fortunately in line with the general distribution of user water quality requirements in the catchment. These range from the highest quality requirements for power stations in the Vaal Dam catchment to acceptable quality based on present standards for urban/industrial use and comparatively lower quality for agriculture in the lower reaches of the system.

In the catchments upstream of Bloemhof Dam effluents from urban, industrial and mining activities have resulted in a marked increase in total salinity of the Vaal River. In the lower catchment irrigation return flows are the major contributor to river salinity. Potential long-term "pollution threats to the important Vaal Dam catchment are atmospheric pollution, diffuse agricultural sources and further industrial development. Eutrophication is already a problem in the Vaal River, particularly in the Barrage and Bloemhof Dam catchments where it is becoming an increasingly serious issue. The problem is partly contained because of the turbid nature of Vaal River water but, as has already been demonstrated for the middle Vaal River, increasing salinity and accompanying decreases in turbidity can enhance primary productivity. Similarly low turbidity water imported from the Lesotho Highlands water project could enhance eutrophication.

Very little is known about micro-pollutants in the Vaal River system. Organic contaminants, from both industrial and agricultural sources have

been detected in water, plants and fish, but not in alarming concentrations. The role that sediments play in the transport of micro-pollutants needs urgent investigation in the light of the expected changed turbidity regime of the river.

Recreational pressure on the Vaal River is high, particularly between Vaal Dam and Bloemhof, and is expected to increase further. In general, conservation is inextricably linked to the overall water supply objectives. A high quality water from the headwater catchments of the east and south-east can be achieved through protection of the natural habitats of these pristine or slightly modified streams. In the highly regulated and modified rivers further downstream the emphasis should be on management of the river and the associated wetland systems for their full range of consumptive and nonconsumptive uses by ensuring that they maintain a high potential for "self-purification".

The workshop listed a number of important water resource management considerations. Above all, effective coordination and integration of policies and activities of relevant departments, authorities, companies and individuals which impinge on the conservation, and sustainable use and management of the catchment's resources is necessary. Strong emphasis was placed on the need to establish clear water quality objectives and management policies for its various subcatchments. The contribution of imported water, available treatment technology and the requirements of regional users will dictate these objectives and policies.

Information and research needs related to these management considerations stress firstly the economic evaluation of the impact of water quality in its different manifestations on the major users and the need to incorporate the environmental requirements and benefits into the overall resources planning.

Identification of information needs at the workshop generally stopped at the management-related level. Finer detail of the limnological/ecological issues will have to be worked out by the research community itself.

PREFACE

The Vaal River Catchment, currently contributing more than 50% of the gross national product, is a focal point for much of South Africa's future development. However, man's activities such as agriculture, forestry, mining, urbanization and power generation coupled to adverse natural climatic conditions such as a highly variable rainfall and excessive evaporation have created a highly regulated and in some areas a highly polluted river system. The Vaal River therefore poses a considerable challenge to the many water resource managers who are committed to ensuring the future supply of appropriate quality water to the various sectors of the economy. With proposed developments such as the Lesotho Highlands Water Scheme in mind, it seemed timely therefore to convene both a workshop and symposium which reviewed existing knowledge and also generated some thoughts on the future.

A Symposium Proceedings containing the views of many specialists has already been- published as an Occasional Report by the Foundation for Research Development. This document contains an overview of the deliberations which occurred during a one day workshop session which was held directly after the symposium. The main objectives were to characterize the ecological problems within the catchment and provide some basis for future research and management activities. The authors, in synthesizing the presented information, have indeed provided the water resource community with some useful food for thought. The document should therefore become an invaluable addition to the growing record of contributions on the Vaal River and its catchment.

R D Walmsley
Coordinator: Inland Hater Ecosystems Programme

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1. INTRODUCTION

The Vaal River has a catchment area of 192 000 km*. Its catchment and supply area contain South Africa's economic heartland, with its centre the Pretoria-Witwatersrand-Vereeniging (PHV) complex. Although the catchment only produces about eight per cent of the mean annual runoff of the country it has the highest concentration of urban, industrial, mining and power generation development in South Africa. In 1975 the Vaal River water supply area produced 55% of the country's gross domestic product and housed 42% of the urban population of South Africa. The mining production represents 79% of South Africa's total. Most of the country's power generation and oil-from-coal industries are situated in the catchment. A total of 155 000 ha of land is irrigated from the Vaal River and agricultural production is now 42% of the country's total. Besides these direct uses there is a tremendous demand for recreational use of the catchment's water resources. The Vaal River can justifiably be called "Africa's hardest-working river" and "the main artery of the South African heartland" {Vaal River Catchment Association 1981; Department of Water Affairs 1985; Raubenheimer et al 1985).

Initially water resources planning had to focus mainly on the imbalance between available supply and growing demand. The first importation of water from the Tugela River started in 1974. Water is also imported from the Komati and Osutu Rivers to meet the needs of the industries growing around coal fields of the Upper Vaal and Olifants catchments. However, with growing demand and increasing river regulation, the proportion of polluted return flows to natural runoff in the Vaal River has increased and led to a steady decline in the quality of water supplied to the PWV area.

In 1974 the Water Research Commission instigated the "PWVS Research Project", the objectives of which were as follows (Henzen et al 1980).

> *The preparation of an inventory of pollution sources; the determination of the impact of pollution on the region; the development of a mathematical model to simulate the movement of pollution through the system; and, the evaluation of alternative pollution abatement and control alternatives.*

The mathematical model has since become a major tool in the analysis of various water management options by the Department of Water Affairs. The emphasis in this phase was on Total Dissolved Solids (TDS) as a pollution indicator to which economic impacts of pollution were also related. Since then it has become apparent that water quality problems in this system are much more complex and need a variety of management measures. A special phosphate standard had to be applied in this and other critical catchments to control growing eutrophication problems. Organic pollution already causes considerable problems in {domestic water) treatment plants. Atmospheric pollution may present a potential long-term threat to the catchment's aquatic resources. Interactions between suspended sediments and dissolved macro- and micro-constituents in the water further complicate the situation. Changes in demand are also taking place through a variety of new users and more stringent quality requirements. Greater environmental awareness and pressure for water recreation facilities have added a further dimension to water resources management.

The purpose of the symposium and workshop was thus to examine a much enlarged spectrum of user water quality needs and the activities in the catchment which affect water quantity and quality. A catchment approach was intended to highlight the interaction between all the relevant man-induced and natural processes.

This document is a summary of the workshop session and gives an overview of the catchment's water supply, demand and quality problems with proposals for research and information needs required to address these problems. However, it must be stressed that the document is not a definitive statement of facts but an overview which should be read in conjunction with the symposium proceedings[1]. Reference should also be made to the detailed Department of Water Affairs internal report by Nel et al (1982) and the recent survey of the lower Vaal by Bruwer et al (1985).

A selected bibliography based on contributions from workshop participants and WATERLIT Vaal River entries is appended to this workshop overview as a source of further detailed information.

The Vaal River Ecosystem: Status and problems. Proceedings of a joint symposium convened by the Foundation for Research Development and the Vaal River Catchment Association. Occasional Report No 5. FRD, CSIR. Pretoria.

2. THE VAAL RIVER SYSTEM

The Vaal River rises on the western slopes of the Drakensberg escarpment and flows about 900 km west-south-west across the interior plateau to join the Orange River near Douglas (Figure 1). The major tributaries of the Vaal drain the Drakensberg in the east, the Witwatersrand in the north and the Maluti Mountains in the south. The Drakensberg area with the highest rainfall (800 to 1 000 mm a""^{1}) and lowest evaporation c. 1 250 mm a^{-1}) is the major catchment. Rainfall decreases and evaporation increases steadily westward to 300 mm and 2 250 mm a"^{1} respectively. The lower reaches of the river are therefore largely dependent on the eastern catchments for water supply.

In the context of water resources management, the Vaal River system involves more than water schemes within the Vaal River catchment alone. Water is imported from the Orange, Tugela, Usutu and Komati catchments and exported to the Limpopo/Crocodile and Olifants catchments. The complex system of interbasin transfers is shown schematically in Figure 2 (see back cover).

The major dams in the Vaal River catchment are given in Table 1. The Vaal River is so regulated by these and numerous small weirs which hold back water for irrigation that there is now only sporadic flow to the Orange River. No other single catchment in the country supports as much agricultural, mining, industrial and urban development, all of which require water and have polluted return flows to the river. The distribution of these activities over the catchment permits division into four zones on the basis of water quality (Figure 1; Oliveira 1986).

TABLE 1. Major dams in the Vaal River catchment

Dam name	River/tributary	Surface area (ha)	Capacity ($10^6 m^3$)
Grootdraai	Vaal River	3 879	358,6
Sterkfontein	Nuwejaarsspruit	6 937	2 656,0
Vaal Dam	Vaal River	32 107	2 535,5
Vaal Barrage	Vaal River	1 700	56,7
Boskop	Mooi	378	20,7
Koppies	Renoster	1 367	41,2
Allemanskraal	Sand	2 697	174,3
Erfenis	Vet	3 308	224,1
Bloemhof	Vaal River	23 427	1 269,2
Vaalharts	Vaal River	2 142	51,2
Spitskop	Harts	2 496	61,3
Rustfontein	Modder	1 162	75,4
Krugersdrift	Modder	1 876	76,7
Tierpoort	Kaffir	911	34,5
Kalkfontein	Riet	4 550	321,8
Douglas Weir	Vaal River	799	17,2

Zone 1: The Vaal Dam catchment

This catchment is the most important supplier of water to the Vaal River. Water quality is good with most mining (gold and coal) and fuel processing plants having minimal return flows to the river. The major agricultural activities, cattle grazing on natural pastures and dryland cultivation are also conducive to good water quality.

Zone 2: The Vaal Barrage subcatchment

This catchment incorporates the rivers which drain the highly industrialized Witwatersrand and delivers a poor quality water to the Vaal. Forty-six per cent of the total runoff from the Barrage catchment is return flow of which 75% is from sewerage works, 11% from industries and 14% from mines. Agriculture has little influence on water quality and increased salinity and eutrophication are therefore the main quality problems.

Zone 3: The Bloemhof catchment

This catchment has sewerage, industrial and, as major contributors, mining return flows which also affect the quality of the Vaal River water.

Zone 4; The Douglas weir catchment

Return flows from irrigation-based agriculture along the tributaries Harts, Riet and Modder dominate water quality in this region but dilution by the Orange River means that the consequences for water quality downstream of Douglas weir are still negligible.

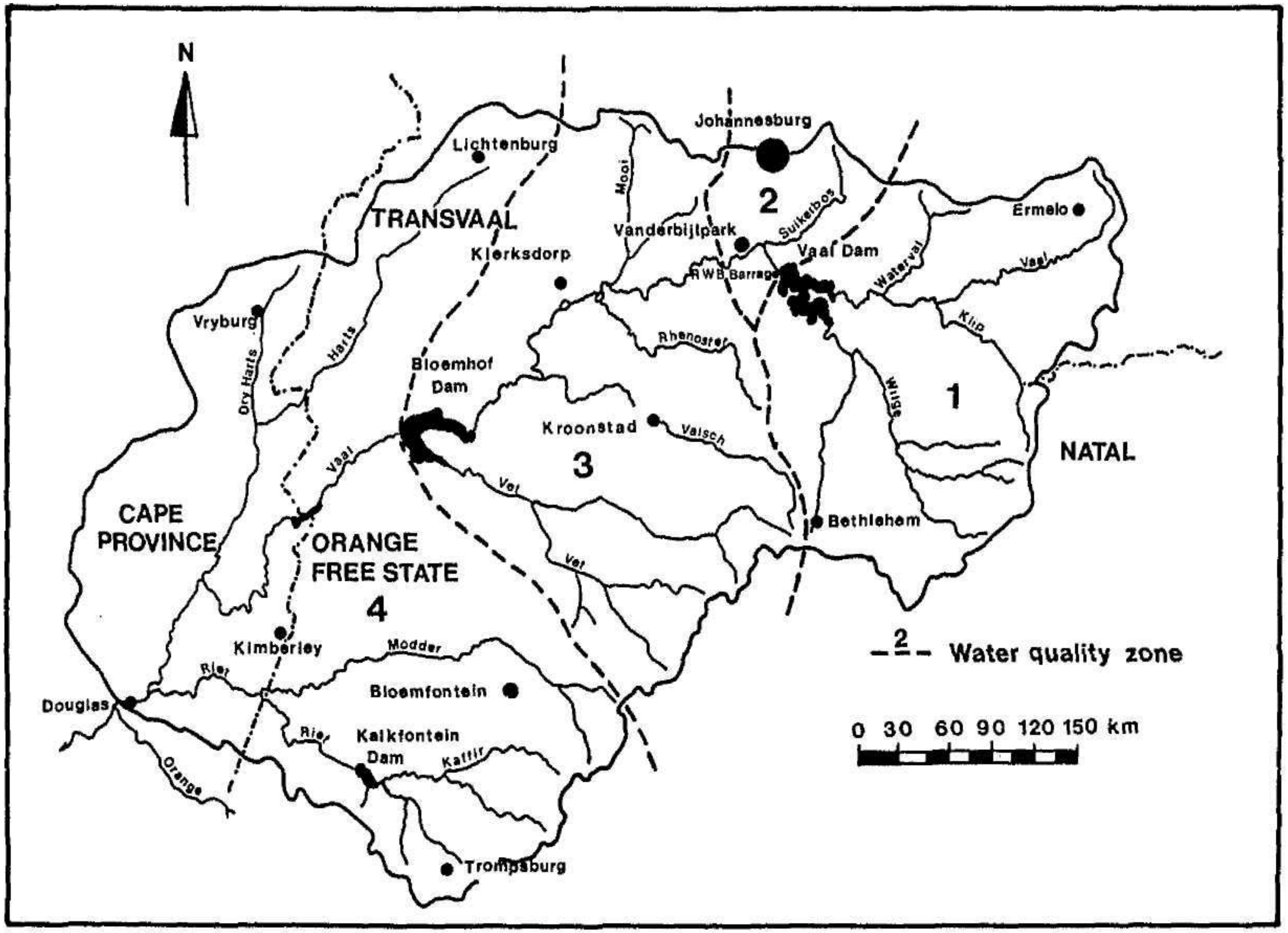

FIGURE 1. The Vaal River catchment showing the division into four zones on the basis of water quality as proposed by Oliveira (1986).

3. WATER QUANTITY AND QUALITY PROBLEMS

3.1 WATER DEMAND

3.1.1 Quantity

The Vaal River is the main source of water for a large part of the South African economy. It serves not only the PWV area but also totally or partially the following (Triebel 1986):

the coal mining activities of the Eastern Transvaal with the large ESCOM power stations, SASOL II and III and other industries with a coal base;

the coal mining activities of the northern Orange Free State with its carbo-chemical industries and power stations;

the gold fields of the Far East Rand near Kinross; -

the Western Transvaal gold fields; The Orange Free

State gold fields;

the iron and manganese mining activities near Sishen; the mining

industry of the Bushveld Igneous Complex near Rustenburg; Kimberley and

other municipalities such as Parys and Standerton;

the large population concentration in Bophuthatswana, north of Pretoria;

the industrial deconcentration points at Brits and Bronkhorstspruit; and

the largest single irrigation project in South Africa - Vaalharts, as well as the many irrigation farms along the Vaal River.

The 1981 usage and projected usage for the years 2000 and 2030 for the four subcatchments is shown below (Raubenheimer et al 1985).

It is clear from Table 2 and Figure 3 that water supply to the PWV area will play the dominating role in future.

Successful implementation of the Government's decentralization and deconcentration policy can lead to reduced water demand growth rates in certain established areas of the PWV complex, but the water demand of the projected growth points, many of which also fall within the Vaal River supply area, will continue to rise. The total demand from the Vaal River will thus probably not be affected very much.

During very severe droughts water restrictions have to be implemented to ensure that dams of the Vaal River system do not run dry. The most severe drought experienced in the Vaal River system began in the 1979/80 season and cannot yet be considered broken. Restrictions of 10% were imposed on urban/industrial use during that season and later (April 1984) were

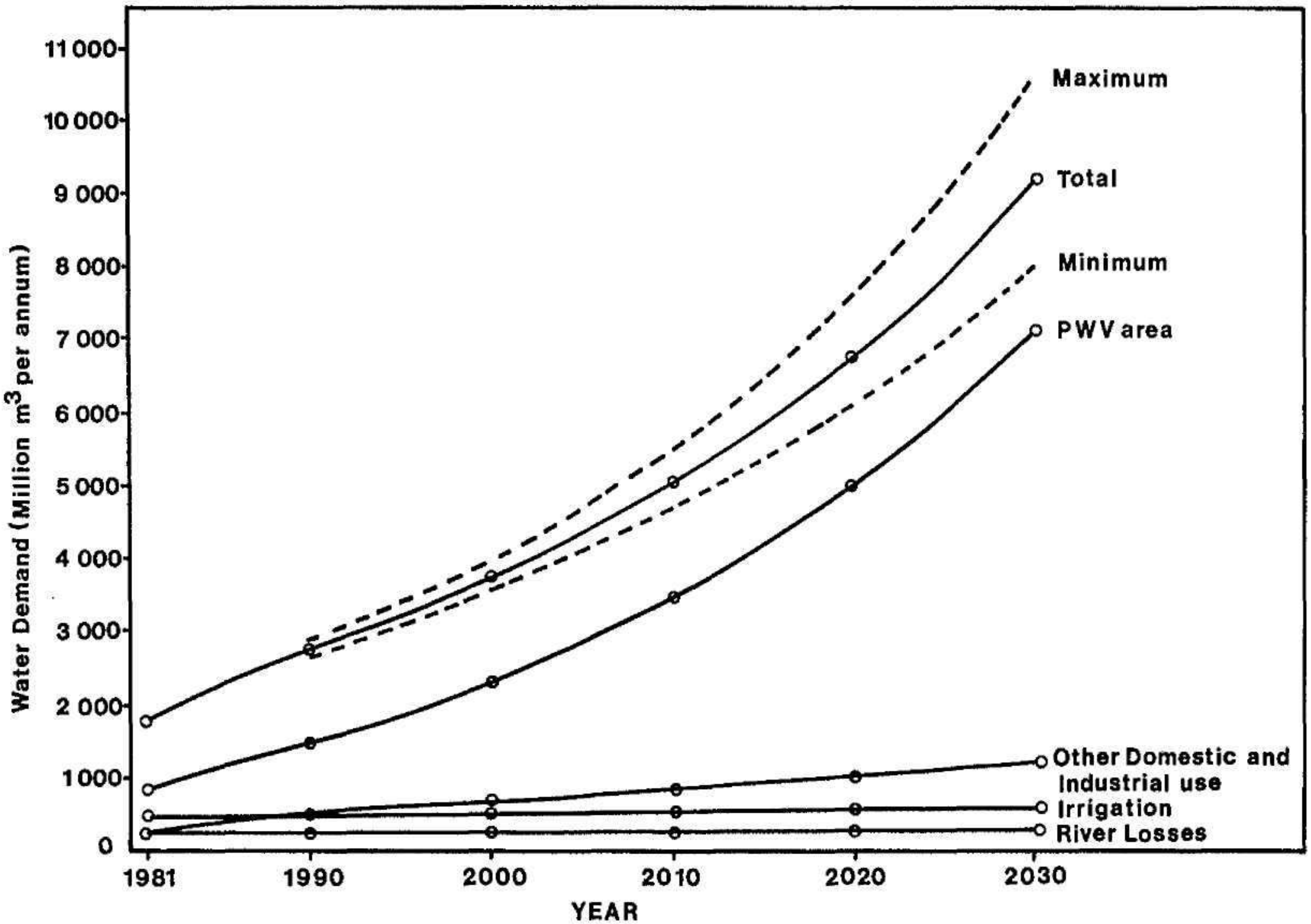

FIGURE 3. Projected water demand from the Vaal River.

increased to 30% where they now stand. Restrictions on irrigation have been even more severe and are currently standing at 50%.

Proportional distribution of abstraction (total volume 1 290 x $10^6 m^3$) during 1984/85 under restrictions was:

PWV region	51%
Other water boards	8%
Electricity and fuel	15%
Mines and municipalities	4%
Irrigation	22%

The seasonal distribution of agricultural demand is fairly uniform under a two crop system and monthly variation in urban/industrial demand is less than 10%, about the mean. The return flows produced are also uniform throughout the year.

TABLE 2. Expected water demand from the Vaal River ($10^6 ra^3 a^{-1}$) (excluding tributaries downstream of Vaal Dam)

User	1981	2000	2030
Vaal River upstream of Vaal Dam			
Urban, industrial and losses	57	363	753
Irrigation	4	7	12
Subtotal	61	370	765
Vaal Dam to Barrage			
Rand Water Board	790	2 086	6 822
Other urban and industrial	103	209	241
Subtotal	893	2 295	7 063
Barrage to Bloemhof Dam			
Urban and industrial	146	252	275
Irrigation	18	47	93
River losses*	103	103	103
Subtotal	267	402	471
Bloemhof Dam to Orange confluence (Douglas Weir)			
Urban and Industrial	27	67	183
Irrigation	455	457	459
River losses*	145	145	145
Subtotal	627	669	787
Total demand from Vaal River	1 848	3 736	9 086

* Seepage, evaporation and unaccounted abstraction.

3.1.2 Quality

Water quality demands for the Vaal catchment are broadly as follows.

Vaal Dam and Barrage catchments	Need highest quality for power and fuel installations; industry.
Bloemhof Dam catchment	Needs acceptable quality based on present standards for urban/industrial use.
Douglas weir catchment	Primarily agriculture where lower quality is acceptable.

Quality demands of different users are broadly the following:

Sectors	Quality
Power stations	Highest quality for boilers, lower for cooling.
Human consumption	70 msm^{-1}, the SABS recommended limit (corresponding to 350 to 550 mgl^{-1} TDS depending on constituents).
Selected industries	Quality demands vary considerably. Zt is not necessarily the TDS level but often the concentration of specific ions which is detrimental to human health, to industrial processes and equipment and to water distribution systems.
Agriculture	Poorer quality can be used for specific crops but will affect production, and farm economics for others. More specific water quality criteria need consideration of soils, growth stage of crops, climate, irrigation technique and chemical composition of irrigation water.

3.2 WATER SUPPLY (QUANTITY)

The water sources for the Vaal River supply area are mainly surface water resources. The resources within the Vaal catchment itself are already overextended and major importation of water from neighbouring catchments is necessary. Other sources that need to be considered are return flows from various uses, groundwater for which development has just started and rainfall stimulation, which is still in a research phase.

3.2.1 Rivers

The sources of the Vaal River total assured yield of 2 445 x 10^6m^3 a^{-1} supply area are listed below and

Source	Yield (10*m^3 a"^{1}) at 1985 development level
Grootdraai Dam	161
Vaal Dam	941
Bloemhof Dam	443
Tugela-Vaal/Sterkfontein	800*
Heyshope Dam	100*
Total assured yield	2 445

Imports to system. Of the 800 x lO^m^3 a-^{1} yield from the Tugela-Vaal/Sterkf ontein scheme only 560 x 10^6m^3 a~^{x} are actually pumped across at the average rate of 20 m^3s~. The difference arises from the higher yield at which Vaal Dam can be operated through this new back-up scheme.

Additional sources and their phasing

Project	Additional yield (10^6m^3 a-^{1})	Start of operation
Zaaihoek Dam in Slang River at 3m^as~^{1} for Majuba Power Station	57	1988
Lesotho Highlands Water Project (LHWP)		
1st phase - 27 m^s"^{1}	850	1995+
2nd phase - 28 m^as~^{1} (additional)	880	

The existing and potential water supply and supplement for the Vaal River Catchment Area are shown in Figure 2 (see back cover).

The flow regime of the Vaal River and its main tributaries has already been considerably changed through flow regulation, abstraction and importation of water. This trend will continue, given the developments outlined above. The present and expected effects in various river reaches are outlined below.

Wilge River. Flows are not greatly changed as a result of abstractions. The major change is the on-off release of up to 60 m^3s^{-1} (can be as high as 110 m^3s~^{1}) from Sterkfontein Dam whenever Vaal Dam is below 15% full.

Liebenbergsvlei River. Abstractions have no major impact on river flow at present. However, major changes will occur when the LHWP comes into operation with an initial 28 m^3s~^{1} and final 70 m^3s-^{1}. This flow addition will be continuous.

Vaal upstream of Grootdraai. There is constant addition to base flow through water importation from the Usutu and Tugela basins, reaching 50% of MAR if all the potential transfer possibilities are exploited.

Grootdraai - Vaal Dam. Grootdraai Dam supplies Eastern Transvaal Highveld users and has consequently greatly reduced the downstream flow in the river. During the recent drought a series of weirs were constructed in the river via which water can be pumped upstream from Vaal Dam.

Intensification of agricultural land use could lead to reduction in runoff. So far no reduction in average runoff can be detected in the flow records available for the Vaal catchment. However, Maaren and Moolman (1986) have postulated through mathematical simulation that existing farm dams in a selected Vaal tributary could reduce runoff by about 10% during average flow conditions and more than 50% during drought conditions. Such effects could, to a large extent, be responsible for the poor runoff response of the Vaal Dam catchment after the long drought of the eighties. The quantification of effects of agricultural land-use changes on runoff presents one of the major challenges to South African hydrologists.

Vaal Dam - Barrage. This catchment is highly influenced by man; average return flow from the urban/industrial sector is about 55% of supply. This is already exceeding the natural mean annual runoff which is about 300 x 10*m^{3}a~^{1} (Pitman 1985). Effluent return flows into the Barrage have amounted to 51% of the total Rand Hater Board supply in recent years. The river in this section is completely weired and water levels are largely influenced by the operation of the Barrage.

Developments in the catchment are also expected to change the natural pattern of runoff. The major impact is expected from urbanization, through increased runoff from paved areas. The paved area of the Barrage catchment has been estimated as 146 km^2 or 1,7% of the total catchment area. By the year 2005 this is expected to have increased threefold, which could almost double the natural runoff (Pitman 1985). This effect needs further substantiation in South Africa through actual measurements in urban catchments.

Barrage - Bloemhof. Most of the tributaries are well utilized. The flow of the Hooi River is supplemented by mine dewatering. This reach of the Vaal is highly regulated to meet demands.

Bloemhof - Douglas. Tributary flows are minimal. The reach is highly regulated as a result of releases from Bloemhof Dam. At present the system is operated so as to have no outflows at Douglas. Importation of Caledon water for Bloemfontein will produce additional return flows to the Hodder River. Orange River water will also be transferred to irrigation along the Riet River, producing additional return flows.

Irrigation abstraction can have a major effect on river flow. Although quantification of this effect should be straightforward, it is hampered by the lack of information regarding private irrigation expansion. For both planning and control purposes it will be essential to get accurate assessments of irrigated areas on a regular basis (every five years). Satellite remote sensing offers excellent opportunities here which must be further explored.

3.2.2 Groundwater

A significant source of groundwater, the dolomites in the PWV and Far West Rand area, is presently being developed. Various options for usage are still under consideration eg emergency (high rate) or continuous (low rate) abstractions and artificial recharge. Possible yields are:

Continuous - 120 x lO^m^3 a"^{1}
Emergency - 500 - 1 000 x lO^m^3 (will take about five to seven years to recharge).

Groundwater utilization will reduce base flow by the amount used. Potential impacts of pollution on groundwater and base flow quality under a variety of groundwater management options will need careful consideration.

3.2.3 Return flow

An important source of water, so far not listed, is return flow from municipalities, industries and agriculture. The return flow into the system amounts to about 30% of use. The biggest quantity is return flow to the Barrage which amounts to about 450 x 10^{fe}m^3 a"^{1}. The return flow from the biggest irrigation water user, Vaalharts scheme, is reused from Spitskop Dam.

3.2.4 Rainfall stimulation

The potential for rainfall and runoff enhancement through weather modification is being intensively investigated by the Weather Bureau of the Department of Environment Affairs in cooperation with the Department of Water Affairs. The research is being conducted in the upper Wilge River catchment because of the importance of augmenting the water supply to the Vaal Dam. The project is still in a process research phase and thus the resource does not yet feature in the present water planning for the Vaal catchment.

3.3 WATER SUPPLY (QUALITY)

3.3.1 General chemical quality

Macro constitutents. The rivers of the catchment upstream of Vaal Dam are characterized by turbid, bicarbonate water with low TDS. Pollution of the Waterval tributary has elevated TDS concentrations (>500 rag I"^{1}) as a result of increased inputs of sulphate, chloride and sodium.

The impact of the LHWP on water quality of the Vaal catchment will be a reduction in the alkalinity of the Liebenbergsvlei tributary and Vaal Dam due to the slightly acidic character of the high mountain water. Turbidity of this water should also be considerably less than for the Vaal catchment, and so increased algal production can be expected in the Vaal Dam. The low salinity and turbidity water will also have a greater erosive power than the Vaal catchment water and could enhance river bank erosion. The later phases of the LHWP will yield a more turbid water.

The Klip River tributary provides the major contribution to the Barrage catchment. it is highly mineralized, with an average conductivity of

100 msnr^{1} (SABS specification for domestic supplies is 70 msnr^{1}). The principal ions are sulphates, chlorides, sodium, calcium and magnesium, which originate from the highly urbanized, industrialized and intensely mined areas of the southern Witwatersrand. In order to minimize the impact of this mineral load and its large fluctuations on domestic water supply the Rand Water Board has embarked on a programme that will enable the blending of Barrage-abstracted water with water of lower mineral content, mainly from Vaal Dam, prior to treatment and to supply a water of uniform quality, not exceeding 300 mg l~^{l}, throughout its supply area.

In the Bloemhof Dam catchment the Vaal River quality is dominated by high sulphate loads with a corresponding smaller contribution of total alkalinity. This is due to the Barrage contribution and to high inputs from the tributaries draining the northern part of the catchment which are heavily contaminated by intensive mining and industrial activities. There is an upward trend in salinity in this reach and maxima of 900 mg I"^{1} TDS and 400 mg I"^{1} sulphate were recorded in 1981 (Bruwer et al 1985). The tributaries in the southern part are low TDS, bicarbonate waters (Van Vliet 1986). The high sulphate and chloride concentrations in this reach are thought to be responsible for the corrosion problems experienced in urban areas. Taste and odour problems experienced by some municipalities are associated with eutrophication. Elevated sodium concentrations are seen as aotential problem of health significance (Bruwer et al 1985).

In the Vaal River downstream of Bloemhof Dam the upstream pollution effects are ameliorated to some extent by inflow of waters of low sulphate and high bicarbonate and chloride levels from the east. However, irrigation return flows contribute high TDS water rich in chlorides via the Harts River in the north. Thus at the lower end of the Vaal River the sulphate problem has been replaced to some extent by one of high chloride and alkalinity, due principally to irrigation return flow.

High salinity of irrigation supply water has already caused some problems in the Vaal catchment downstream of the Barrage. Elevated chloride concentrations have resulted in cessation of tobacco production in the Parys region and the high sodium level has led to sail problems in the Douglas area (Bruwer et al 1985). Provision of water from a new scheme on the Orange River provides some of the irrigators in the Douglas area with a better quality water.

In general, the best quality waters of the Vaal catchment are still found in the catchment of Vaal Dam and quality deteriorates downstream. Potential long-term pollution threats to the important Vaal Dam catchment are atmospheric pollution, diffuse agricultural sources and further industrial development. An example of this is the planned development of labour intensive industries in Qwaqwa which may include poor quality effluent producers.

3.3.2 Factors affecting water quality management

Power and fuel generation and mining. The Vaal catchment and supply area yields 79% of South Africa's mining production. Furthermore most of the country's coal-fired power stations are located here as well as the oil-from-coal industries (Raubenheimer et al 1985).

Coal mining

Coal mining, limited to the Vaal Dam and Barrage catchments, is mainly underground with some open cast mining. The impact on water in both cases is an increase in acidity, sulphates and TDS. In general the impact on groundwater is a long-term one but is thought to be of low magnitude. The impact is also a function of the mining operating technique. If there is a collapse of the overburden when extraction is practised, the pollution potential could be enhanced by greater seepage of water to the problem formations. Seepage with elevated conductivity from rehabilitated spoil material used as backfill can also collect in subsurface depressions in the lowest mined coal seam floor. The whole matter of groundwater quantity and quality in rehabilitated spoils is receiving attention at present. When there is good housekeeping open cast mining need not present a problem to surface waters. Groundwater and rain accumulating in the open pit is pumped out to settlement dams and treated, if necessary, before discharge. Overflow into streams is, however, still causing problems in some areas. Where such mine drainage discharges into streams a characteristic red to yellow deposit of iron components is formed on the streambed, the pH and oxygen content is lowered and living organisms are destroyed, hence impairing the self-purification powers of the stream. When strips of mined areas are back-filled the pollution impact is considerably lessened. Strip mine lakes are formed when the last act or final void of an opencast mine is not backfilled and is allowed to fill with water. Toerien et al (1983) found these waters to be somewhat mineralized but otherwise of good enough quality to be used for irrigation or to support aquaculture or recreational angling for certain species of fish.

Gold mining

The majority of South Africa's gold mines lie within the catchments of the Barrage, and Bloemhof and Vaal Dams. Mining activities can give rise to water pollution by a number of mechanisms, the most significant being oxidation of pyrite in gold bearing reef, to dissolved iron and sulphuric acid. This mechanism is particularly problematic in old excavations. Mine service water can have a low pH value as well as a high salt content (TDS ranging from 1 500 to 4 000 mg l^{-1}). Discharge of lime (or soda ash) neutralized brackish mine service water, as well as wastewater from reduction works may present problems to the environment and need to be carefully monitored and controlled.

Mine dumps, consisting of worked out reefs, contain a significant amount of pyrite (0,8 to 1,6% as S) which can oxidize to form sulphuric acid. Revegetation of mine dumps has been demonstrated as an effective means to limit environmental (both air and water) pollution by binding the sediments and reducing surface runoff. Mine dumps, not revegetated, contribute significantly to the pollution in rivers in close proximity to these dumps. In contrast, surface water which infiltrates the dumps is neutralized in their alkaline interiors.

Cyanide pollution from gold mines is not considered a significant problem, since the cyanide is directly associated with gold recovery and these effluents are very well managed on site. Cyanide that does escape the process and is discharged in the effluent to the slimes dams, forms insoluble iron cyanides.

Fuel production and power generation

Fuel processing produces many atypical pollutants in effluents (eg sodium, fluorides and a variety of nonbiodegradable organic compounds). Furthermore the effluent from satellite industries may contain extremely high concentrations of phosphorus, nitrates and ammonia (up to a few thousand milligrams per liter). At present SASOL I discharges its effluent into the Vaal River below the Barrage. Dilution water from the Barrage is sometimes necessary to maintain acceptable fluoride levels at Parys. SASOL II and III are still storing their effluent in evaporation ponds and maintain a positive water balance. However, such storages need very careful design and maintenance to ensure that no seepage or large-scale accidental spillage takes place.

Potential water pollution sources from power generating plants are oil spills and highly alkaline ash water. The occasional spill can have a serious, immediate effect on the local stream. Neither should, however, present problems if properly managed on site. Ash dumps have long-term low intensity effects on water quality. Return flows from power stations are diverted to the dumps where they evaporate. Ho flows are thought to reach ground and surface waters if properly managed. This still needs to be confirmed for specific local conditions.

Atmospheric pollution from power generation and fuel production poses real and potential problems to public health, agriculture and the water environment. Enhanced metal corrosion is a further problem. Although extensive monitoring is underway, the pollution budget, made up of various emissions, relocation and modifications during transport and wet and dry deposition, is far from quantified. As far as the Vaal catchment is concerned, both imports and exports of air pollutants are possible. A special feature to South African air pollution is the highly stable atmospheric condition during anticyclonic conditions which predominate in winter. Impacts on agriculture, forestry and on the water environment have so far not been demonstrated in South Africa. Emission control in South Africa to date is mainly related to the health hazard. Because of the very gradual build-up of these problems and the potential widespread and long-term impacts, as experienced overseas, very careful monitoring of the pollution budget and potential impacts is essential.

Urban and industrial development. The Vaal catchment and its supply area houses 42% of the urban population of South Africa and is responsible for 56% of the total industrial production (Raubenheimer et al 1985). The largest concentration of these activities is in the PWV complex which falls mainly in the Barrage catchment. Pollution of water resources through industrial and municipal effluents, solid waste disposal and other diffuse sources is the major problem relating to this land use.

Eutrophication

Eutrophication of receiving waters is the major problem with effluents from urban development. Some of the manifestations of eutrophication in the Vaal catchment are discussed in section 3.3.3. The special phosphate standard is currently applied in the Vaal Dam and Barrage catchments to reduce eutrophication. The standard has not yet been enforced in the Bloemhof Dam catchment, but the extension given till 1988 can be withdrawn should it prove necessary (Oliveira 1986). Various effluent reuse strategies, either direct or after discharge into a stream, provide options for the future water management strategy in South Africa. A particular problem of any reuse policy is the resultant increase in TDS concentration. Management options in this regard, including blending, desalination, salt sinks and bypassing to downstream discharge points are presently investigated by the Department of Water Affairs.

Solid wastes

Disposal of solid waste is becoming a problem as municipalities find it increasingly difficult to find suitable disposal sites. If not disposed of in a proper manner, solid wastes can give rise to pollution of surface and ground waters. The type of contamination that can occur from this source is variable and includes pesticides, heavy metals, polychlorinated hydrocarbons and salts. The chemical oxygen demand of solid waste dump leachates is often higher than raw sewage (Oliveira 1986). Solid wastes have been shown to have serious long-term effects on underground water quality in other countries. With the increased use of groundwater in the Vaal catchment this problem will need careful consideration and study. Solid waste disposal in pans could lead to destruction of the ecosystem (eg Welkom) apart from being aesthetically displeasing.

Hydrological effects

Hydrological effects of urbanization are very important at the local authority level. Flooding potential is increased, runoff quality deteriorates (oils, organic pollutants, metals, pathogens and increased salinity) and canalization of streams transfers the flooding problem downstream. A canalized river section has little or no self-purification potential and presents a large safety risk for inhabitants in the urban environment.

Squatting

Rudimentary urban development and squatting have very similar problems to planned urban development. Air pollution levels from coal and wood burning are generally high. Solid wastes are mainly an aesthetic problem but could also lead to deterioration in water quality. Lack of proper sewerage leads to increased uncontrolled diffuse nutrient pollution. Pathogens from these diffuse sources are probably the biggest hazard.

Organic contaminants

A survey by Bruwer et al (1985) showed micro-organic contamination along the entire length of the Vaal River downstream of the Barrage. In the concentration range of 0,25 to 0,5/A-g 1~* up to 80 compounds have been detected, many typical of domestic and industrial effluents. There was also evidence of bio-accumulation of polychlorinated biphenyls (PCBs) and chlorinated pesticides in fish.

Van Steenderen et al (1986) report a high degree of organic contamination in the Vaal River below the Barrage to Parys. High concentrations of phenolic compounds were found. Phenolics in water can cause serious taste and odour problems, especially after chlorination.

Bruwer et al (1985) point out, however, that the concentrations of organic contaminants in fish of the lower Vaal are 100 to 1 000 fold lower than those reported for watersheds of the North American Great Lakes.

Agriculture and Forestry. The Vaal River catchment is responsible for about 42% of South Africa's agricultural production and this plays a vital role in the food production of the country. Agricultural activities cover the whole catchment area and land use is divided into roughly equal parts between intensive cultivation, mixed fanning and stock farming (Slabber 1980). There is virtually no afforestation in the catchment.

Irrigation

Agricultural water use (irrigation) represents 22% of the total water use in the catchment. Agricultural impacts on the water environment are related to abstractions, return flows, influences on water quality and modifications to the hydrological regime due to changed land use. The quantity effects have already been discussed in 3.2.1.

Irrigation return flow makes a major contribution to increased salinity in the Vaal River particularly below the Barrage. The quantity and salinity of the return flows are a function of a variety of factors, including type of soil, irrigation practice, groundwater table situation and quality of water applied. The raised salinity levels can affect downstream users (irrigation, industrial and potable water supply) and it also results in decreased turbidity in the greater part of the Vaal River. The greater light penetration in turn results in increased primary productivity, which is reflected in extensive stands of rooted underwater macrophytes in sections of the lower Vaal River (Grobler et al 1986).

Erosion

Little evidence is available of increased erosion due to changes in land use and thus reduction in storage capacity of the major storage dams is not severe. Turbidity in Vaal Dam can in fact be regarded as beneficial from a water quality point of view as it suppresses algal growth as a result of eutrophication.

Nutrient pollution

Diffuse loads of nutrients from runoff from fertilized agricultural land should only have a very limited effect on eutrophication at this stage compared to point sources although early season flushes may cause increased peaks of nutrients in rivers and reservoirs.

Intensive animal feeding units can be a source of pollution if not properly managed. They occur throughout the catchment and are controlled as point sources (Oliveira 1986).

Pesticides

The use of pesticides on agricultural land can lead to the death of nontarget organisms and so a decrease in aquatic species diversity. Complaints of fish, bird and animal kills attributed to pesticide applications are often received (Oliveira 1986). The long-term detrimental effects related to bio-accumulation in aquatic fauna and flora are not known. Such bio-accumulation has been detected in fish between the Barrage and Douglas (Bruwer et al 1985). The most commonly encountered chlorinated pesticide in fish is ppDDE, a metabolite of ppDDT. Bruwer et al (1985) also reported a trend which may be indicative of a gradual disappearance of chlorinated pesticides from the environment. Such surveys should be followed up in potential problem tributaries with intensive agricultural activity like the Harts River.

Conservation and recreation

Conservation

Demands on the Vaal system for water supply are exceptionally high and the river and its tributaries are the only water bodies into which effluents can be discharged. All rivers, except the extreme headwaters, are therefore highly regulated and modified, giving conservation a broader meaning beyond that of wildlife and habitat protection so often attributed to it by the layman. Conservation of aquatic resources in the Vaal river catchment must be viewed in the IUCN context of an already highly modified system.

In general, conservation is inextricably linked to the overall catchment objective of supplying adequate quality water for human use. In the headwater catchments of the east and south-east, conservation of pristine or slightly modified streams will achieve the protection of natural habitats and ensure a reliable supply of high quality water to the downstream reaches where demand is greater. Below the Grootdraai Dam where the Vaal and most tributaries to the north are highly modified, conservation should largely adopt other objectives.

1. Management of aquatic ecosystems, natural or modified, should ensure that they maintain a high potential for "self-purification". This includes both in-channel communities important in pollutant removal and fringe plant communities which stabilize the banks thus reducing erosion and silt load.

2. Provide for a full range of consumptive (hunting, fishing etc where the resource is used up during recreation) and nonconsumptive (bird and wildlife watching, picnicing etc, where the resource supply is not reduced) aquatic recreational activities. Recreation of course demands good water quality so that the two objectives are closely related. It is important to recognize in this context, that the extent to which any aquatic system has departed from a self-sustainable state may be measured in the units of energy or monetary input required to rectify the situation. The magnitude of these inputs is dependent on current public values, with the levels of corrective action being set by what is publically acceptable at the time.

Recreation

The major concentration of both consumptive and nonconsumptive recreational activities occurs between the Vaal Dam and Bloemhof, and while this general trend will remain, the intensity of use can be expected to spread both up- and downstream as demand increases. The following impacts on the water resources will therefore need to be monitored.

1. Modification of the riparian zone.
2. Fuel and oil spills, bank erosion and resuspension of sediment from power-boating.
3. Disturbance of human enjoyment, fish, birds and same.
4. The introduction or spread of alien plants.

Consumptive uses of the system have a finite capacity which needs to be established for each use and each section of the river and its tributaries. Nonconsumptive use will, however, increase steadily and conflict between the two can be expected to rise. A detailed land-use plan is therefore required for at least the riparian zone of the river to overcome the potential conflict and meet objectives in the face of increasing recreational demand.

3.3.3 Eutrophication: causes and consequences

Information on the algal concentrations and assemblages in the Vaal River downstream of Vaal Dam indicates that the river is eutrophied and polluted. Very large blooms of planktonic algae are observed, especially in sections of low flow or above weirs (Pieterse 1986). Extensive infestations of aquatic macrophytes also occur in sections of this river stretch (Bruwer 1986).

There are few historical data on the nutrient status of the Vaal River. Bruwer et al (1985) report ortho-phosphate levels of between 0,15 and 0,28 mg 1~* in the stretch up to the Vaal/Skoonsprait confluence and 0,01 and 0,06 mg 1^{-1} in the downstream stretch up to Douglas weir. Grobler et al (1986) quoted a mean total phosphate of 0,14 mg 1~* and mean ortho-phosphate of 0,06 mg I"^{1} in Vaal Dam and 0,06 and 0,02 mg I"^{1} for the same constituents in Bloemhof Dam respectively. Despite a higher nutrient status, chlorophyll concentrations in Vaal Dam are much lower than in Bloemhof Dam (about l^cg 1^{-1} compared to about 27ytig I"^{1} in Bloemhof Dam). Grobler et al (1986) ascribe this difference in primary production to the reduced turbidity and increased light penetration, partially as a result of increasing salinization in the Vaal River downstream of the Vaal Dam.

Viljoen and van der Merwe (1986) show a strong upward trend in chlorophyll values in the Barrage between 1974 and 1985. In the 1980*s values higher than 30/t g 1^{-1} chlorophyll a are occurring between 40 and 60% of the time. The presence of algae in raw water used for domestic purposes causes interference with the treatment processes and problems in the distribution system. The algae may also pose a health hazard and impair the aesthetic quality of the potable water supplied. This has major cost implications and expensive technology, including the use of activated carbon, which may be necessary in future to treat the water to acceptable standards (Viljoen and van der Merwe 1986). Similar problems have been reported for most of the major domestic water suppliers downstream of the Barrage (Bruwer et al 1985). Algal growth also has negative impacts in agriculture, particularly on distribution and application systems (Bruwer et al 1985).

With the expected doubling of return flow volume to the Barrage by the year 2000 and the policy that all return flows must be used, an increase in nutrient loading to the lower Vaal River may be expected. The effect of the phosphate standard, however, should limit the extent of the increase (Bruwer et al 1985).

The extent and nature of the aquatic macrophyte problem is described by Bruwer (1986). Water hyacinth *(Eichhornia crassipes)* infestation has spread to river stretches from Parys to Bloemhof Dam and has impacts on water supply and particularly on recreation. It is envisaged that adequate control of the present level of infestation will cost an initial 3,6 to four million rand with an annual follow-up of one million rand. Biological control measures are also currently being investigated. Water hyacinth is already present in Bloemhof Dam and if control measures, involving riparian owners, are not implemented effectively interference with recreation at this dam can be expected.

Furthermore longer stretches of the river could become completely covered with hyacinth, possibly resulting in complete deoxygenation of the water and resultant water treatment problems and fish kills.

4. WATER RESOURCE MANAGEMENT OPTIONS

Water demand already exceeds the natural yield of the Vaal River catchment and the growth in demand will have to be met by other sources. Hater importation from other catchments will be the major additional source.

Local resources should be developed as fully as possible to minimize the importation needs. In this regard groundwater development and rainfall stimulation research should have high priority in the Vaal catchment.

The imbalance between supply and demand will place more emphasis on demand management in future. With its limited water resources South Africa cannot allow unregulated use of its water. Where the demand can be economically reduced this must be done.

A much greater emphasis on river control will be necessary to ensure equitable distribution of the resource and prevent wastage. This requires good measurements of flow, abstraction and of area under irrigation.

The assurance of water supply requirements of various sectors must still be evaluated. For this purpose the cost of nonsupply to these sectors must be determined. Where possible, consumers must develop strategies to cope with a variable supply situation.

Considerable water savings may still be possible in the agricultural sector. This will require the upgrading of irrigation techniques in certain schemes and a review of the economics of irrigation water supply. Water-supply-crop production curves are required for this purpose.

In general, downstream deterioration in water quality is fortunately in line with the general water quality requirements in the catchment. With some exceptions, agriculture can still tolerate the poorer quality in the lower part of the system. This will change as the quality deteriorates further. To evaluate management options in this regard water quality-crop production curves are required.

To maintain a favourable quality distribution in the Vaal catchment it may be necessary to encourage certain industries to relocate themselves in areas where their water quality requirements and effluent production can be better accommodated.

There should be as little wasteful use of the best quality water as possible. A large percentage of high quality water is utilized by power stations, whereas only a small percentage is required for boiler feed water. The major water use in power generation, ie cooling, could do with poorer quality water from effluents. This is also a question of economics.

Cascading water distribution systems could be implemented in which the effluents from one user could be used by another. This is already practised within particular industries and could be expanded by local authorities.

As water purification knowledge is growing it may become cheaper for certain industries to put up their own specialized treatment plants.

Consideration should be given to withholding certain effluent return flows to the Barrage. The mining sector which produces 25% of the salt in eight per cent of the water load to the Barrage is a prime candidate. The economic implications of such a step need careful evaluation, particularly in the light of the limited economic life of mines.

Water pollution control policies may vary with time. During certain periods while the Lesotho Highlands Water Project is phased in, there will be a surplus of water and dilution may be a feasible option. Furthermore future technological developments may make certain pollution control measures (ie desalination) economically more feasible in time.

Effluent standards may also vary regionally depending on the volumes involved, the ecological effects of discharges and the requirements of downstream users.

With the greater use of groundwater sources in future special efforts must be directed at controlling groundwater pollution.

The impact of diffuse pollution sources on the aquatic environment must be carefully monitored to ensure timely control measures.

At present no water is reserved for maintenance of riverine ecology other than the normal releases in the river, including return flows. The environmental water demands are not well defined but it is thought that they can mostly be accommodated in the operating policy without using additional water. This is already the case for recreational purposes, eg canoe races.

The overall objective would be to manage water resources on a sustainable yield basis. For this purpose the self-purification properties of the river and associated wetland systems must be maintained.

In all instances the general policy must be to manage the resources to the maximum national net benefit. Macro-economic analyses will be required to achieve this.

To achieve optimal and sustained multipurpose water use, a much greater coordination and integration of water and related land management activities will be required.

5. INFORMATION AND RESEARCH NEEDS FOR THE VAAL RIVER CATCHMENT

The single most important statement from the workshop was the need far a coordinated catchment management programme. Such a programme would have the following aims:

1. Encourage effective coordination of policies and activities of relevant departments, authorities, companies and individuals which impinge on the conservation, sustainable use and management of the catchment's resources, especially soil, water and vegetation.

2. Ensure the continuing productivity of soils, a satisfactory yield of water of good quality and the maintenance of appropriate protective and productive vegetative cover.

3. Ensure that land within the catchment is used within its capabilities in a manner which retains as far as possible, options for future use.

The quality and quantity of water at any point in a river is an expression of the interactions between biotic and abiotic processes, man-induced or natural, which take place in the upstream catchment. Water resources management must therefore have the same overall aims and will require a conceptual or planning framework, to guide decision-makers, which is supported by a known range of management options or "tools". The preceding text of this document provides both a conceptual framework and a proposal of major options but these are first attempts based on a poor data base. This section on information and research needs is the first step in the iterative processes of improving the data base and the management programme.

As there is no clear water quality management policy for the Vaal catchment at present, priorities have not been assigned to the information and research needs generated by the workshop. Numbering is thus only followed for future reference purposes. The sequence used is broadly; development of policies and plans; inventory and monitoring needs; the evaluation of a variety of impacts. Page numbers in brackets refer to the text where a particular need is indicated.

1. Economic assessment of pollution control policy options <pp 22).

2. Economic assessment of effluent reuse options (pp 16, 21).

3. Review and evaluate methods for treating eutrophic waters (pp 21).

4. Evaluation of the economic consequences of various levels of quality of the Vaal River water resources to be able to set water quality targets.

5. Development of conservation and recreation plans and strategies based on detailed inventory and classification of these systems (pp 16, 18-19).

6. Planning of land use in the riparian zone of the Vaal and its major tributaries (pp 18).

7. Determination of environmental water demands (pp 22-23).

8. Inventory, classification and economic assessment of the role of wetlands in catchment hydrology and water quality (pp 16-18 but widely applicable).

9. Inventory of conservation status, importance and potential of pristine or near-pristine tributaries and wetlands.

10. Establishment of an organic pollutant monitoring system (pp 16-17).

11. Supplementation of existing pollution surveillance with biological assessment (Biotic indices).

12. Development of techniques for the remote sensing of land-use changes (pp 16, 19-20).

13. Quantification of the atmospheric pollution {pp 15).

14. Establishment of the levels of pollutants and recreation related disturbances that a particular section of the river (includes riverine fringe and associated wetlands) can carry and still retain the elements of basic ecosystem functioning <pp 18-19, 22).

15. Improved understanding of the hydrological and water quality impacts of (a) urbanization and (b) agricultural practices (pp 11, 13).

16. The role of farm dams in the catchment water balance (pp 11).

17. The implications of squatter settlements for surface and groundwater quality (pp 16).

18. Evaluation of the impact of current solid waste (urban, industrial and mining) disposal policies on the water environment (pp 13, 16).

19. Consequences of (a) strip mine lakes (b) power station effluent dumps and (c) fuel processing effluent dumps for water quality and riverine biota (pp 13-15).

20. The effects of pollution on groundwater quality under various groundwater management options (pp 12).

21. Factors affecting water quality in the Vaal Dam and the effects of future management options on water quality (pp 4, 12).

22. The effects of changes in salinity on primary production in Vaal Dam and the rest of the system (pp 17).

23. The impacts of water transfer schemes on donor and receiver ecosystems (pp 12-13).

24. The sources, manifestations and consequences of dissolved and particulate organic matter loads in rivers (pp 16).

25. Development of relationships which couple air pollution to its effects on aquatic systems (pp 15).

26. The potential impact of weather modification on the environment.

27. The potential impact of groundwater development on the environment.

28. The influence of river regulation on the growth and distribution of indigenous (eg *Phragmltes, Potamogeton)* and exotic *(Eichhornia)* aquatic plants (pp 19-20).

29. More detailed studies of the blackfly problem aimed at improved control of blackfly.

30. Relationships between irrigation water quality and production of specific crops (pp 21).

31. The accumulation of pesticides in the aquatic food chain (pp 17-18).

32. The effects of high inorganic sediment turbidity on algal production and pollutant removal (pp 17-18).

33. Pipeline corrosion: cause, consequences and prevention (pp 12).

SELECTED BIBLIOGRAPHY

Archibald R E M 1968. Studies on the ecology and systematics of the diatoms (Bacillariophyta) from some South African rivers. MSc Thesis, Rhodes University.

Basson M S 1978. Flood forecasting for reservoir operation by deterministic hydrological modelling. University of the Witwatersrand, Hydrological Research Unit Report 1/78, 1-155.

Bekker A P 1980. Effect of statutory restrictions on the use of water from the Vaal River. Vaal River Catchment Association. Focus on the Vaal, papers of a symposium, Pretoria, 13 March, 1980. van Duuren F A, Potgieter F J and du Preez J F (editors), pp 153-155.

Best H J 1985. Water pollution aspects related to the mining industry. Mine Ventilation Society of South Africa. Symposium on mine water systems, 6-8 March 1985, Sun City Conference Centre, Bophuthatswana. PP 1-17.

Birch G F 1983. The clay mineralogy of sediments in the Vaal Dam and in the rivers supplying and draining the dam upstream of the barrage. Water SA 9/3, 117-124.

Botha J L, de Wet H 1984. The Sasol Two water system - economic implications of water quality. Vaal River Catchment Association. Symposium on water supply for the Vaal River catchment area and economic implications of water quality. CSIR, Pretoria, 16 March 1984. pp 1-14.

Brandt F D 1981. The occurrence and treatment of bothriocephalosis in the common Carp, *Cyprinus carpio* in fish ponds with notes on its presence Transvaal. Water SA 7/1, 35-42.

*Bruwer C A 1986. Macrophytes in the Vaal River. Symposium on the Vaal River ecosystem: status and problems. Occasional Report No 5. FRD, CSIR. Pretoria, pp 149-157.

Bruwer C A, van Vliet H R, Sartory D P and Kempster P L 1985. An assessment of water related problems of the Vaal River between Barrage and Douglas Weir. Technical Report No 121, Department of Water Affairs, Pretoria, pp 1-192.

Car M and de Moor F C 1984. The response of Vaal River drift and benthos to *Simulium* (Diptera-Nematocera) control using *Bacillus thuringiensis* (H-14). Onderstepoort Journal of Veterinary Research 51, 155-160.

Chutter F M 1963. Hydrobiological studies on the Vaal River in the Vereeniging area. Part 1. Introduction, water chemistry and biological studies on the fauna of habitats other than muddy bottom sediments. Hydrobiologia 21, 1-65.

Chutter F M 1967. Hydrobiological studies on the Vaal River and some of its tributaries, including an introduction to the ecology of *Simulium* in its lower reaches. PhD (Zoology) Thesis, Rhodes University.

Chutter F M 1967. Hydrobiological studies on the Vaal River. NIWR, CSIR Special Report WAT 38 (in two parts), Pretoria.

Chutter F M 1968. On the ecology of the fauna of stones in the current in a South African river supporting a very large *Simulium* (Diptera) population. Journal of Applied Ecology 5, 531-561*

Chutter F N 1970. Hydrobiological studies in the catchment of Vaal Dam, South Africa. Part 1. River zonation and the benthic fauna. Int. Revue ges. Hydrobiol. 55, 445-494.

Chutter F M 1971. Hydrobiological studies in the catchment of Vaal Dam, South Africa. Part 2. The effects of stream contamination on the fauna of stones-in-current and marginal vegetation biotopes. Int. Rev. ges. Hydrobiol. 56, 227-240.

Chutter F M 1971. Hydrobiological studies in the catchment of Vaal Dam, South Africa. Part 3. Notes on the Cladocera and Copepoda of stones-in-current, marginal vegetation and stoney backwater biotopes. Int. Rev. ges. Hydrobiol. 56, 497-508.

Chutter F M 1986. Biotic indices and water quality* Symposium on the Vaal River ecosystem: status and problems, 20 March 1986. Occasional Report Ho 5. FRD, CSIR, Pretoria, pp 209-223.

Cillie G G and van Vuuren L R 1984. Water reuse: possibilities and limitations. Symposium on water supply for the Vaal River catchment area and economic implications of water quality. 16 March 1984. CSIR, Pretoria, pp 1-16.

Clinning C F and Fouche C J 1986. Areas of conservation and recreational value within the Vaal River Catchment. Symposium on the Vaal River ecosystem: status and problems. 20 March 1986. Occasional Report No 5. FRD, CSIR, Pretoria, pp 224-234.

Cloete G S and Human J J 1980. Cotton production under irrigation and different cultivation practices at Vaalharts and Upington. Agroplantae (Pretoria) 12/2, 17-22.

Daneel A B 1970. The water requirements of the mining industry. Water year 1970. Convention on water for the future. November 1970, Pretoria, pp 1-8.

De Moor F C 1982. Determination of the number of instars and size variation in the larvae and pupae of *Simulium chutteri* lewis 1965 (diptera: Siauliidae) and some possible implications. Canadian Journal of Zoology (Ottawa) 60/6, 1374-1382.

De Moor F C 1986. Blackfly problems in and along the Vaal River. Symposium on the Vaal River ecosystem: status and problems. 20 March 1986. Occasional Report No 5. FRD, CSIR, Pretoria, pp 158-174.

De Moor F C, Chutter F M and de Moor I J 1986. Drift behaviour and micro-habitat selection in the pre-imaginal stages of *Simulium chutteri* (Diptera, Simuliidae). Hydrobiologia 133(2), 143-154.

Department of Water Affairs 1985. Vaal River systems analysis. Description of physical systems and operating rules. BKS Water Resources Associates Report. DWA Report No PC000/00/4385.

^Department of Water Affairs 1985. Draft report on the management of South African water resources. Department of Water Affairs, Pretoria.

Du Plessis H M 1984. Economic implications of water quality: irrigation water. Symposium on water supply for the Vaal River Catchment area and economic implications of water quality. CSIR, Pretoria 16 March 1984. pp 1-12.

Durand J and Hamman H 1982. Spray irrigation at Vaalharts - is it a good practice? SA Irrigation (Johannesburg) 4/6, 19-22.

Elges H F 1982. The dams of the Tugela-Vaal project. Civil Engineer in South Africa (Johannesburg) 24/8, 375-377.

Grobler D C, Brawer C A and Hall G C 1982. A comparison of chemical load estimation algorithms using data obtained by sampling four South African rivers at varying frequencies. Water SA 8/3, 121-129.

Grobler D C, Toerien D F and de Wet J S 1983. Changes in turbidity as a result of mineralisation in the lower Vaal River. Water SA 9/3, 110-116.

Grobler D C and Silberbauer M J 1985. The combined effect of geology, phosphate sources and runoff on phosphate export from drainage basins. Water Research (Oxford UK) 19/8, 975-981.

*Grobler D C, Toerien D P and Rossouw J W 1986. Effects of sediment on water quality in the Vaal River system. Symposium on the Vaal River Ecosystem: status and problems. Occasional Report No 5. FRD, CSIR, Pretoria, pp 115-148.

Harrison A D, Keller P and Lombard W A 1963. Hydrobiological studies on the Vaal River in the Vereeniging area. Part 2. The chemistry, bacteriology and invertebrates of the bottom muds. Hydrobiologia 21, 66-89.

"Henzen M R, Wiechers H N S and Chapman H C 1980. Research needs for the future. Paper presented at the "Focus on the Vaal" Symposium, Pretoria, March 13, 1980.

Herold C E 1980. A model to compute on a monthly basis diffuse salt loads associated with runoff. University of the Witwatersrand, Hydrological Research Unit report, pp 1-71.

Herold C E 1981. A model to simulate daily river flows and associated diffuse-source conservative pollutants. University of the Witwatersrand, Hydrological Research Unit report, pp 1-403.

Herold C E 1981. A model to simulate the monthly water and salt balance in the Vaal River water supply system. University of the Witwatersrand, Hydrological Research Unit report, pp 1-191.

HeroId C E 1981. A model to simulate the daily water and salt balance in the Vaal River water supply system. University of the Witwatersrand, Hydrological Research Unit report, pp 1-180.

Herold C E 1982. A deterministic simulation model to aid selection of management strategies for combating mineral pollution in the Pretoria-Witwatersrand-Vereeniging (PWV) region. International Association of Hydrological Sciences. International Commission on Hater Quality publication Ho 139, 245-254.

Hugo M L 1980. Die buitelugontspanningspotensiaal van die Vaalrivier. Fase I: Vredefortkoepel. Potchefstroom University for CHE, Potchefstroom.

Laburn R J 1976. Some aspects of water management in the Pretoria, Witwatersrand, Vereeniging metropolitan region. Hater Resources Bulletin (UBBAHA ILL) No 12/1, 65-81.

Lenhard G and du Plooy A 1965. Studies on bottom deposits of the Vaal River System. Hydrobiologia 16, 271-291.

*Maaren H and Moolman J 1986. The effects of farm dams on hydrology. Paper presented at the Second South African National Hydrology Symposium, Pietermaritzburg, September 16-18, 1985.

Maian H C 1960. Survey of the Vaal Dam Catchment area. Part 1. The chemical composition of the main tributaries. CSIR. Research Report 166, 1-31.

Mason-Williams S 1984. The Bethlehem run-off augmentation research project: past, present and future. Department of Environment Affairs Technical Report So TR118, 1-75.

Hiddleton B J, Pitman H V and Hidgley D C 1981. Surface water resources of South Africa. Volume II: drainage region C - the Vaal Basin, Part 1 (text). University of the Witwatersrand, Hydrological Research Unit Report No 8/81.

Middleton B J, Pitman H V and Hidgley D C 1981. Surface water resources of South Africa. Volume II: drainage region C - the Vaal Basin, Part 2 (appendices). University of the Witwatersrand, Hydrological Research Unit Report No 8/81.

Midgley D C and Townshend P D 1984. High flood levels along the barrage reach of the Vaal River. Civil Engineer in South Africa (Johannesburg) 26/2, pp 53, 56-57.

Mileikowsky R N 1980. A mathematical model for simulating daily salinity fluctuation in the Vaal Barrage. University of the Hitwatersrand Hydrological Research Unit Report No 4/80.

Mulder P F 1986. Fish populations of the Vaal River. Symposium on the Vaal River ecosystem: status and problems. Occasional Report No 5. FRD, CSIR, Pretoria, pp 200-208.

*Nel A, Hessels P and Barta B 1982. Orange Vaal Heirs Project: Environmental and socio-economic impact assessment. Report No V/E 004. Department of Environment Affairs, Pretoria.

*Oliveira M P 1986. Sources of pollution in the Vaal River. Symposium on the Vaal River ecosystem: status and problems. Occasional Report No 5. FRD, CSIR, Pretoria, pp 32-45.

*Pieterse A J H 1986. Aspects of ecology and significance of algal populations of the Vaal River. Symposium on the Vaal River ecosystem: status and problems. Occasional Report No 5. FRD, CSIR, Pretoria. PP 175-199.

*Pitman W V 1985. Hydrology of the Barrage catchment. Part of Vaal River system analysis by BKS Water Resources Associates in association with SS&O, Department of Water Affairs, Pretoria.

Pitman W V and Basson M S 1980. Operation of reservoirs for flood control in areas with limited water resources. International Association of Hydrological Sciences publication 129. Proceedings of the Oxford symposium, 15-18 April 1980. pp 535-543.

Pretorius S J, Oberholzer G and van Eeden J A 1976. The Tugela-Vaal State Water Scheme as a bilharzia risk. South African Medical Journal (Cape Town) 50/25, 968-972.

Rogers K H 1986. The value and functions of wetlands in catchments. Symposium on the Vaal River ecosystem: status and problems. Occasional Report No 5. FRD, CSIR, Pretoria, pp 98-114.

*Raubenheimer A J, Midgley D C and Vrey W J H 1985. Verslag van die Komitee van Ondersoek insake Watervoorsiening vir die Vaalriviergebied. Pretoria.

Rudd R T 1973. The impact of slimes-dam formation on water quality and pollution. Journal of the South African Institute of Mining and Metallurgy (Johannesburg), pp 184-192.

"Slabber J D 1980. Benutting van landbouhulpbronne. Paper presented at the 'Focus on the Vaal' Symposium, Pretoria, March 13, 1980.

Stander G L, Malan W C and Henzen M R 1962. The chemical quality of the water of the Vaal River between the Barrage and Kimberley. NIWR, CSIR report W14, Pretoria, pp 1-14.

Stephenson D 1985. The economics of alternative water supplies for the Witwatersrand. Imiesa (Johannesburg) 10/8, 11-13, 15.

Steyn D J and Toerien D F 1976. Eutrophication levels of some South African impoundments 4. Vaal Dam. Water SA 2/2, 53-57.

Steynberg M C, Viljoen F C and Pieterse A J 1985. Eutrophication in the Vaal Barrage: past, present and future. Biennial conference and exhibition of the Institute of Water Pollution Control, southern African branch, Durban, 27-30 May Vol 1. pp 1-17.

Streutker A 1977. The dependence of permanent crop production on efficient irrigation and drainage at the Vaalharts Government Water Scheme. Water SA 3/2, 90-103.

Streutker A 1981. Irrigation* crop yield and drainage on the Vaalharts Irrigation Scheme 1. The contribution of farm water usage, irrigation management and leakage from the canal system to waterlogging. Water SA 7/2, 97-106.

Streutker A and Molenaar H W 1981. Irrigation, crop yield and drainage on the Vaalharts Irrigation Scheme 2. The occurrence of and the influence of drainage on salinised soil. Hater SA 7/3, 175-184.

Streutker A, van Vliet N and Molenaar H W 1981. Irrigation, crop yield and drainage at the Vaalharts Irrigation Scheme 3. The influence of salinization above a shallow ground table on the yield of wheat and other crops. Water SA 7/4, 255-264.

Streutker A, Durand D J and Kotze F G 1983. Irrigation, crap yield and drainage on the Vaalharts Irrigation Scheme 4. Good flood irrigation on a fine sandy soil. Hater SA 9/4, 163-176.

Theron S J, Hassett A J and Siebert M 1983. The organic and inorganic quality of raw and treated drinking-supplies in the Pretoria-Hitwatersrand-Vereeniging area. Biennial conference and exhibition of the Institute of Hater Pollution Control, southern African branch, papers. 16-19 May 1983, London. 4/01-4/11.

-Toerien D F, Halasley R D, Botha J D and Mitchell S A 1983. The summer limnology of South African strip mine lakes. Report of the Institute for Environmental Sciences, University of the Orange Free State, Bloemfontein. 60 pp.

*Triebel C 1986. Hater resources planning for the Vaal River catchment area. Symposium on the Vaal River ecosystem: status and problems. Occasional Report No 5. FRD, CSIR, Pretoria, pp 98-114.

"Vaal River Catchment Association 1981. Africa's hardest-working river. Bulletin of the Vaal River Catchment Association, Pretoria.

Van der Merwe S H 1984. The economic implications of water quality in the supply of potable water by the Rand Hater Board. Symposium on water supply for the Vaal River catchment area and economic implications of water quality. CSIR, Pretoria, 16 March 1984. pp 1-23.

Van der Riet P 1975. Simulation of inter-basin water transfer systems with special reference to the Tugela Vaal Scheme* University of the Hitwatersrand Hydrological Research Unit Report 8/75, 1-85.

Van Rensburg J F, van Rossum P G and Hattingh H H 1978. Organic chemical pollution of the raw water supplies of the Pretoria/Witwatersrand/ Vereeniging region - a health hazard. Conference of the Institute of Hater Pollution Control, southern African branch. Port Elizabeth, 13-17 March 1978. pp 1-21.

Van Robbroeck T P 1979. Inter-basin water transfers in South Africa. Civil Engineer in South Africa (Johannesburg) 21/2, 29-35.

*Van Steenderen R A, Theron S J and Hassett A J 1986. Organic micro-pollutants in the Vaal River. Symposium on the Vaal River ecosystem: status and problems. Occasional Report No 5. FRD, CSIR, Pretoria. PP 58-78.

*Van Vliet H R 1986. General chemical quality of the Vaal River. Symposium on the Vaal River ecosystem: status and problems. Occasional Report No 5. FRD, CSIR, Pretoria, pp 58-78.

Viljoen F C 1984. The necessity of phosphate restrictions within the Vaal River Barrage catchment. Imiesa (Johannesburg) 9/9, 11, 13-15.

*Viljoen F C and Van der Merwe S W 1986. Problems and economics of bulk water supply. Symposium on the Vaal River ecosystem: status and problems. Occasional Report No 5, FRD, CSIR, Pretoria, pp 58-78.

Viljoen F C and Haynes R E 1985. Financial implications of eutrophication. Institute for Pollution Control, southern African branch. Proceedings of the symposium on the impact of phosphate on South African waters, Pretoria, 22 November 1985. pp 1-18.

Vinciguerra M T and Heyns J 1984. Freshwater nematodes from South Africa 8. New and known species Actinolaimoidea. South African Journal of Zoology (Pretoria) 19/3, 135-140.

Vos J A 1982, The determination of flood damage in rural settlements based on 1975 floods in the Vaal River as well as instructions for the reduction of flood damage Volume 1. University of the Orange Free State Institute of Social and Economic Research report, pp 1-319.

Vos J A 1982. The determination of flood damage in rural settlements based on 1975 floods in the Vaal River as well as instructions for the reduction of flood damage Volume 2. University of the Orange Free State, Institute of Social and Economic Research report, pp 1-64.

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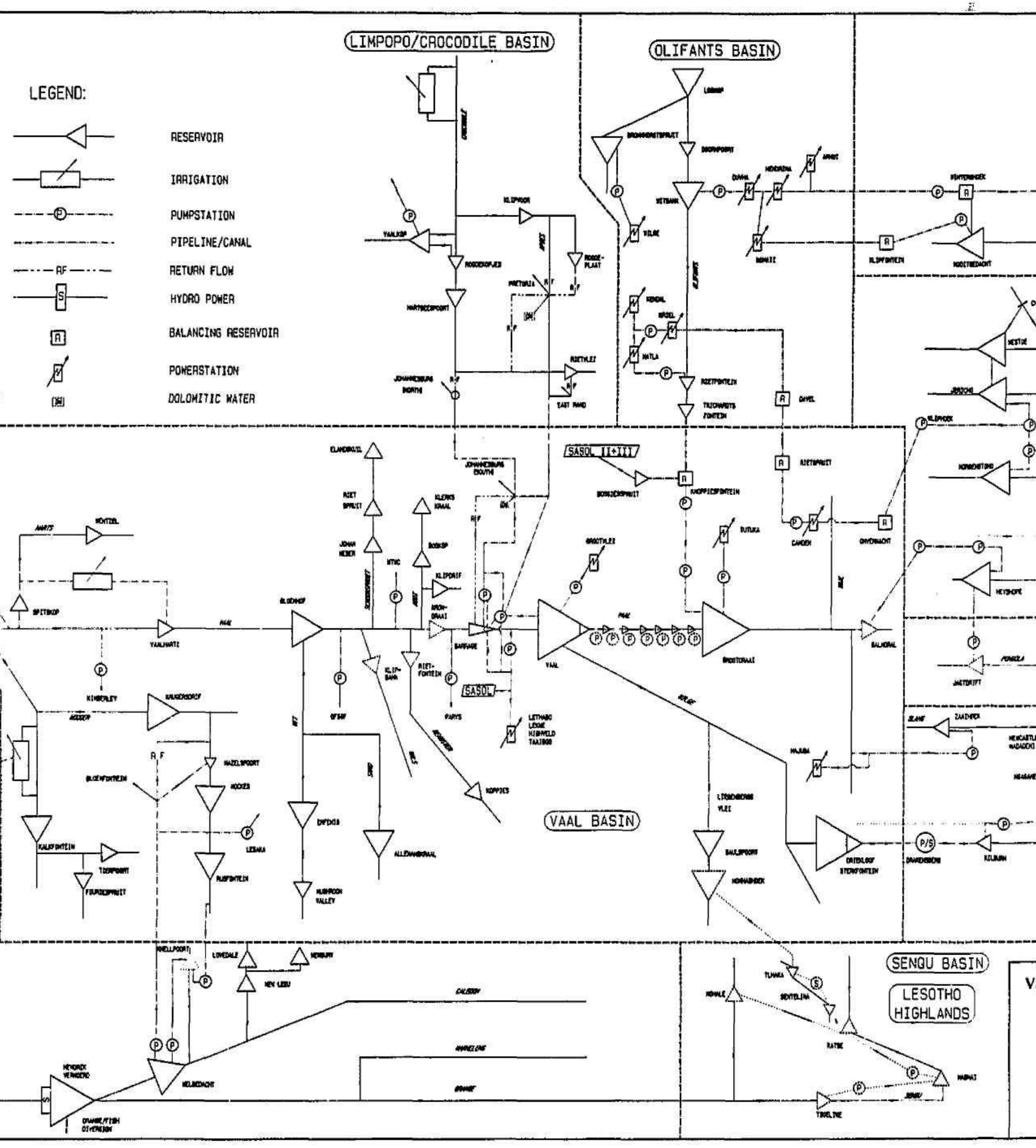
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