AN ECONOMIC AND TECHNICAL EVALUATION OF REGIONAL TREATMENT OPTIONS FOR POINT SOURCE GOLD MINE EFFLUENTS ENTERING THE VAAL BARRAGE CATCHMENT

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EXECUTIVE SUMMARY

AN ECONOMIC AND TECHNICAL EVALUATION OF REGIONAL TREATMENT OPTIONS FOR POINT SOURCE GOLD MINE EFFLUENTS ENTERING THE VAAL BARRAGE CATCHMENT

This report is divided into five chapters and three appendices. The first chapter gives an introduction to the project and an outline of relevant background information. The second chapter discusses the sequence of events that lead to the development of the proposed desalination strategies, while chapter three gives the methodology adopted for the comparison of the strategies. Chapter four presents the proposed conceptual desalination strategies together with budget costs and direct savings to users resulting from their implementation. In chapter five the specific and general conclusions and recommendations are discussed and recommendations for further research are proposed. The content of the five chapters is summarised below.

INTRODUCTION AND BACKGROUND

Recent studies have indicated that four gold mines (Grootvlei, DRD, WAGM and ERPM) are contributing as much as 26% of the salt load entering the Vaal Barrage by way of their point source discharges. It has further been estimated that this salt load is contained in only 5% of the flow.

In August 1995 an environmental impact assessment commissioned by the Department of Minerals and Energy concluded that the proposed quantity and quality of mining effluent to be discharged from Grootvlei to the Blesbokspruit would have a limited detrimental effect on the relevant receiving water bodies. Some months later a red slime was observed in the Blesbokspruit. This caused wide-spread concern that the Ramsar certified wetland within the Blesbokspruit was under threat from the introduction of polluted mine water. A number of studies were commissioned to assess the extent of the damage and to recommend methods of minimising the impact.

It was the conclusion of the Grootvlei Joint Venture Committee, that three possible future scenarios needed to be considered with regard to whether de-watering should be allowed to continue or not.

The first scenario considered, was that of ceasing the pumping at Grootvlei immediately, which would imply immediate closure of the mine. It was concluded that the implementation of this scenario would be detrimental to the regional economy and would merely defer the problem until the water table had risen sufficiently for decant to take place at Nigel.

The second scenario considered, was that of allowing pumping to continue (and hence mining) while ensuring that the pumped effluent was clarified and the high iron concentration was reduced to acceptable levels prior to discharge. This scenario was considered to be an acceptable short-term solution because it was concluded that the Blesbokspruit wetland would be able to withstand the effects of a saline discharge for approximately two years without undue negative impact.

The third scenario considered was that of allowing pumping and mining to continue but with the proviso that the pumped effluent be desalinated. It was recognised that this option would be costly and hence the second option was implemented immediately and desalination was deferred until a cost-effective method of desalination could be selected.

Against this backdrop and current water treatment pilot plant trials at Grootvlei this project was commissioned, with the following objectives:

1. Propose conceptual strategies for the cost-effective management/treatment of point source mining effluents emanating from Grootvlei, DRD, WAGM (Randfontein No 4 shaft) and ERPM.
2. Confirm the current contribution of these point source discharges to the total salt load entering the Vaal Barrage and ascertain the downstream effects of reducing the salt load upstream.
3. Estimate the costs to users of water from the Vaal river between the Vaal dam and Balkfontein, which can be ascribed to the point source discharges, for purposes of comparison with the costs of management/treatment.

BASIS FOR THE DEVELOPMENT OF STRATEGIES

In order to develop conceptual strategies for the management/treatment of mining effluents, it was necessary to gather sufficient information to determine the extent of the problem and the locations that required the most urgent attention. This was completed in four phases.

In the first phase, estimates of water qualities and quantities were compiled with the assistance of the four mines. In the second phase, the salt load emanating from each of the mines was compared. It was immediately obvious that Grootvlei contributed a disproportionately large load (approximately 80%) compared to the other three mines. Data was also gathered on the water qualities and quantities in the river system between the Vaal dam and the Vaal barrage. These data indicated that the four mines contributed approximately 35% of the total salt load entering the Vaal Barrage and in approximately 6% of the flow. The 9% increase in the salt load and 1% increase in flow, compared to studies prior to the end of 1996, are due to the increased discharge rate from Grootvlei since 1996.

In phase three it was necessary to devise a method of comparing various treatment processes in an equitable manner, which would cater for the different water recoveries and salt rejections of the processes. It was decided that each process would be compared in a side-stream configuration, the product water from which, would be re-blended with the main stream to conform to a pre-determined TDS concentration. Budget costs were then estimated for each process to provide an indication of the most cost-effective processes. Savings to users downstream were estimated to provide an indication of the benefits that would result from implementing of the different treatment processes. However, income derived from the sale of potable water or by-products was not included in these benefits. The annual expenses associated with desalination were calculated to be up to 8 times greater than the savings accruing to downstream users in an average 5-year river flow cycle. In a dry 5-year cycle, annual expenses were found to be up to 6 times greater than savings accruing to downstream users. From this finding it was clear that any income which could be derived from a particular process through the sale of water or by-products, should be included in the cost calculation to offset the annual expenses and obtain a more realistic figure. The "side-stream" method of comparing the processes therefore needed to be modified since the product water was to be sold and no longer re-blended with the main stream.

In phase four estimates were, therefore, made of the quantities of by-products and/or potable water (if applicable) which could be produced by each process and from these, the potential income from the sale of these by-products was estimated. This laid the foundation from which conceptual strategies could be formulated.

METHODOLOGY TO ASSESS THE STRENGTHS AND WEAKNESSES OF DIFFERENT STRATEGIES

In order to assess the strengths and weaknesses of the various strategies it was important to quantify the overall benefits or costs of each strategy.

Direct costs of treatment were estimated by subtracting the annual operating costs (which include repayment of capital) from the annual income derived from the sale of by-products. The effect of a given price in reducing the salt load entering the Vaal Barrage was then estimated by use of a water and salt balance model (Aquabat®). The model was set up in order to estimate the TDS concentrations at a number of different abstraction points along the Vaal river. A change in the salt load upstream could then be modelled to produce an estimate of the change in salt load at different abstraction points.

The estimated TDS concentrations at the major abstraction points allowed for user savings to be estimated using a salinity costing model specifically adapted for the purpose. According to the type of abstractor, (Eskom, Rand Water etc.) a reduction in salt load was thus converted into an annual monetary saving. The report provides details on how the treatment costs (e.g. rate of real interest rate and payback period used for the calculation of annual capital repayment) were estimated and how the Aquabat and salinity cost models were set up and used.

This methodology enabled not only a comparison of the *costs* of different strategies but just as importantly, a comparison of the *effect* of different treatment strategies.

The comparison generates three main outcomes:

1. Treatment *is* profitable and even without addition to the savings to users downstream; an overall benefit arises.

2. Treatment is *not* profitable but the savings to users downstream offset this annual loss and yield an overall benefit.

3. Treatment is *not* profitable and the savings to users downstream do *not* offset this annual loss and hence there is no overall benefit.

The development and assessment of the strategies were based on the following main assumptions:

1. Desalination processes that have been tested on a pilot scale are technically feasible for use as part of a water management strategy in this study.
2. Specific prices of by-products were assumed. Changes in these prices will have an affect on the costs determined in this study. Uncertainty exists regarding the quality of the elemental sulphur produced by the Biosulphate process it is thus not included as a by-product.
3. The capital required for initial construction of a process is paid back over a period of 20 years at a real interest rate of 8%.
4. Enhanced spray evaporation was assumed as the brine treatment option for those processes that do not include brine treatment.
5. Potable water is sold at 200 c/m^3.
6. The additional levy of 90 c/m^3 on subsurface abstraction would be varied and was thus not factored into the economic calculations.
7. The mix of activities within the various economic sectors is similar for the Middle Vaal- and the Vaal Barrage catchment (for which the salinity costing model was developed).
8. The ingress of water from Blesbokspruit into the Grootvlei mine workings is in the order of 50% of the volume pumped out of Grootvlei. This assumption is based on experience at the mine and should be investigated properly before any strategies that rely on this assumption are implemented.

The study and models developed for this study have the following limitations:

1. The costs determined and used in the study are budget costs. These costs are furthermore dependent on the quantity and quality of the water to be used.
2. The study focuses on the Vaal Barrage catchment. Additional economic benefits in the Middle Vaal, due to lower salinity in the Vaal River, were not included.
3. Future development and changes in catchment management that will affect the Vaal Barrage catchment were not considered in the study.
4. The minimum accuracy of the water and salt balance was set as 70%. The actual balances are in the range of 80% - 90% accuracy.
5. The water and salt balance model is a static model calibrated for a 5-year moving average. The model is more accurate for average to dry 5-year periods and should not be used for very wet 5-year periods, unless it is re-calibrated for high rainfall scenarios.
6. The user cost model has a margin of error, e.g. an overestimation of 35% of salinity will result in costs being overestimated by 44% (see Table 3.2).

CONCEPTUAL STRATEGIES FOR REDUCING THE SALT LOAD TO THE VAAL BARRAGE

The eight conceptual strategies that were selected, are aimed at providing practical alternatives for reducing the salt load emanating from the four mines. Some of these strategies can be used in combination with others and cover alternatives that do not necessarily involve desalination.

Strategy 1 involves the desalination of 130 Ml/d of effluent (at a TDS of 4 156 mg/l) discharged from Grootvlei Mine. The costs and benefits of eight different desalination processes are given, namely: AQUA-K, ASTROP, Biosulphate, EDR, GYP-CIX, RO, SAVMIN and SPARRO.

For *strategy 2* costs and benefits are estimated for the combined treatment of the 16 Ml/d of effluent produced at East Rand Propriety Mines (ERPM) and the 130 Ml/d produced at Grootvlei. The ERPM effluent is piped to Grootvlei and the capital and operating costs of the pipeline are included.

Strategy 3 deals with the combined treatment of the 7 Ml/d of effluent produced at Durban Roodepoort Deep Mine (DRD) with the 40 Ml/d of effluent produced at Western Areas gold Mine (WAGM). The DRD effluent is assumed to be piped to WAGM.

In keeping with the idea of regional treatment, *strategy 4* was set up to provide for the combined treatment of the effluents from all four mines at Grootvlei. The costs of reticulating the effluents from DRD, WAGM and ERPM are included.

Strategy 5 explores the concept of "brine bleeding". It is sometimes possible to take advantage of the higher and low salinity flows experienced in summer for disposal of a portion of the brine produced by a desalination plant. The applicability of this method of reducing treatment costs is assessed in the context of the effluent discharged from Grootvlei to the Blesbokspruit.

It has been suggested that up to 50% of the water currently being de-watered from Grootvlei originates from the Blesbokspruit. *Strategy 6* explores the possibility of constructing a 65 Ml/d open by-pass channel parallel to the Blesbokspruit to reduce the ingress of water into the Grootvlei workings. It is assumed that the construction of the channel reduces the quantity of water entering Grootvlei by 50% and hence only 65 out of a possible 130 Ml/d is required to be de-watered. The 65 Ml/d which is de-watered is assumed to be desalinated and the channel is designed to convey 65 Ml/d during summer and no flow during winter.

Strategy 7 also involves a by-pass channel but in this case it is designed to convey 130 Ml/d in summer (of which 65 Ml/d is de-watered from Grootvlei and the remaining 65 Ml/d originates from above Grootvlei in the Blesbokspruit) and 65 Ml/d in winter (this is de-watered from Grootvlei). This strategy is essentially the same as strategy six, although desalination is not assumed to take place.

For *strategy 8* the flow being de-watered from Grootvlei be pumped to the Kafferspruit, which drains northwards to the Klipspruit and the Bronkhorstspruit dam. The capital and operating costs of the pipeline are estimated for flows of 35, 65 and 130 Ml/d. The *savings* to users of water from the Vaal system are included but the additional *costs* to users in the Bronkhorstspruit system are not included. The total costs and benefits of this strategy can therefore not be compared directly with the other seven strategies.

The strategies listed above were compared for an average 5-year hydrological cycle (calculated over the last 100 years) and a dry 5-year hydrological cycle. The reason for this was that a dry 5-year cycle produces a worst case scenario since the effect of dilution is minimal.

CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH

The costs that were determined for the various strategies and the ranking of the strategies are presented in Tables E.1 – E.3, and summarised below.

It was concluded that during an average 5-year cycle the most promising strategy in terms of total benefit was strategy 7 (installation of 130 Ml/d channel with no desalination). The next most promising strategy was strategy 6 (installation of 65 Ml/d channel with desalination), followed by strategy 3 (desalination of combined flow from DRD and WAGM), 1 (desalination of Grootvlei only) and 2(desalination of combined flow from ERPM and Grootvlei). User savings were only estimated for abstractions below the Vaal dam up to and including the Vaal Barrage. The reason for this is that the inclusion or exclusion of user savings *below* the Barrage would not change the rank already established but would in all cases increase the benefits. In order to remain conservative therefore, the user savings below the Barrage were not included.

Table E.1: Summary of Total Costs

Strategy	Process	Direct cost ($Rx10^6/a$)	Direct benefit ($Rx10^6/a$)	Direct cost or benefit ($Rx10^6/a$)	Average 5-year cycle		Dry 5-year cycle	
					Indirect benefit ($Rx10^6/a$)	Total cost or benefit ($Rx10^6/a$)	Indirect benefit ($Rx10^6/a$)	Total cost or benefit ($Rx10^6/a$)
1	AQUA-K	-221	190	-31	28	-3	38	8
1	ASTROP	-259	98	-161	28	-133	38	-122
1	Biosulphate	-74	0	-74	15	-59	20	-54
1	EDR	-175	76	-99	28	-71	38	-61
1	GYP-CIX	-202	79	-123	28	-95	38	-84
1	RO	-235	81	-154	28	-126	38	-116
1	SAVMIN	-158	13	-145	19	-126	24	-121
1	SPARRO	-191	101	-19	28	-62	38	-52
2	AQUA-K	-250	213	-37	32	-5	43	6
3	AQUA-K	-74	43	-31	3	-28	4	-27
3	SAVMIN	-34	36	2	3	5	1	3
4	AQUA-K	-347	258	-89	34	-55	47	-42
5	SPARRO	-191	101	-91	7	-84	9	-81
6	*AQUA-K*	*-111*	*95*	*-16*	*28*	*12*	*38*	*22*
7	Channel 35 Ml/d	-0.5	0	-0.5	14.7	14.2	19.9	19.4
7	Channel 65 Ml/d	-0.7	0	-0.7	14.7	14.0	19.9	19.2
7	Channel 130 Ml/d	-1.2	0	-1.2	14.7	13.5	19.9	18.7
8*	Pipeline Transfer 35 Ml/d	-2.2	0	-2.2	28.0	25.8	38.3	36.1
8*	Pipeline Transfer 65 Ml/d	-3.2	0	-3.2	28.0	24.8	38.3	35.1
8*	Pipeline Transfer 130 Ml/d	-5.0	0	-5.0	28.0	23.0	38.3	33.3

* Strategy 8 is not taken into consideration, as it necessitates an additional study, which is outside the scope of this project

Table E.2: Strategies ranked according to Total cost/benefit for Average 5 year cycle

Rank	Strategy	Description	Treatment Process	Treatment flow (Ml/d)	Total cost or benefit ($Rx10^6/a$)
1	7	130 Ml/d channel only	None	0	14
2	6	65 Ml/d channel and treatment	AQUA-K	65	12
3	3	DRD and WAGM combined	SAVMIN	47	5
4	1	Grootvlei	AQUA-K	130	-3
5	2	Grootvlei and ERPM combined	AQUA-K	146	-5

Table E.3: Strategies ranked according to Total cost/benefit for Dry 5-year cycle

Rank	Strategy	Description	Treatment Process	Treatment flow (Ml/d)	Total cost or benefit ($Rx10^6/a$)
1	6	65 Ml/d channel and treatment	AQUA-K	65	22
2	7	130 Ml/d channel only	None	0	19
3	1	Grootvlei	AQUA-K	130	8
4	2	Grootvlei and ERPM combined	AQUA-K	146	6
5	3	DRD and WAGM combined	SAVMIN	47	3

For the dry 5-year cycle the most promising strategy was strategy 6 (installation of 65 Ml/d channel with desalination). The next best was strategy 7 (installation of 130 Ml/d channel with no desalination) followed by strategies 1 (desalination of Grootvlei only), 2 (desalination of combined flow from ERPM and Grootvlei) and 3 (desalination of combined flow from DRD and WAGM).

Apart from the *specific* conclusions given above a number of *general* conclusions were also made and these are listed in point form below.

1. The desalination of typical calcium sulphate scaling mining effluents with a TDS exceeding 4 000 mg/l indicates that in order to minimise annual costs, the production and sale of high value by-products is essential (potable water can be considered to be a by-product).

2. The production and sale of potable water can usually offset the costs of treating a calcium sulphate scaling effluent with a TDS of below 700 mg/l.

3. The cost of *treating* the 130 Ml/d effluent from Grootvlei is approximately equivalent to *reticulating* that same flow a distance of between 70 and 380 km depending on the process selected. With further process refinements and innovative financing, these figures can be reduced considerably.

4. The "treatment" of brine is usually expensive whatever method is used and hence the process philosophy adopted should as far as possible incorporate brine treatment into the main process in a synergistic manner to minimise transfer of the problem.

5. The reduction of ingress into a mine is an extremely cost-effective method of both minimising de-watering and minimising the quantity of water that requires desalination. If desalination is self-sustainable with regard to funding then prevention of ingress becomes less important. In the case of the Blesbokspruit it is recommended that a project be set up to determine the quantity of seepage which ultimately enters the Grootvlei workings.

6. In order to plan any desalination strategy it is essential to continually gather relevant information regarding water flows and qualities. The procurement of a complete data set is usually more time consuming than the implementation of the final solution.

7. The highest cost burden of combating salinity is currently being carried by the household sector and not by industry as might be expected.

8. The "user savings" are economic costs: they take into account the costs borne by those other than the polluter. As such, they can be used to form a basis for internalising externalities. Some economic instruments that could be of use in this regard, are discussed.

9. The "polluter pays principle" is based on the internalisation of externalities and therefore is central to the equitable resolution of pollution costs currently being borne by the end user.

RECOMMENDATIONS

From the conclusions and recommendations of this study the following topics for further research are proposed:

1. An evaluation of the feasibility of bypassing the Blesbokspruit wetland with a channel to minimise the ingress of water into the Grootvlei mine workings. This study will also have to determine the quantity, quality and location of the water ingress into the Grootvlei mine workings from the Blesbokspruit.

2. The future water management of the Blesbokspruit should be defined to optimise and integrate the implementation of strategies from this study and proposed future development within the Blesbokspruit catchment.

3. A study within the Vaal Barrage catchment is required to confirm and refine the salinity cost model used in this study.

4. The most feasible economic strategy to encourage the internalisation of externalities should be investigated before it is implemented.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS I

EXECUTIVE SUMMARY
INTRODUCTION AND BACKGROUND i
BASIS FOR THE DEVELOPMENT OF STRATEGIES ii
METHODOLY TO ASSESS THE STRENGTHS AND WEAKNESSES OF DIFFERENT STRATEGIES iii
CONCEPTUAL STRATEGIES FOR REDUCING THE SALT LOAD TO THE VAAL BARRAGE iv
CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH vi

1. CHAPTER 1 .... 1.1
INTRODUCTION AND BACKGROUND
- **1.1 MOTIVATION 1.1**
- **1.2 HISTORY AND BACKGROUND 1.1**
- **1.3 PROJECT OBJECTIVES 1.6**
- **1.4 DEFINITIONS 1.6**

2. CHAPTER 2 .... 2.1
SEQUENCE LEADING TO THE DEVELOPMENT OF STRATEGIES
- **2.1 INTRODUCTION 2.1**
- **2.2 PHASE 1 .... 2.1**
- **2.3 PHASE 2 .... 2.2**
- **2.4 PHASE 3 .... 2.3**
- **2.5 PHASE 4 .... 2.6**

3. CHAPTER 3 .... 3.1
METHODOLOGY FOR ASSESSMENT OF STRENGTHS AND WEAKNESSES OF DIFFERENT STRATEGIES
- **3.1 INTRODUCTION 3.1**
- **3.2 TREATMENT COSTS 3.1**
  - 3.2.1 Introduction 3.2
  - 3.2.2 Plant parameters 3.2
  - 3.2.3 Unit costs 3.2
  - 3.2.4 Financial parameters 3.2
  - 3.2.5 Expenses 3.4
    - *3.2.5.1 Capital cost 3.4*
    - *3.2.5.2 Operating cost 3.4*
  - 3.2.6 Income 3.4
    - *3.2.6.1 Sale of potable water 3.4*
    - *3.2.6.2 Sale of by-products 3.5*

3.2.7 Costs without brine disposal or capital repayments 3.5
3.2.8 Disclaimer 3.5
3.3 THE AQUABAT MODEL 3.5
3.3.1 Water and salt balance model for the Vaal Barrage catchment 3.5
3.3.1.1 Water management in the Vaal Barrage catchment 3.5
3.3.1.2 Water and balance model: AQUABAT 3.7
3.4 COSTS TO THE USERS DOWNSTREAM 3.10
3.4.1 Implementation 3.10
3.4.2 Sensitivity 3.12
3.5 ASSUMPTIONS AND LIMITATIONS 3.12

4. CHAPTER 4 4.1
CONCEPTUAL STRATEGIES FOR REDUCING THE SALT LOAD
4.1 INTRODUCTION TO STRATEGIES 4.1
4.2 STRATEGY 1 4.1
4.2.1 Introduction 4.1
4.2.2 Costs and Benefits 4.1
4.2.3 Conclusions 4.5
4.3 STRATEGY 2 4.5
4.3.1 Introduction 4.5
4.3.2 Costs and Benefits 4.7
4.3.3 Conclusions 4.7
4.4 STRATEGY 3 4.8
4.4.1 Introduction 4.8
4.4.2 Costs and Benefits 4.8
4.4.3 Conclusions 4.10
4.5 STRATEGY 4 4.10
4.5.1 Introduction 4.10
4.5.2 Costs and Benefits 4.12
4.5.3 Conclusions 4.13
4.6 STRATEGY 5 4.13
4.6.1 Introduction 4.13
4.6.2 Conclusions 4.17
4.7 STRATEGY 6 4.17
4.7.1 Introduction 4.17
4.7.2 Costs and Benefits 4.19
4.7.3 Conclusions 4.20
4.8 STRATEGY 7 4.20
4.8.1 Introduction 4.20
4.8.2 Costs and Benefits 4.22
4.8.3 Conclusions 4.22
4.9 STRATEGY 8* 4.23
4.9.1 Introduction 4.23
4.9.2 Costs and Benefits 4.23
4.9.3 Conclusions 4.23
4.10 OTHER CONSIDERATIONS 4.25
4.10.1 Externalities 4.25

4.10.2 Economic Instruments 4.25

5. CHAPTER 5 .... 5.1
CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH
5.1 CONCLUSIONS AND RECOMMENDATIONS 5.1
5.2 FURTHER RESEARCH 5.5

APPENDIX A:
MANAGEMENT OPTIONS AND TREATMENT PROCESSES
A.1 INTRODUCTION A.1
A.2 MANAGEMENT OPTIONS
A.2.1 Contaminant Production A.1
A.2.2 Contaminant Transport A.1
A.2.3 Use Requirements A.2
A.2.4 Management structures A.2
A.3 TREATMENT OPTIONS A.2
A.3.1 General Discussion of Treatment technologies A.2
A.3.1.1 Full Desalination processes A.2
A.3.1.2 Partial Desalination A.6
A.3.1.3 Constructed Wetlands A.8
A.4 SCREENING OF TECHNOLOGIES A.8
A.5 DESCRIPTION OF PROCESSES FOR WHICH BUDGET COSTS ARE DERIVED
A.5.1 Conventional Reverse Osmosis A.8
A.5.1.1 Introduction A.8
A.5.1.2 Process Flow Diagram A.9
A.5.1.3 Process Description A.9
A.5.1.4 System Pros and Cons A.10
A.5.2 Electrodialysis Reversal A.10
A.5.2.1 Introduction A.10
A.5.2.2 Process Flow Diagram A.11
A.5.2.3 Process Description A.11
A.5.2.4 System Pros and Cons A.12
A.5.3 The GYP – CIX ® process A.12
A.5.3.1 Introduction A.12
A.5.3.2 Process Flow Diagram A.12
A.5.3.3 Process Description A.13
A.5.3.4 System Pros and Cons A.13
A.5.4 The SPARRO ® process A.13
A.5.4.1 Introduction A.13
A.5.4.2 Process Flow Diagram A.14
A.5.4.3 Process Description A.14
A.5.4.4 System Pros and Cons A.15
A.5.5 The ASTROP ® process A.15
A.5.5.1 Introduction A.15
A.5.5.2 Process Flow Diagram A.16
A.5.5.3 Process Description A.16

A.5.5.4 System Pros and Cons A.16
A.5.6 The AQUA – K process A.17
A.5.6.1 Introduction A.17
A.5.6.2 Process Flow Diagram A.17
A.5.6.3 Process Description A.18
A.5.6.4 System Pros and Cons A.18
A.5.7 The SAVMIN ® process A.18
A.5.7.1 Introduction A.18
A.5.7.2 Process Flow Diagram A.19
A.5.7.3 Process Description A.19
A.5.7.4 System Pros and Cons A.20
A.5.8 The THIOPAQ ® process A.20
A.5.8.1 Introduction A.20
A.5.8.2 Process Flow Diagram A.21
A.5.8.3 Process Description A.21
A.5.8.4 System Pros and Cons A.22
A.6 METHODS OF CONCENTRATE DISPOSAL
A.6.1 Introduction A.22
A.6.2 Evaporation ponds (unlined) A.22
A.6.3 Evaporation ponds (lined) A.23
A.6.4 Lined ponds with enhanced spray evaporation A.23
A.6.5 Disposal via pipeline to the Indian Ocean A.23
A.6.6 Crystallisors A.24
A.6.7 Spray Dryers A.24
A.6.8 Calandria crystallisors A.25
A.7 RAW WATER DATA FOR GROOTVLEI, ERPM, WAGM AND DRD
A.7.1 Grootvlei A.26
A.7.2 ERPM A.27
A.7.3 WAGM (Randfontein Estates no 4#) A.28
A.7.4 DRD A.29
A.8 WATER BLEND DATA **A.30**
A.8.1 Strategy 1 .... A.30
A.8.2 Strategy 2 .... A.30
A.8.3 Strategy 3 .... A.31
A.8.4 Strategy 4 .... A.31
A.8.5 Strategy 5 .... A.31
A.8.6 Strategy 6 .... A.31
A.8.7 Strategy 7 .... A.31
A.8.8 Strategy 8 .... A.32
A.9 BUDGEST COST ESTIMATES FOR THE EIGHT CONCEPTUAL STRATEGIES
A.9.1 Strategy 1
A.9.1.1 AQUA – K ® A.33
A.9.1.2 ASTROP ® A.34
A.9.1.3 BIOSULPHATE A.35
A.9.1.4 EDR A.36
A.9.1.5 GYP – CIX ® A.37
A.9.1.6 RO A.38
A.9.1.7 SAVMIN ® A.39

A.9.1.8 SPARRO ® A.40

A.9.2 Strategy 2

A.9.2.1 AQUA – K ® A.41

A.9.3 Strategy 3

A.9.3.1 AQUA – K ® A.42

A.9.3.2 SAVMIN ® A.43

A.9.4 Strategy 4

A.9.4.1 AQUA – K ® A.44

A.9.5 Strategy 5

A.9.4.2 SPARRO ® A.45

A.9.6 Strategy 6

A.9.6.1 AQUA – K ® A.46

A.9.7 Strategy 7

A.9.7.1 35 Ml/d Capacity Channel with no Desalination A.47

A.9.7.2 65 Ml/d Capacity Channel with no Desalination A.48

A.9.7.3 130 Ml/d Capacity Channel with no Desalination A.49

A.9.8 Strategy 8

A.9.8.1 35 Ml/d Capacity Pipeline Transfer to Northern Catchment (no desalination) A.50

A.9.8.2 265 Ml/d Capacity Pipeline Transfer to Northen Catchment (no desalination) A.51

A.9.8.3 130 Ml/d Capacity Pipeline Transfer to Northern Catchment (no desalination) A.52

A.10 EXAMPLE OF SPREADSHEETS USED FOR RE-BLEND AND DISCHARGE

A.10.1 ASTROP ® for re-blend to 300 mg/l A.53

A.10.2 ASTROP ® for re-blend to 750 mg/l A.54

A.10.3 ASTROP ® for re-blend to 1500 mg/l A.55

APPENDIX B:
WATER AND SALT BALANCES WITH AQUABAT MODEL

B.1 OBJECTIVES B.1

B.2 CATCHMENT AND SUB-CATCHMENTS BOUNDARIES B.3

B.3 WATER CIRCUITS AND FLOW DIAGRAM B.3

B.4 DATA COLLECTION AND MONITORING PROGRAMME B.11

B.4.1 Water quality and quantity data B.11

B.4.2 Meteorological data B.14

B.4.3 Physical characteristics of the catchment area B.14

B.5 WATER AND SALT BALANCES FOR SUB AND MAIN CATCHMENTS B.15

B.6 WATER AND SALT BALANCE MODEL – WATER MANAGEMENT TOOL B.19

B.7 CONCLUSIONS AND RECOMMENDATIONS B.24

APPENDIX C: THE CALCULATION OF USER COSTS INCURREDBY USING WATER OF VARYING SALINITY LEVELS

C.1 OBJECTIVE **C.1**
C.2 SCHEMA **C.1**
C.3 BACKGROUND **C.1**
C.4 METHODOLGY AND OUTPUT **C.1**
C.4.1 User cost curves C.2
C.4.2 Approach C.3
C.4.3 Scenarios C.5
C.4.4 Sensitivity C.6
C.5 FINAL RESULTS **C.7**
C.6 REFERENCES **C.9**

LIST OF TABLES

Table E1: Summary of Total Costs ... vi
Table E2: Strategies ranked according to Total cost/benefit for Average 5 year cycle . vii
Table E3: Strategies ranked according to Total cost/benefit for Dry 5-year cycle ... vii

Table 2.1: Summary of Water Qualities ... 2.1
Table 2.2: Comparison of Salt Loads ... 2.2
Table 2.3: Flows into the Vaal Barrage Catchment ... 2.3
Table 2.4: Abstractions and Releases from the Vaal Barrage ... 2.3
Table 2.5: Percentage Salt Removal for Varying Target TDS Concentrations ... 2.4
Table 2.6: Expenses ($Rx10^6$/annum) and Flows for Different Processes ... 2.5
Table 2.7: Comparison of User Savings and Treatment Expenses ... 2.6
Table 2.8: Expenses and Flows for no Re-Blend (Straight Through) Configuration ... 2.7

Table 3.1: User Costs at Various TDS Levels in R/Ml. ... 3.10
Table 3.2: Sensitivity of Model to Variations in TDS Levels ... 3.12

Table 4.1: Strategy 1 Unit Costs ... 4.3
Table 4.2: Strategy 1 Total Costs ... 4.4
Table 4.3: Strategy 2 Unit Costs ... 4.7
Table 4.4: Strategy 2 Total Costs ... 4.7
Table 4.5: Strategy 3 Unit Costs ... 4.8
Table 4.6: Strategy 2 Total Costs ... 4.10
Table 4.7: Strategy 4 Unit Costs ... 4.12
Table 4.8: Strategy 4 Total Costs ... 4.12
Table 4.9: Strategy 5 Unit Costs ... 4.16
Table 4.10: Strategy 5 Total Costs ... 4.17
Table 4.11: Strategy 6 Unit Costs ... 4.19
Table 4.12: Strategy 6 Total Costs ... 4.20
Table 4.13: Strategy 7 Unit Costs ... 4.22
Table 4.14: Strategy 8 Unit Costs ... 4.23

Table 5.1: Summary of Unit Costs ... 5.1
Table 5.2: Summary of Total Costs ... 5.2
Table 5.3: Strategies ranked according to Total cost/benefit for Average 5 year cycle . 5.2
Table 5.4: Strategies ranked according to Total cost/benefit for Dry 5-year cycle ... 5.4

Table A.1: System Pros and Cons. ... A.10
Table A.2: System Pros and Cons ... A.12
Table A.3: System Pros and Cons ... A.13
Table A.4: System Pros and Cons ... A.15
Table A.5: System Pros and Cons ... A.16
Table A.6: System Pros and Cons ... A.18
Table A.7: System Pros and Cons ... A.20
Table A.8: System Pros and Cons ... A.22
Table A.9: Capital and operating costs of the above methods of disposal ... A.24

Table A.10: Grootvlei – Average results obtained from sampling after the HDS plant.... A.26
Table A.11: EPRM – Average results from February 1991 to September 1995. Effluent Discharged to Elsburg spruit A.27
Table A.12: WAGM – Average discharge to Reitspruit during April and May 1997 ...... A.28
Table A.13: DRD – Average discharge quality to Klip river between September 1992 and May 1992 .... A.29
Table A.14: Grootvlei effluent A.30
Table A.15: Blend of ERPM and Grootvlei effluents A.30
Table A.16: Blend of DRD and WAGM effluents A.31
Table A.17: Blend of Grootvlei, ERPM, WAGM and DRD effluents A.31

Table B.1: Sub-catchments for water and salt balance model B.3
Table B.2.a: Main return flows in the Vaal Barrage catchment B.12
Table B.2.b: Main abstractions in the Vaal Barrage catchment B.13
Table B.3: Flow monitoring points and their associated problems. (DWAF,1997)........ B.14
Table B.4: Sub-catchments' MAR (Ml/season) for the base case B.15
Table B.5: TDS loads added by diffuse sources (seepage from mines) B.15
Table B.6: Water quality at Barrage (mg/l TDS) for water management strategies B.19
Table B.7a: Flows into the Vaal Barrage catchment B.24
Table B.7b: Abstractions and releases from the Vaal Barrage catchment B.24

Table C.1: Costs of Combating Various Levels of Salinity for Various Water Users in R/Ml of Water Used C.3
Table C.2: Details of Water Users Studied C.4
Table C.3: Status Quo User Costs During an Average Year C.5
Table C.4: Status Quo User Costs During a Dry Year C.5
Table C.5: Details of the User Costs for Each Scenario C.7
Table C.6: Sensitivity of User Impacts to Changes in TDS C.8

LIST OF FIGURES

Figure 1.1: Vaal Barrage catchment with location of Grootvlei, ERPM, DRD and WAGM 1.2

Figure 2.1: Schematic of "Sidestream" Configuration 2.4
Figure 2.2: Expenses and Flows for no Re-Blend (Straight Through) Configuration... 2.7
Figure 2.3: Graph of Financial Viability of Various Processes 2.8

Figure 3.1: Example of Cost Calculation Spreadsheet 3.3
Figure 3.2: Steps followed in Development of Water and Salt Balance Model 3.9
Figure 3.3: Graph of User Costs at Various TDS Levels 3.11

Figure 4.1: Strategy 1 – Treatment of Grootvlei effluent 4.2
Figure 4.2: Strategy 2 – Treatment of combined effluent from Grootvlei and ERPM.. 4.6
Figure 4.3: Strategy 3 – Treatment of combined effluent from DRD and WAGM 4.9
Figure 4.4: Strategy 4 – Treatment of combined effluent from WAGM, DRD, ERPM and Grootvlei 4.11
Figure 4.5: Strategy 5 – Treatment and reuse Grootvlei effluent and "bleed" brine into Blesbokspruit 4.14
Figure 4.6: Schematic Diagrams of "Brine Bleeding" Scenarios 4.16
Figure 4.7: Strategy 6 – Divert portion of Blesbokspruit and treat and reuse Grootvlei effluent 4.18
Figure 4.8: Schematic Diagrams of the Effect of Installing a 65 Ml/d Concrete Channel 4.19
Figure 4.9: Strategy 7 – Divert portion of Blesbokspruit and discharge Grootvlei effluent 4.21
Figure 4.10: Schematic Diagrams of the Effect of Installing a 130 Ml/d Concrete Channel 4.22
Figure 4.11: Srategy 8 – Transfer Grootvlei effluent to Bronkhorstspruit dam catchment 4.24

Figure 5.1: Graph of ranked strategies for Average 5-year cycle 5.3
Figure 5.2: Graph of ranked strategies for Dry 5-year cycle 5.4

Figure A.1: Process Flow Diagram A.9
Figure A.2: Process Flow Diagram A.11
Figure A.3: Process Flow Diagram A.12
Figure A.4: Process Flow Diagram A.14
Figure A.5: Process Flow Diagram A.16
Figure A.6: Process Flow Diagram A.17
Figure A.7: Process Flow Diagram A.19
Figure A.8: Process Flow Diagram A.21
Figure A.9: Diagram of typical high temperature Crystallisor A.24
Figure A.10: Diagram of typical Spray Dryer A.25
Figure A.11: Diagram of Calandria Crystallisor A.25

Figure B.1: Procedural steps to develop water and salt balance B.2
Figure B.2: Sub-catchment boundaries and location of monitoring points in Vaal Barrage catchment B.4
Figure B.3a: Flow Diagram of Vaal Barrage Water Reticulation System – Total Catchment B.5
Figure B.3b: Flow Diagram of Vaal Barrage Water Reticulation System – Blesbokspruit Catchment (Sub-catchments 4a and 4b) B.6
Figure B.3c: Flow Diagram of Vaal Barrage Water Reticulation System – Suikerbosrand Catchment (Sub-catchments 6a, 6b and 7) B.7
Figure B.3d: Flow Diagram of Vaal Barrage Water Reticulation System – Rietspruit Catchment (Sub-catchment 2a, 2b and 3) B.8
Figure B.3e: Flow Diagram of Vaal Barrage Water Reticulation System – Klip River Catchment (Sub-catchments 1a, 1b, 1c and 5) B.9
Figure B.3f: Flow Diagram of Vaal Barrage Water Reticulation System – Vaal River Catchment (Sub-catchment 8, 9,10a and 10b) B.10
Figure B.4a: Comparison of simulated and measured water flow at Vaal-Barrage B.17
Figure B.4b: Comparison of simulated and measured water quality (TDS) at Vaal Barrage B.17
Figure B.4c: Comparison of simulated and measured salt load at Vaal-Barrage B.18
Figure B.5a: Water quality for average 5 year cycle (summer) B.20
Figure B.5b: Water quality for average 5 year cycle (Winter) B.21
Figure B.6a: Water quality for dry 5 year cycle (Summer) B.22
Figure B.6b: Water quality for dry 5 year cycle (Winter) B.23

Figure C.1: User Cost Curves C.4
Figure C.2: Histogram of Desalination Costs vs. User Impacts C.8

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 MOTIVATION

Information from recent studies (DWAF, 1995; Pulles *et al.*, 1996; Reports submitted to the Grootvlei joint venture committee, 1996), indicated that four gold mines Durban Roodepoort Deep (DRD), East Rand Proprietary Mines (ERPM), Grootvlei and the former Western Areas Gold Mine (WAGM) are contributing as much as 26% of the salt load entering the Vaal Barrage by way of their point source discharges. This 26% of the salt load is contained in only approximately 5% of the total flow, indicating that management/treatment of this source should be a high priority in terms of reducing the salt load into the system. The location of the four mines is shown in Figure 1.1.

The costs associated with this salt load are felt by many abstractors of water from the Vaal system including Rand Water, the Western Transvaal Regional Water Company [recently changed to Mid-Vaal Water Company; in this report the previous name will still be used], Goudveld Water. These abstractors in turn pass these costs on to their end users, such that a substantial portion of the liability for pollution is carried by the end user rather than the polluter.

Although these effluents make up only about 5% of the flow into the Vaal Barrage, they contribute a disproportionate salt load to the water resource. It is important to realise that the effluents which are currently being pumped from underground mining operations to surface are largely derived from mining which has taken place over the last 100 years and are therefore not the sole responsibility of the pumping mines. In addition, the quality of the pumped water differs from mine to mine

The imposition of policies and regulations which attempts to make operating mines carry the sole financial responsibility for dealing with these effluents, may result in premature closure of these mines leading to adverse impacts for the local economy. In addition, such strategies which force mine closure may cause abandoned mines to flood, which may perpetuate or exacerbate the problem.

It is therefore important that these and other point source discharges be regarded as a regional if not a national problem, which requires a co-ordinated management strategy, with inputs from both the mining industry and regulatory authorities.

1.2 HISTORY AND BACKGROUND

During the 1980's the South African Land and Exploration Company Limited (Sallies) was de-watering approximately 50 Ml/d from its number 1 shaft. This de-watering was subsidised in an agreement between the Far East Rand Water Committee (FERWC) and the State. The agreement was originally set up to assist with the costs of pumping seepage water from neighbouring defunct mines which threatened to flood a possible 280 tons of exploitable gold reserves.

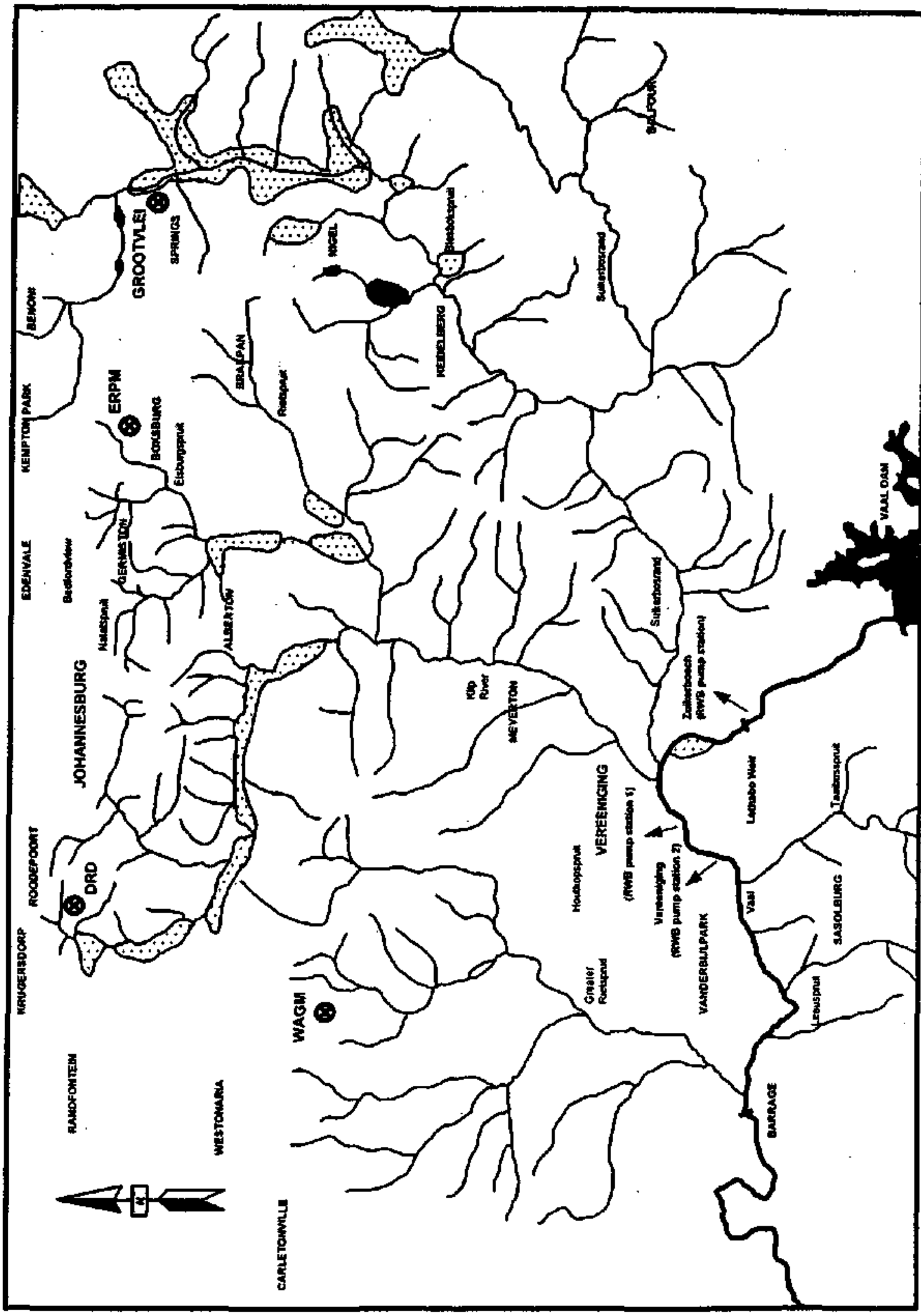


Fig 1.1 : Vaal Barrage catchment with location of Grootvlei, ERPM, DRD and WAGM.

Sallies was the deepest of the mines in the Far East Rand Basin (FERB) and in spite of the de-watering subsidy from the State was forced to close for economic reasons, in 1991. The next deepest mine is Grootvlei, with Nigel being the next in the sequence.

After the closure of Sallies, it was deemed more cost-effective to discontinue pumping from Sallies No 1 shaft and a strategy was then drawn up to continue de-watering from Grootvlei No 3 Shaft. However, due to the difference in depths between to two mines it was not necessary to implement the new strategy immediately and hence Grootvlei applied for a discharge permit to continue de-watering when the water table reached the base of its No 3 shaft.

In August 1995 an Environmental Impact Assessment was commissioned by the department of Mineral and Energy Affairs which concluded that the intended discharge from Grootvlei would have limited detrimental effect on the Blesbokspruit wetland system. As a result of this finding, a permit was granted by DWAF and three months later de-watering was commenced at Grootvlei. It was immediately apparent that the volumes pumped were considerably greater than was originally estimated.

Volumes of between 80 Ml/d and 100 Ml/d were pumped from the new station and some months later residents near the Grootvlei bridge observed fish kills which appeared to be associated with a red slime. It was later determined that the red slime was iron hydroxide which was apparently not toxic *per se*, but which had probably killed the fish by smothering their gills and preventing oxygen transfer.

This event sparked widespread concern that the Blesbokspruit and in particular the Ramsar certified wetland were under threat and hence the State was obliged to intervene. On 15 May 1996 the discharge permit was withdrawn and negotiations commenced immediately on suitable criteria for the re-issue of the permit. The water was subsequently sampled and tested and it was found that by a combination of raising the pH and aeration, a quality suitable for discharge in the short term could be obtained.

An interim permit was then issued on 28 May 1996 and pumping recommenced after the construction of some temporary ponds to permit liming and aeration.

Accepting that the solution was only a temporary one, Cabinet commissioned a series of cost-benefit analyses in order to provide guidelines for future decision making on the issue. The reports focused on three scenarios.

The first scenario evaluated was that of ceasing pumping at Grootvlei immediately, which would mean discontinuing mining. It has been estimated that the rate of rise of water on cessation of pumping would be approximately 0,3 m/d. This implies that the water table would reach the base of the dolomites in approximately three years and would decant from Nigel between 5 and 9 years from cessation of pumping. The closure of Grootvlei would be detrimental to the regional economy and would merely defer the problem until decant commenced at Nigel. Although certain mines in the FERB remain marginal it was concluded that even a phased withdrawal of mining may present stability risks and would not be financially viable. The Ramsar site would not be affected by this scenario.

The second scenario evaluated the impact of maintaining pumping such that mining could continue but the dewatered effluent would be clarrified following iron removal and pH adjustment. The Blesbokspruit wetland was considered to be able to withstand the effects of the saline discharge without undue impact over the short term (two years). However, for the longer term it was concluded that severe impact would occur, not only to the wetland but also to the local agricultural sector via salinisation of soils and subsequent loss of productivity. Compensation for this would need to be carried out according to the polluter pays principal (Stewart Scott Inc, 1997).

The third scenario evaluated the impact of continued pumping and mining, with the proviso that the dewatered effluent is desalinated. This would ensure minimal environmental impact and the benefits to the economy associated with continued mining would still be realised. However, the costs of this scenario according to available figures, were considerably greater than those associated with scenario 2. The value of the wetland (or the cost of losing this important habitat) was not included, since it is extremely difficult to attach a price to such a feature.

The conclusion from the study was that scenario 1 should not be considered further because of the unreasonably high cost benefit ratio. In the short term (up to two years) it was suggested that scenario 2 be implemented and that planning for the efficient implementation of scenario 3 be commenced immediately. It was recommended that desalination of the Grootvlei water be carried out in two phases. The first involved the selection of suitable processes from pilot studies carried out at the mine and the identification of an implementing agent to construct and operate the plant (Rand Water and ERWAT were among the companies suggested to fulfil this role). The second was the actual construction and commissioning of the most appropriate process. The time scale for the two phases was not to exceed two years.

In response to this, Stewart Scott Consulting Engineers were appointed by Grootvlei mine to compile tender documents for pre-qualification for the erection of a number of pilot plants at Grootvlei. Five tenders were short-listed and the cost of operating and evaluating the performance of the seven pilot plants was estimated at R 7 million. It was emphasised at the time that although this cost seemed considerable, it was vital to establish the most cost effective method of desalination for this particular water prior to implementation at full scale since desalination of mining effluents is very capital intensive. It would also allow for optimisation of the process and a firm estimate of the future capital and operating costs of the full scale plant.

The proposal was accepted in principle but because of the costs of adopting this methodology and the issue as to who would contribute to the costs a number of other initiatives commenced which were indirectly linked to the problem at Grootvlei and were aimed at reducing pollution.

- Strategic Water Management Plan (SWAMP) /AMANZI project

Efforts to develop a Strategic Water Management Plan were lead by JCI. The original management plan involved only mines within JCI and the process suggested was based on anaerobic sulphate removal ahead of an artificial wetland. The effluent from the wetland was to be passed through a GYP-CIX process for final polishing prior to stabilisation, filtration and chlorination and production of potable water.

The original plan was then expanded to include other gold mines, at their option, and the project name was changed to AMANZI and now falls under the direction of JCI Projects. Subsequent to the formation of Amanzi, specifications were drawn up to invite tenders for a "preferred operating partner".

On adjudication an agreement was signed with the METSI EGOLI consortium and a detailed feasibility study is under way. Currently, the main objectives of the consortium are to select processes and locations for these processes to enable the production of potable water and water for use in Agriculture. It is envisaged that a single water utility company be formed to address all mine water related problems on the Reef.

- Proposed 20 Ml/d mine water treatment plant for JCI (Ltd.)

In July 1997 a feasibility study on the treatment of mining effluent discharged from WAGM north shaft (now Randfontein No 4 Shaft) was completed by Stewart Scott consulting Engineers for JCI. Fourteen separate streams with differing qualities were identified and a blend of certain of the streams was considered for treatment to produce potable water. A preliminary design was carried out for the production of 20 Ml/d of potable water. The process selected involved a high lime step (for removal of Uranium and heavy metals); a softening step using soda ash and a 7 Ml/d side-stream nano-filtration plant to reduce the sulphate concentration. With filtration and chlorination, it was estimated that the operating cost of the plant would be between 67 c/m^3 and 69 c/m^3.

- Rand Water Process Development unit

Following the recommendation by Stewart Scott, initially only the GYP-CIX process (ion exchange) was established as a pilot plant at Grootvlei. In October 1997, Grootvlei Proprietary Mines approached Rand Water to act as an observer and provide technical advice with respect to the desalination of the mine effluent produced at Grootvlei. After it became apparent that Rand Water could benefit from the possible production of potable water on the FERB their role became more active and assistance was provided in the compilation of an evaluation protocol for the comparison of various treatment processes. Three further technologies were therefore selected for pilot plant operation: the Aqua-K process (membrane technology with crystallisor incorporated in brine treatment); the SAVMIN process (calcium sulphate precipitation with ettringite recycle) and a biological anaerobic/aerobic system being developed by Rhodes University (sulphate removal and sulphur production).

Since the Rhodes University process was still in the early stages of development it was not evaluated comparatively as were the other three processes.

It was concluded that with regard to the production of potable water from the Grootvlei effluent the Aqua-K process presented the lowest risk of not achieving the required specification for potable water.

The process has subsequently been operated at pilot scale over a further trial period to confirm plant performance, the quality of by-products and to address radioactivity concerns. The installation of a 10 Ml/d plant at Grootvlei is planned.

The above initiatives are being (or have been) carried out concurrently with this project and have contributed to the understanding of the complexities of the overall pollution problem from a management perspective.

1.3 PROJECT OBJECTIVES

The primary objectives of the research project were as follows;

1. To propose conceptual strategies which can cost-effectively be employed to manage/treat *point source mining effluents from four gold mines* (Durban Roodepoort Deep (DRD), East Rand Proprietary Mines (ERPM), Grootvlei and the former Western Areas Gold Mine (WAGM). [WAGM north shaft is now referred to as Randfontein Estates no 4 shaft. However, the abbreviation used in this document is WAGM.] These effluents are currently being discharged into the Vaal Barrage catchment.

2. To confirm the current contribution of these point source discharges to the total salt load entering the Vaal Barrage and to ascertain the downstream effects of reducing the salt load upstream.

3. To estimate the costs to users of water from the Vaal river between the Vaal dam and Balkfontein (Goudveld water abstraction point) which can be ascribed to these points source discharges, for the purpose of comparison with the costs of management/treatment.

1.4 DEFINITIONS

In order to provide further clarity on the objectives of the project, the following discussion gives definitions for key words which appear in the project title and in the objectives outlined above.

Economic evaluation:

In this project the meaning of economic evaluation is the calculation of "costs of treatment" and "savings resulting from treatment". A direct comparison can then be made between the two.

Technical evaluation:

It is essential that any option chosen be technically, as well as financially feasible so that a practical solution is ultimately determined.

Regional:

Options for management/treatment are considered on a regional scale to attempt to find an optimal solution for the total pollution problem and not just a solution for specific areas within the region.

Conceptual Strategies:

The strategies for management/treatment are defined in outline only and are accompanied by budget capital and operating costs to enable comparison between the strategies.

Point source:

The project only deals with certain high load point source discharges whose concentrations and flows can be measured on surface. It does not include seepage from individual slimes dams, rock dumps and other diffuse sources of ground-water pollution, but an estimated value of seepage from all the slimes dams is included.

Vaal Barrage catchment:

For the purposes of this project, the Vaal Barrage catchment is defined as the catchment area between the Vaal dam and the Barrage. It is accepted that the quality of the water leaving the Barrage affects all the users downstream. However, this project only concerns itself with the users above the Goudveld water abstraction point (Balkfontein) since generally speaking, users closer to the Barrage will see a greater impact than those further downstream.

Salt load:

In this project the salt load is defined by the total dissolved solids (TDS) concentration measured in mg/l. In the cases where only conductivity measurements are available, these have been converted to TDS values.

Costs to users:

Budget costs to major consumers of water from the Vaal river between the Vaal dam and Balkfontein will be calculated by assessing the financial implication to users of reducing the salt load upstream.

CHAPTER 2

SEQUENCE LEADING TO THE DEVELOPMENT OF STRATEGIES

2.1 INTRODUCTION

The first part of the project was to gather sufficient information to enable realistic strategies to be developed. The sequence leading to the development of strategies was separated into various phases. These phases are discussed below.

2.2 PHASE 1

In the first phase of the project it was necessary to obtain information on each of the four mines (DRD, Grootvlei, ERPM and WAGM) with regard to the qualities and quantities of their respective effluents. It is conceded that these figures will undoubtedly fluctuate according to changing de-watering patterns and flooding of shaft areas. A summary of the salient characteristics of the four effluents is given in Table 2.1. Further details of each effluent can be found in Appendix A.7.1 - A.7.4.

Table 2.1: Summary of Water Qualities

Quality	Mine	DRD	ERPM	Grootvlei	WAGM	DWAF guidelines: Domestic use
Flow	Ml/d	7	16	130	40	
TDS	mg/l	3499	4184	4156	812	70
pH		4.9	7.8	9	6.3	6 - 9
Turbidity	NTU	*	4184	35.94	17	1
Total Hardness	mg/l as $CaCO_3$	*	2727	1789	498	200
Calcium	mg/l	*	735	523	142	150
Chloride	mg/l	50.1	79	223	20	250
Magnesium	mg/l	*	212.3	117	35	70
Sulphate	mg/l	2112	2200	2085	577	200
Alkalinity	mg/l as $CaCO_3$	*	66.2	55	12	200
Sodium	mg/l	128	195	306	34	100
Iron	mg/l	*	15	7.91	0.2	0.1

* Refers to figures not available and should NOT be assumed zero

From Table 2.1, it is apparent that the main characteristics of the effluents from ERPM and Grootvlei are that they contain:

- High concentrations of calcium and magnesium, which contribute to the excessive total hardness value.
- High concentrations of sulphate which contribute to the excessive TDS value.
- High concentrations of sodium.

The above characteristics are also likely to apply to the effluent from DRD, although the calcium and magnesium concentrations were not available.

The combination of high concentrations of calcium, magnesium and sodium, together with high levels of sulphate is invariably indicative of a water which is close to or exceeds saturation with respect to calcium sulphate and consequently has a high calcium sulphate scaling potential. The calcium, magnesium and sodium ions form ion pairs with the sulphate so that a proportion of the sulphate is "paired" (~30%) and the remainder is "free"(~70%). Naturally, the presence of high concentrations of calcium and carbon dioxide also indicates that the carbonate system will play a role. The formation of calcium carbonate can be expected once the solubility product of its respective ionic concentrations is exceeded.

The effluent from WAGM also has an elevated sulphate concentration (although only ~ 600 mg/l, compared to the value of > 2 000 mg/l exhibited by the other mines) which also contributes to an unacceptably high TDS. The contaminated dolomitic water pumped from WAGM will be included in the evaluation as it is of better quality and, through dilution, may increase the treatment options of the combined effluent.

It is clear from the flows and TDS concentrations outlined in Table 2.1 that the greatest salt load contribution comes from Grootvlei.

In the second phase of the project it was therefore necessary to determine the relative contributions of the four mines to the total salt load entering the Barrage and to determine which region requires the most immediate attention.

2.3 PHASE 2

Table 2.2 shows a comparison of the salt load contributions from the four mines.

Table 2.2: Comparison of Salt Loads.

Mine	TDS (mg/l)	Conductivity (mS/m)	Flow (Ml/d)	TDS Load (t/d)	% of Total
Grootvlei	4 156	342	130	540	81
WAGM	812	116	40	32	5
DRD	3 499	288	7	24	4
ERPM	4 184		16	67	10
Total			193	664	100

From Table 2.2 it is apparent that approximately 80% of the salt load generated by the four mines emanates from Grootvlei. This implies that if the salt load at Grootvlei could be dramatically reduced, then up to 540 t/d out of a total of approximately 664 t/d could be prevented from entering the Vaal Barrage. (This does not include for the effects of recycling any product water, which may be produced by a desalination plant. Clearly, even if potable water were produced, after use, a portion of it would ultimately find its way to the Vaal river).

To enable the figures in Table 2.2 to be put into perspective, water qualities and flows from all major tributaries of the Vaal River between the Vaal Dam and the Barrage were assembled. Tables 2.3 and 2.4 represents a summary of this data (more detail can be found in

Appendix B) and it illustrates that the four mines contribute approximately 35% of the total salt load and only 6% of the total flow. This figure is even greater than an earlier approximation of 26%. The increased salt load from the mines, determined by this study, is mainly due to the fact that Grootvlei has increased its pumping rates significantly since late 1995. The previous studies were done during the period before the significant increase in pumping rate was started. A 75% reduction in salt load from Grootvlei would thus translate to a reduction of approximately 20% of the total load entering the Vaal Barrage. It was therefore decided that attention must, to some extent, be focused on Grootvlei although the whole region should still be considered.

Table 2.3: Flows into the Vaal Barrage Catchment.

Description	Flow (Ml/a)	TDS Load (t/a)
Vaal Dam releases	548 800	96 200
Grootvlei, DRD, ERPM and WAGM	69 500	239 100
Other Mines and Industries	256 600	297 600
Runoff	257 100	47 500
Sub-Total	**1 132 000**	**680 400**

Table 2.4: Abstractions and Releases from the Vaal Barrage.

Description	Flow (Ml/a)	TDS Load (t/a)
To Middel Vaal	615 400	290 400
Rand Water	271 000	55 700
Industry	84 200	24 900
Irrigation and other losses	55 400	433 700
Sub-Total	**1 026 000**	**804 700**

Tables 2.3 and 2.4 are a summary of the overall water and salt balance for the Vaal Barrage catchment. The balances are based on available data from 1991 to 1997 and more detail is presented in Appendix B. The overall accuracy of the balances are 90% for the water balance and 82% for the salt balance, when the total inflows and outflows of the catchment are compared. This accuracy is within the 70% accuracy that was defined as the minimum for this project.

2.4 PHASE 3

In order to reduce the salt load currently being discharged at Grootvlei it was necessary to consider both management and treatment. The benefits emanating from improved management are generally the most cost effective since if management structures are already in place these need only be modified and hence capital outlay can be minimised. However, it is difficult to quantify these benefits in a manner that will allow direct comparison with the savings accruing to users downstream. It was therefore decided that, in the first instance, attention should be focused on treatment options. A detailed discussion on management options occurs in Appendix A.2.

To provide information on a range of potential treatment options applicable to Grootvlei, it was decided to select processes that were both technically feasible and had been proven at least at pilot scale.

There were two reasons for this. The first was that the number of potential options needed to be condensed to enable the comparisons made between the options to be carried out in greater detail, so that meaningful budget costs could be derived. The second reason was that it frequently takes a number of months to eliminate scale-up problems encountered when taking a lab scale process to pilot scale or taking a pilot scale process to full scale.

Having selected various processes (see Table 2.6) it was then necessary to devise a method by which they could be compared in a fair manner, since each process has a unique water recovery and salt rejection associated with it for any particular water. To accomplish this, the process was modelled in a side-stream configuration and the product water was re-blended with the main stream (see Figure 2.1).

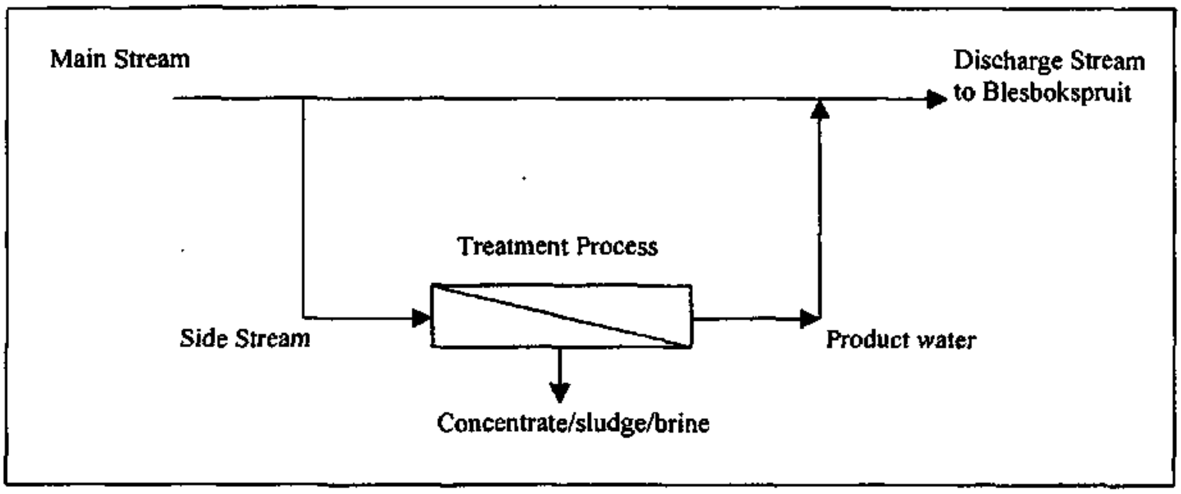


Figure 2.1: Schematic of "Sidestream" Configuration.

To enable comparison of the various processes the TDS concentration of the "discharge stream" was set at a particular value. This meant that if a particular process had a very high water recovery and salt rejection, then a smaller "side stream" flow would be necessary to ensure that when the "product water" flow was re-blended with the "main stream", the required target concentration was achieved. A smaller "side stream" flow for any particular process would signify a reduced overall process cost.

The required discharge concentration was originally set at a TDS concentration of 300 mg/l. However, certain of the processes were not capable of attaining this. Hence another two target values were introduced namely, 750 mg/l and 1 500 mg/l. Table 2.5 shows a comparison of the percentage removal for 300 mg/l, 750 mg/l and 1 500 mg/l.

Table 2.5: Percentage Salt Removal for Varying Target TDS Concentrations.

Target discharge concentration (mg/l)	300	750	1 500
% salt reduction to Blesbokspruit *	93	82	64
% salt reduction to Vaal Barrage *	27	24	19

* The current discharge TDS was taken as 4 156 mg/l

On the basis outlined above, a number of processes were compared on a budget level, to enable broad conclusions to be drawn as to their feasibility regarding the treatment of the effluent currently being discharged from Grootvlei. These processes are discussed in detail in Appendix A and are listed in Table 2.6. Table 2.6 summarises the findings of this phase of the project.

Table 2.6: Expenses (R x10^6/annum) and Flows for Different Processes.

				Reblend (TDS = 300 mg/l)					Reblend (TDS = 750 mg/l)					Reblend (TDS = 1 500 mg/l)				
Strategy No	Process	Total (T)/Partial (P) Desal.	Best attainable TDS (mg/l)	Inflow to plant (Ml/d)	Brine flow (Ml/d)	Product flow (Ml/d)	Discharge to river (Ml/d)	Expenses (R x10^6/a)	Inflow to plant (Ml/d)	Brine flow (Ml/d)	Product flow (Ml/d)	Discharge to river (Ml/d)	Expenses (R x10^6/a)	Inflow to plant (Ml/d)	Brine flow (Ml/d)	Product flow (Ml/d)	Discharge to river (Ml/d)	Expenses (R x10^6/a)
1	EDR	T	779											107	21	85	109	143
1	RO	T	489						122	18	104	112	221	98	15	83	115	179
1	GYP-CIX	T	891											112	34	78	96	174
1	SPARRO	T	447						120	8	112	122	177	85	7	88	123	140
1	Biosulphate*	P	2099											130	1	129	129	74
1	ASTROP	T	139	125	13	123	117	250	112	11	101	119	223	89	9	80	121	178
1	SAVMIN	P	891											106	2	104	128	138
1	AQUA-K	T	216	128	5	122	125	216	113	5	108	125	192	89	4	85	126	151

* Although the Biosulphate process is the next least expensive after the AQUA-K process, its inability to produce potable water is problematic (monovalent ion concentrations in the product water are too high). Cost recovery from the sale of elemental sulphur has not been included because of uncertainty regarding the quality of the elemental sulphur produced.

It is important to note that the expenses detailed in Table 2.6, include for repayment of capital and operating costs but do not include for any income derived from the sale of by-products. Clearly, in the above case, the product water is re-blended with the main stream and discharged into the Blesbokspruit. In instances where the cells in Table 2.6 are blank, the process is not able, under normal circumstances (i.e. for example, without dosing excessive quantities of anti-scalants or having excessive pre-treatment prior to being fed to the process) to achieve the target TDS value. The best achievable value is shown and should be taken as an indication of the water recovery and salt rejection of the respective processes.

The values in Table 2.6 illustrate a number of important points.

- Only two processes (ASTROP and AQUA-K) are capable under normal circumstances of producing the target re-blend TDS of 300 mg/l from the Grootvlei effluent.
- As expected, the increased cost of treating to a higher quality is substantial. As an example, the ASTROP process will cost in the order of: R 178,19 x10^6 /a to achieve a target TDS of 1 500 mg/l; R 223,35 x10^6 /a to achieve a target TDS of 750 mg/l and R 249,56 x10^6 /a to achieve a target TDS of 300 mg/l. (Details given in Appendix A.10)
- Without including the Biosulphate process, all of the processes fall within the relatively narrow range between R 138.28 x10^6/a and R 179.33 x10^6/a to achieve a target of 1 500mg/l. It must be stressed however, that although the "costs" are similar, the

"benefits" accruing from the sale of by-products may vary widely between the different processes. Hence the feasibility cannot be based purely on the values in Table 2.6.

- The SAVMIN process is currently not able to remove mono valent ions and hence can only be classified as a partial desalination process for the Grootvlei water. However, for waters with low concentrations of mono valent ions the SAVMIN process can be classified as a full desalination process.

Table 2.7 gives the user savings that have been estimated for the AQUA-K process at the three target TDS values and their corresponding discharge flows into the Blesbokspruit. Income from any source is not included.

Table 2.7: Comparison of User Savings and Treatment Expenses.

Target TDS (mg/l)	300	750	1 500
Expenses (R x10^6/a)	216.04	191.71	150.65
User Savings (R x10^6/a)	27.15 (38.30)	24.56 (33.95)	19.32 (24.39)

A comparison of the treatment costs and the user savings indicates that without the inclusion of income derived from the sale of water or by-products it is uneconomical to treat the effluent, since the amount saved per annum is considerably less than the cost of treatment. With the annual expenses being considerably higher than the user savings it is impossible to justify treatment. However, it must be remembered that the treatment costs do not include for the sale of by-products and since the product water is re-blended into the main stream, this also is not available for sale. This was done to achieve a comparison more rapidly and also to ensure the comparison was conservative. In spite of this, it was clear from the above finding that all treatment costs must be included to provide a more realistic picture of the costs and benefits of the various processes. In addition to this, the concept of re-blending, which was originally put forward to enable fair comparison of the various processes needed to be modified. To this end it was decided to model the process such that the product water was no longer re-blended with the main stream but isolated so it could be made available for sale as potable or service water. These modifications were carried out in phase four of the investigation, which is discussed below.

2.5 PHASE 4

Having highlighted the disparity between the user savings and the treatment costs, a more detailed analysis of the potential income which could be derived from the sale of by-products from each of the treatment processes was undertaken. In addition to this, the product water was no longer assumed to be re-blended with the main stream but was assumed to be sold in order to offset the costs of treatment. The side stream configuration outlined above was replaced with the assumption that the total flow of 130 Ml/d was to be treated, regardless of the process.

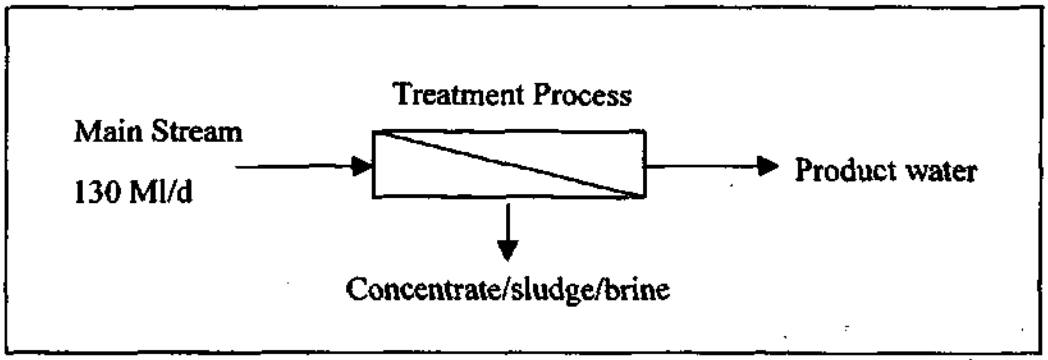


Figure 2.2: Schematic of "Straight Through" Configuration

Table 2.8 follows the same format as Table 2.6 above except that in addition to costs of treatment ("expenses"), the income and net profit is also shown for each process.

Table 2.8: Expenses and Flows for no Re-Blend (Straight Through) Configuration.

				No Reblend						
Strategy No	Process	Total (T)/Partial (P) Desal.	Best attainable TDS (mg/l)	Inflow to plant (Ml/d)	Brine flow (Ml/d)	Product flow (Ml/d)	Discharge to river (Ml/d)	Expenses (R x10^6/a)	Actual income (R x10^6/a)	Actual profit (R x10^6/a)
1	EDR	T	779	130	26	104	0	175	76	-99
1	RO	T	489	130	20	111	0	235	81	-154
1	GYP-CIX	T	891	130	39	91	0	202	79	-123
1	SPARRO	T	447	130	9	121	0	191	101	-91
1	Biosulphate*	P	2099	130	1	129	0	74	0	-74
1	ASTROP	T	139	130	13	117	0	259	98	-161
1	SAVMIN	P	891	130	3	127	0	128	13	-145
1	AQUA-K	T	216	130	5	125	0	221	190	-31

* See comment at Table 2.6

From the figures above it is apparent that the overall costs of treating the Grootvlei effluent are still substantial but in certain instances considerably less than the cost given in Table 2.6. It should be remembered that the total flow of 130 Ml/d is assumed to be treated and hence if by-products are not available to offset the cost of treatment then, as with the SAVMIN process, the cost for not re-blending is greater than for the side stream configuration. In addition to this the quality of the product water approximates the "best attainable TDS" and is not re-blended to conform to a specific target value.

Figure 2.3 illustrates the financial figures outlined in Table 2.8 and demonstrates that there is little correlation between the "expenses" and the potential "profit". The figures in Table 2.8 form the basis for Strategy 1, which is discussed in detail Chapter 4 and includes a further breakdown of the costs.

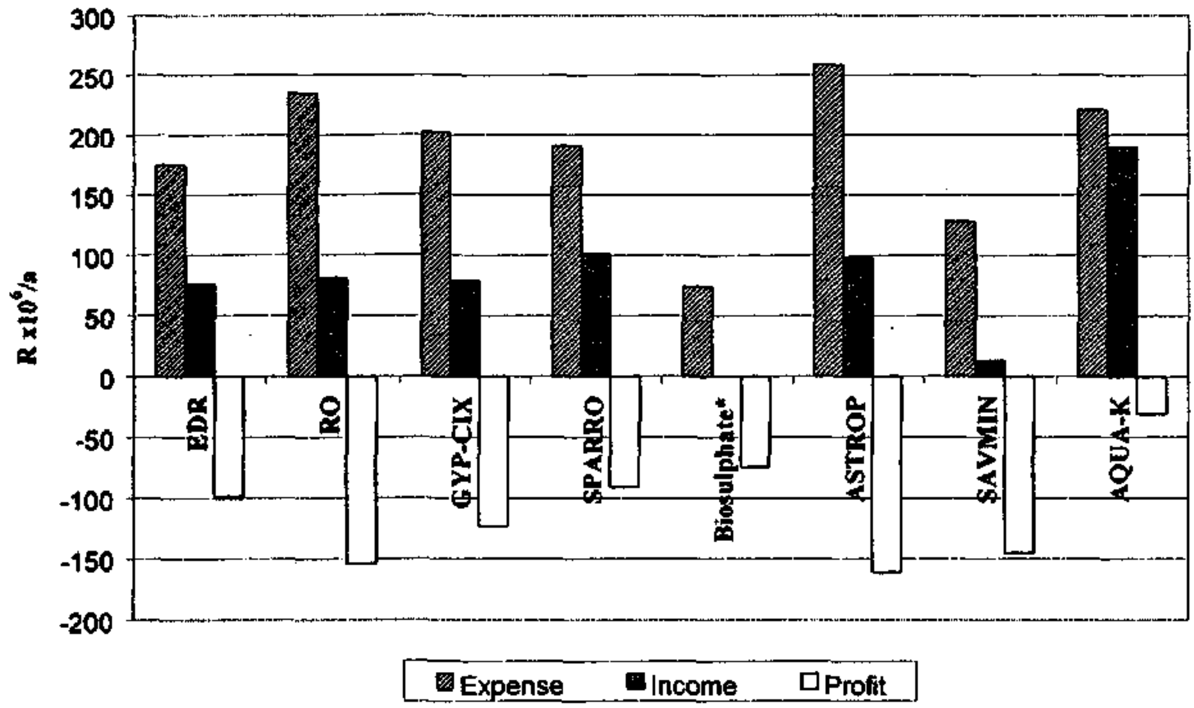


Figure 2.3: Graph of Financial Viability of Various Processes.

Various general conclusions were drawn from the information presented above with regard to the selection of strategies, which are discussed in more detail in Chapter 4.

- The reduction of TDS is technically feasible using a number of different treatment processes.
- The cost-effectiveness of processes varies widely.
- Generally speaking, if effluent quality has a relatively low TDS (~ 700 mg/l – 1 500 mg/l) then capital and operating costs can be offset by the sale of water alone. If, however, the effluent quality has a TDS in the region of 4 000 mg/l or greater then the sale of water alone is unlikely to ensure cost recovery and hence attention needs to be focused on the production and sale of other by-products
- An overall reduction of 20% of the total salt load entering the Vaal Barrage can be achieved by removing 75% of the salt load currently being discharged from Grootvlei.

CHAPTER 3

METHODOLOGY FOR ASSESSMENT OF STRENGTHS AND WEAKNESSES OF DIFFERENT STRATEGIES

3.1 INTRODUCTION

If raw sewage is discharged into a river the effects are generally noticed immediately in that fish kills are observed and the oxygen demand exerted is harmful to the biota in the river. The effects of discharging mining effluents to a river are generally less noticeable provided precipitates do not form as occurred in the Blesbokspruit. As a result of this, it is often difficult to quantify the impact of discharging a mining effluent to a river.

Given that the management options for minimising effluent production have been successfully implemented and recognising that desalination is relatively expensive, it is vital to ensure that the costs of treatment are outweighed by the benefits. It is also important to be able to quantify the benefits so that the cost of treatment can be justified.

In order to quantify the overall benefits for various treatment strategies in this project, direct costs (or benefits) of treatment were compared with the indirect benefits. The direct costs were estimated by subtracting the annual operating costs from the annual income derived from the sale of by-products. The indirect benefits were estimated by generating a saving to downstream users from a reduction in the TDS of the water abstracted.

This was carried out by firstly quantifying the discharge flow and TDS concentration to the river for a particular process. A water and salt balance model (AQUABAT ®) was then used to route this salt load through the relevant river tributaries (e.g. Blesbokspruit) and ultimately into the Vaal River system. The model enabled TDS concentrations to be determined at different abstraction points. According to the type of abstractor (e.g. Irrigation, Eskom, Rand Water etc.), the reduction in TDS resulting from treatment upstream was converted to a monetary saving, using a user cost model. This enabled the effect of a certain treatment strategy to be directly quantified in monetary terms and hence compared to the costs of treatment.

This comparison generates various possibilities of which three are listed below from the *most* desirable to the *least* desirable:

1. Treatment results in a direct benefit (i.e. treatment is profitable), an indirect benefit (i.e. saving to users downstream) and consequently an overall benefit.

2. Treatment results in a direct cost (i.e. treatment is not profitable), an indirect benefit (i.e. saving to users downstream) and an overall benefit.

3. Treatment results in a direct cost (i.e. treatment is not profitable), an indirect benefit (i.e. saving to users downstream) and an overall cost.

In the first possibility, the treatment project is self-funding and thus should be implemented without delay. The second possibility illustrates a situation where third party intervention may be required to subsidise the treatment plant to ensure that the benefits can be realised. The third possibility illustrates a situation where the cost is higher than the benefit and hence treatment should not be undertaken.

The eight strategies in Chapter 4 are assessed according to the above criteria.

3.2 TREATMENT COSTS

3.2.1 Introduction

The discussion below explains the mechanics of the spreadsheets that have been used to estimate the Budget Costs used in this report (an example spreadsheet is shown in Figure 3.1 - the remaining spreadsheets can be found in Appendix A.9). The layout for each process is identical in order for comparisons to be made on an equitable process, but the text differs slightly on occasion. The objective of displaying these calculations is to give the reader a breakdown of the overall costs given in the body of the report and an idea of the main process and financial parameters that were used to derive the costs. A change in these parameters will clearly have an impact on the costs and thus the effect of varying these parameters is shown in the two smaller tables on the right of the spreadsheets. These are included so that if the reader believes that a parameter adjustment is required, the effect of varying the parameter can readily be determined without the need for the original spreadsheet file.

3.2.2 Plant parameters

Most membrane processes are broadly classified according to their water recoveries and salt rejections. (For simplicity, this classification has been adopted for *all* the processes discussed in this report). In practice the water recovery and salt rejections are influenced by a number of factors such as, the degree of softening in pre-treatment and the quantity and type of anti-scalents dosed. The figures given, are estimates of the best attainable recovery and rejection under normal operating conditions for the given water. Fluctuations in dosing quantities etc. which are required to achieve these conditions are reflected in the operating cost.

The flows and concentrations given are calculated using the water recovery and salt rejection values.

3.2.3 Unit costs

If unit costs were available in the literature, these were used. If no figures were available these unit costs were reverse calculated from other known figures used elsewhere in the spreadsheet. The effect of adjusting the income derived from the sale of potable water and by-products is given in a separate table on the right.

3.2.4 Financial parameters

It was assumed for all the processes that the capital required for initial construction is paid back over a period of 20 years at a real interest rate of 8%. While it is conceded that a small capital amount can possibly be paid off in less than 20 years and that interest rates will fluctuate over the period, these figures were used for all processes and hence still enable realistic comparisons to be made.

The effect of varying the number of years of payback and the interest are given in a separate table on the right.

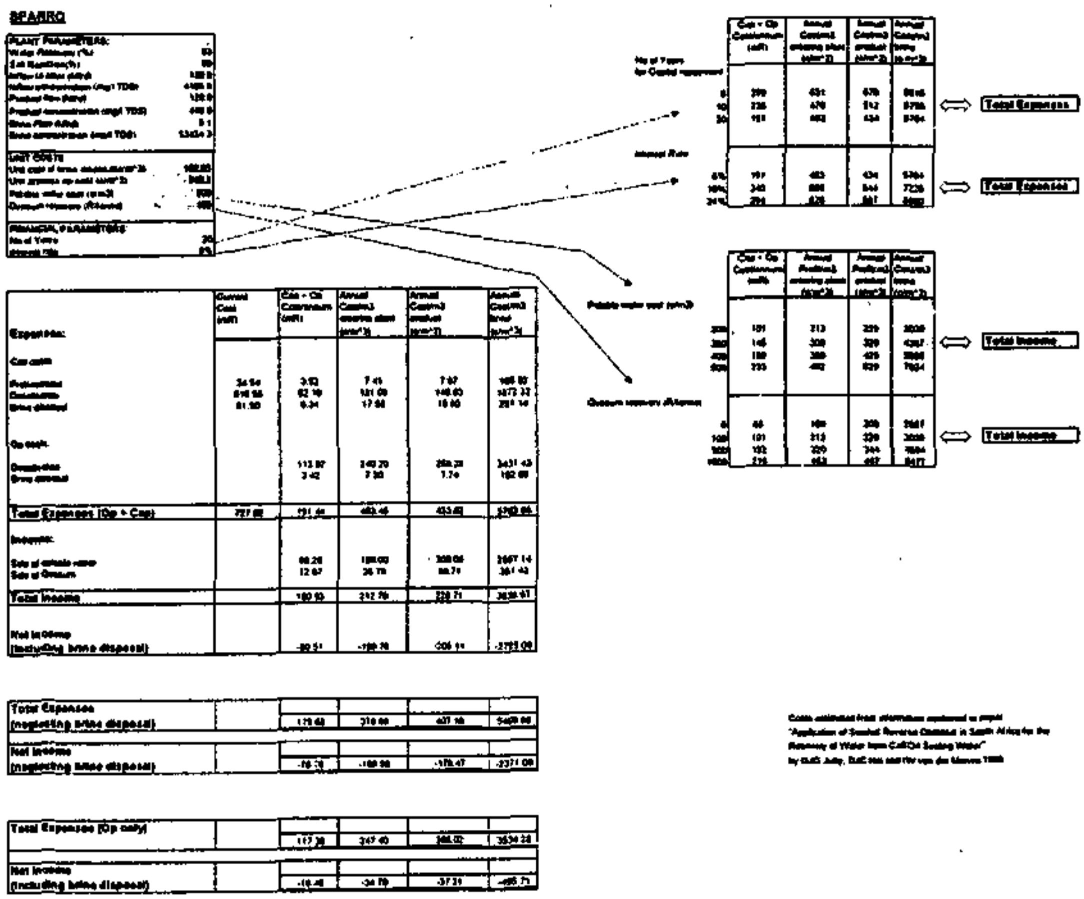


Figure 3.1: Example of Cost Calculation Spreadsheet for the SPARRO Process

3.2.5 Expenses

3.2.5.1 Capital cost

The capital costs are divided into pre-treatment, desalination and brine disposal (if applicable). The pre-treatment cost includes for softening, flocculation and filtration etc. (dependent on the process type). If a pipe or concrete channel is included in a strategy then the relevant capital cost is included. Using the number of years of capital repayment and the interest rate the capital costs are converted to annual costs. The *unit* capital costs are then calculated according to the flow entering the plant, or produced as product water or brine.

3.2.5.2 Operating cost

The operating costs are divided into desalination (membrane replacement, chemical dosing etc.) and brine disposal (if applicable).

Where applicable, the costs of brine treatment were estimated by assuming the use of enhanced spray evaporation as a method of brine treatment (see Appendix A.6 for more details). The processes for which enhanced evaporation was assumed were: RO, EDR, GYP-CIX, SPARRO and ASTROP. The AQUA-K process, although RO-based, makes use of a crystallisor and the Biosulphate and SAVMIN processes produce sludges or precipitants which require dewatering.

The total annual expense of the plant is calculated by addition of the annual capital repayment and operating costs.

3.2.6 Income

3.2.6.1 Sale of potable water

If potable water is produced, provided it is not re-blended and discharged to the river, it is assumed to be sold for 200 c/m^3. Although this figure approximates the current price of potable water sold to mines, it is anticipated that the cost of potable water will rise in response to greater future demand. It is accepted that currently Rand Water would only be prepared to pay in the order of R 1,20 to R 1,50 per m^3 particularly although current projections indicate a potential positive growth for water consumption on the far East Rand in the short term. Additionally, the proposed 90 c/m^3 levy on subsurface abstraction has NOT been factored into these calculations and may have the effect of making the production of potable water totally uneconomical. This levy is mainly due to the implementation of water schemes and it is possible for mines to apply for concession. To make the water management strategies economically viable it is thus assumed that this concession will be granted. The sale of by-products therefore becomes extremely important and processes such as the Biosulphate process may be at a greater advantage since potable water may not be produced and the sale of sulphur may be able to offset the treatment costs.

The effect of increasing the unit sale price of potable water is shown in a separate table on the right of the spreadsheet.

3.2.6.2 Sale of by-products

Particularly for high TDS waters, the production and sale of by-products can assist in greater cost recovery. Since the price obtained for the sale of by-products may fluctuate, the effect of fluctuation is shown in a separate table on the right of the spreadsheet.

3.2.7 Costs without brine disposal or capital repayments

At the base of the spreadsheet an estimate is also given of the total annual expenses if brine disposal is not required. This is given so that if, for example, a plant is located near a suitable disposal site, an estimate can still be obtained. It also gives an idea of the overall contribution of brine disposal to the annual cost.

Finally, also at the base of the spreadsheet, an estimate is given of the annual cost once the capital cost is no longer included (i.e. after the 20-year payback period). This gives an idea of the annual operating cost and net income possible if the profits from another venture within the proposed operating company can be directly committed to the construction of a plant. This strategy may, for example, be used to lighten a tax burden by depressing profits. This serves to highlight the importance of considering the optimal financing of any proposed desalination plant.

It may well be, that if low interest finance is available, it is more viable to select a process that has a high capital cost but a comparatively low operating cost.

3.2.8 Disclaimer

It should be remembered that the costs presented in this report are budget costs. In addition, the cost-effectiveness of the process depends on the quantity and quality of the water to be treated. The selection of a particular process for a conceptual strategy should not be regarded as an endorsement of that process.

3.3 THE AQUABAT MODEL

3.3.1 Water and salt balance model for the Vaal Barrage catchment

3.3.1.1 Water management in the Vaal Barrage catchment

To compare the different water management strategies for the four gold mines it will be necessary to develop a water and salt balance model for the relevant catchment. The middle Vaal River catchment (from the Barrage to Bloemhof Dam) is heavily dependent on the flow and quality of water released from the Vaal Barrage. Any changes in the water quality released from the Vaal Barrage will thus have an impact on water users from the middle Vaal River. The aim of this study is to compare different water management strategies within the Vaal Barrage. It should be noted that if the water users in the middle Vaal River catchment are included in the scope of the study the indirect benefit for all the strategies will be affected in the same proportion. The aim of the study is thus not to define definitively the indirect benefits of the water management strategies, but to compare the benefits and costs of the different strategies. The inclusion of the water users in the middle Vaal River will thus not alter the screening of the strategies and the boundary of the water and salt balance includes, therefore, only the Vaal Barrage catchment.

The Vaal Barrage catchment is one of the most developed areas in South Africa and the streamflows are mainly influenced by industrial, mining and municipal return flows, abstractions, urban runoff and irrigation. To develop a water and salt balance model for the catchment it is important to understand the hydrology of the catchment and the water management within the catchment. These two aspects will be discussed in more detail below.

Relatively comprehensive research has been undertaken to understand the hydrology of the Vaal Barrage catchment. The Vaal Barrage catchment encompasses the incremental catchment that drains into the Vaal River between the Vaal Dam and the Vaal Barrage (DWAF catchment numbers C 210 and C 220) and is illustrated in Figure 1.1. The catchment covers an area of 8 651 km^2 and the main tributaries are the Blesbokspruit, Suikerbosrand River, Klip River (which includes the Elsburgspruit, Natalspruit and the Rietspruit), Greater Rietspruit and Taaibosspruit. The sub-catchments that were defined to develop the water and salt balance model correspond to the different tributaries of the main catchment and are discussed in more detail in Appendix B.

The development within the catchment has continually placed an increased pressure on the water resources of the catchment. The Vaal River supplies almost 80% of the water abstracted from river systems within the catchment. The capacity of the Vaal River as a resource has been reached as early as 1975 and water had to be imported from other catchments to satisfy the growing demands. This demand is currently being satisfied by major transfer schemes importing water into the Vaal River. The development of a water and salt balance model for the Vaal River system becomes more and more complex as different catchments are being integrated with each other. When a water and salt balance model is developed for an individual catchment, such as the Vaal Barrage catchment, it is necessary to be aware of the complexity of the system and how the complexity will influence the modeling.

The increase in salinity levels, due to return flows from urban, industrial and gold mining activities within the Vaal Barrage catchment, results in unacceptable water quality for water users downstream of the Vaal Dam. To maintain an acceptable water quality within the Vaal River various water management strategies have been investigated and implemented.

The salinity in the Vaal River was initially managed with the "*300 mg/l blending option*". The treated water from Rand Water, abstracted from its three abstraction points (Figure 1.1), was "blended" with treated water from the Vaal Dam to supply water with a final TDS concentration of 300 mg/l. The water quality at the Suikerbosrand, Escom and Iscor abstraction points suffered under this management strategy, due to backflow from the Klip River. The Lethabo Weir was built to solve the problem. The weir was built downstream of the Escom abstraction point and upstream of the Suikerbosrand abstraction point. Escom and Iscor benefited from this management strategy as the better quality water upstream of the Lethabo Weir was separated from the poorer water quality downstream. Part of the management strategy was to keep releases form the Vaal Dam at a minimum. This had a negative implication for the water users along the middle Vaal River, which were mostly supplied with return flows from the Vaal Barrage catchment.

New water management strategies were investigated, due to the negative impacts of the "blending" option and the increased deterioration of the water quality. This resulted in the "*600 mg/l dilution option*". According to this management strategy a calculated amount of water is released from the Vaal Dam, over the Lethabo Weir, to dilute the TDS concentration in the Vaal Barrage to 600 mg/l. It was estimated that Rand Water could abstract from the

Vaal Barrage catchment an amount equal to the return flows from the catchment and obtain the rest from the Vaal Dam. This will provide Rand Water with water that has a maximum TDS concentration of 300 mg/l. The advantage of this option is that water with a lower salinity will be released from the Vaal Barrage and should benefit users in the middle Vaal River, downstream of the Barrage. An assessment of the "*dilution option*" was done in 1997 (Geldenhuys, 1997) and the model for the system was refined. The "*dilution option*" is currently still in operation as the management strategy for the Vaal Barrage.

3.3.1.2 Water and salt balance model: AQUABAT

The water and salt balance models that have been developed for the Vaal Barrage catchment are mainly dynamic models that require different time steps. These models require vast amount of data and are mostly suitable for detail studies of the catchment. In a situation where a screening level assessment is undertaken and a relatively quick assessment of a number of different options is required, the high level of detail and accuracy of these models are not required. As this study falls into this category the choice of water and salt balance model is driven by the following requirements:

- A relatively low level of accuracy is required (70 % - 80 % accuracy).
- High flexibility, i.e. a model that can be changed with relative ease.
- Relatively quick simulations to model numerous different "what-if" scenarios.

Due to these requirements and the objectives of the project, the use of the water and salt balance software AQUABAT is deemed adequate to develop the desired model. AQUABAT is software that has been developed by Pulles, Howard and De Lange specifically for the development of water and salt balances. When a water and salt balance model has been developed it can be changed with relative ease. The static water and salt balance models that can be developed with the software are, therefore, very flexible and can be used to model various different "what-if" scenarios within minutes.

The main disadvantage of the model is that it is static and does not accommodate seasonal fluctuations and the effect of retention. To minimise the effect of this limitation the following methodology was used:

- Data was divided into seasonal periods, i.e. summer (October to March) and winter (April to September).
- Statistical averages were used for data over a five-year period.
- Statistical averages for five-year periods from 1970 to 1994 were used to calibrate the model.

Dividing the data into two seasonal sets will assist with assessing seasonal effects. The use of five-year periods for the data will minimise the effect of retention time mainly caused by dams, but will, however, also reduce the effect of long-term rainfall cycles. The use of a five-year moving average will provide manageable data sets for a static model, but will decrease the range of variations and result in smoother data curves. This will enable one to develop a static model with AQUABAT that takes seasonal effects in consideration and is calibrated for a five-year moving average, with the ensuing lower level of accuracy. The model has thus been developed taking the current water users and effluents in consideration, any future developments, e.g. additional users or effluent, or changes in the management of the catchment have not been taken into account.

The water and salt balance model requires all the relevant water flows and quality input and output data. This data comprises:

- Return water flows from point sources
- Releases from the Vaal Dam
- Water from diffuse sources
- Runoff
- Point water abstractions
- Flow from the Vaal Barrage catchment to the middle Vaal River
- Evaporation
- Irrigation
- Bedlosses

Data for the period 1991 – 1997 was collected from various sources and is discussed in more detail in Appendix B. For the period 1970 – 1994 data was collected and used to calibrate the model, as discussed above.

The water and salt balance model was developed in accordance with the basic principles and steps as recommended by *Best Practice Guideline 1: Water and Salt Balances* (BPG 1) (DWAF, 1999). The recommended steps from BPG 1 were adapted as indicated in Figure 3.2, due to the fact that the Vaal Barrage is a large and complex system, and does have an existing monitoring system. As this is a screening level study to compare different water management strategies for further investigation, it was decided that the model should have an accuracy of 70% – 80% accurate.

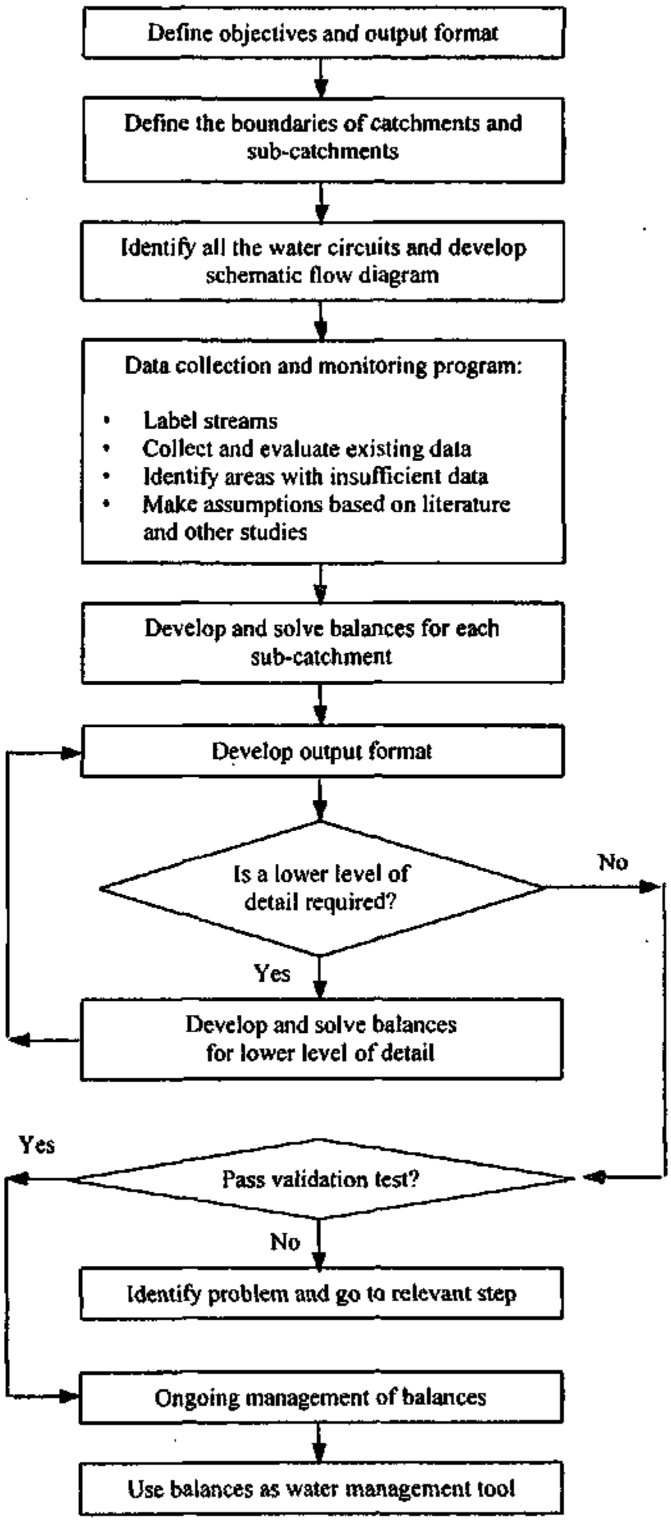


Figure 3.2: Steps Followed in Development of Water and Salt Balance Model.

3.4 COSTS TO THE USERS DOWNSTREAM

The approach to determining the costs to users of facing varying degrees of salinity in their abstracted water is based on estimating the actual direct costs to users, rather than imputing these costs indirectly. A major amount of the input was derived from an unpublished report submitted to the Water Research Commission and the Department of Water Affairs and Forestry entitled "Determining the Impact of the Salinisation of South Africa's Water Resources with respect to Economic effects" by Urban-Econ in 1999. The report details a study to model the costs of salinity to water users, by means of direct research and field work into the actual costs borne by users in various sectors as a result of rising salinity levels.

The Urban-Econ study was carried out for the middle Vaal River and covered many economic sectors, including mining, industries, agriculture and households, which are also the sectors of interest for this study. It was assumed that the mix of activities within these sectors would be essentially similar to that in the Vaal Barrage and that the data from the Urban-Econ report could be used in this study. The user costs from this database represent the costs to each sector of activity of combating various levels of salinity in water received.

Large enterprises such as Eskom, Sasol and Iscor were not covered by the Urban-Econ study. For the purposes of this study, therefore, these user costs were estimated from actual costs of desalination, and water qualities used by these sectors.

Levels of salinity for which data was available went from 200 mg/l to 1 200 mg/l in discrete 200 mg/l steps. This data was subsequently linearly interpolated to give steps of 10 mg/l. Costs in all cases are expressed in R/Ml for each salinity level, at 1998 prices.

Table 3.1 shows user costs that were finally adopted for this study. Figure 3.3 shows the same information in graphical form.

Table 3.1: User Costs at Various TDS Levels in R/Ml.

Sector	TDS							
	200 (mg/l)	400 (mg/l)	500 (mg/l)	600 (mg/l)	800 (mg/l)	1 000 (mg/l)	1 200 (mg/l)	1 300 (mg/l)
Residential	0	1 269	1 903	2 537	3 806	5 075	6 344	6 978
Water boards	0	1 196	1 823	2 456	3 620	4 784	5 949	6 531
Eskom	0	159	239	318	477	636	795	875
Sasol	0	159	239	318	477	636	795	875
Iscor	0	105	158	210	315	420	525	578
Irrigation	0	0	0	323	323	347	370	381
Industry	0	179	352	559	650	740	831	876
Mining	0	35	51	57	85	122	175	201

3.4.1 Implementation

The next step was to convert these unit user costs above into annualised total costs for each sector, taking into account the relevant abstraction levels, and the salinity which would be faced by each abstractor, under all the scenarios being considered.

A spreadsheet model was used for this purpose, and the inputs were:

- the unit user costs applicable to each sector (as described above), and
- the abstraction and salinity levels applicable to each abstractor.

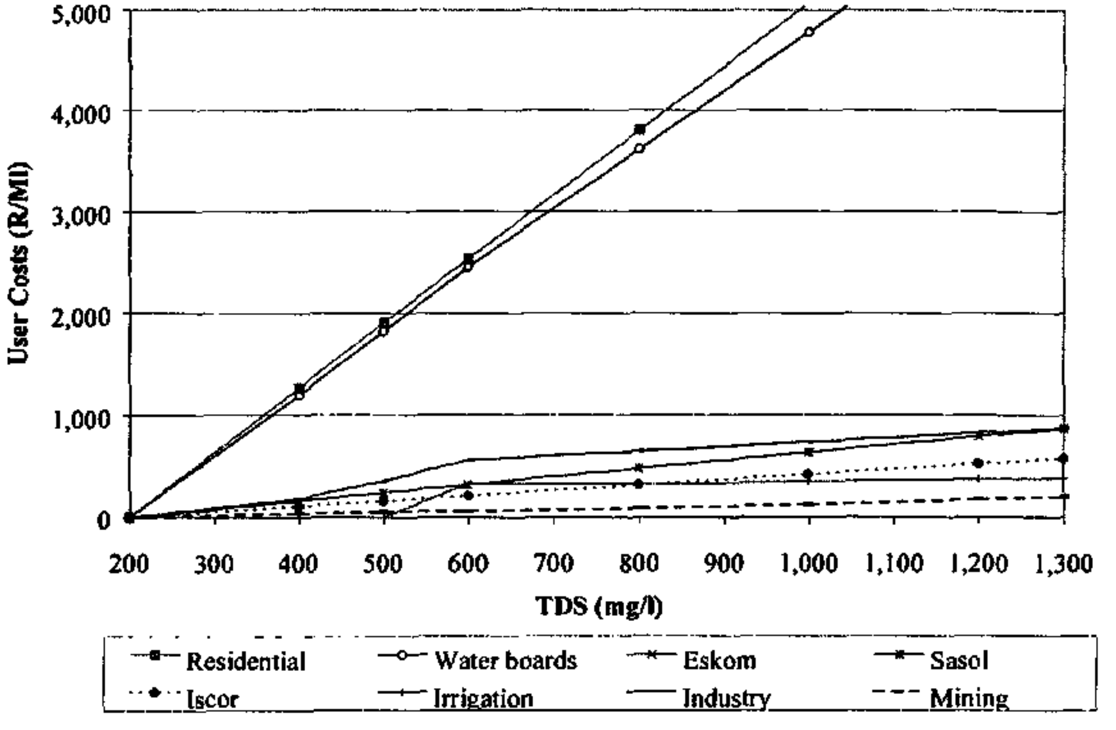


Figure 3.3: Graph of User Costs at Various TDS Levels.

These latter data were provided by the Aquabat model, which is described in Section 3.3 above and in Appendix B below.

The approach taken to quantify user costs was first to calculate the cost to users of combating the levels of salinity which they have been facing up to the present, i.e., with no additional desalination being undertaken at Grootvlei or any other sites. These base costs were calculated on the basis of an average 5-year cycle, and a 5-year dry cycle.

Various scenarios were then examined under which different desalination strategies were assumed for Grootvlei (and other) mines. The changes in salinity levels, which would then face downstream abstractors, were calculated using Aquabat and new user costs were calculated. The difference between these new costs and the base costs then represented the change in user costs as a result of the desalination activities represented by each scenario.

The difference between these changes in user costs, and the cost of setting up and running the desalination regime represented by each scenario then gives a measure of the economic viability of each scenario.

Thus:

- If desalination costs = change in user costs, then there is a break-even situation, and the economic impact is neutral;

- If desalination costs < change in user costs, then the economic impact is positive, and the measures put forward in the scenario could be implemented;

- If desalination costs > change in user costs, then the economic impact is negative, and the measures put forward in the scenario should not be implemented.

3.4.2 Sensitivity

The model was tested for sensitivity to variation in the levels of salinity which were presented to it. The results of all scenarios were tested, as well as an average of all the results. It was found that if salinity levels were overstated by 35% then costs would be overstated by 44%. If salinity levels were understated by 35% then costs would be understated by 42%. Thus there is a slight sensitivity to changes in salinity levels over a wide range, but in the range being used for this study, the model can be considered to be quite robust.

Table 3.2: Sensitivity of Model to Variations in TDS Levels

% Change in TDS	% Change in output	
	Strategy 1	Average
-35%	-48%	-44%
-25%	-30%	-29%
-10%	-8%	-9%
0%	0%	0%
10%	18%	16%
25%	31%	30%
35%	43%	42%
50%	46%	55%

3.5 ASSUMPTIONS AND LIMITATIONS

The development and assessment of the various strategies are based on certain assumptions and have some limitations. The are also assumptions and limitations applicable to the development of the water and salt balance model and the user cost model. The following assumptions were made in this study:

- Desalination processes that have been tested on a pilot scale were deemed technically feasible to be used as part of water management strategy in this study.
- Specific prices of by-products were assumed (as discussed in Appendix A) and changes in these prices will have an affect on the costs determined in this study. Uncertainty exists regarding the quality of the elemental sulphur produced by the Biosulphate process and is thus not included as a by-product.
- The capital required for initial construction of a process is paid back over a period of 20 years at a real interest rate of 8%.
- Enhanced spray evaporation was assumed as the brine treatment option for processes that do not include brine treatment.

- It is assumed that potable water is sold at 200 c/m^3 (see section 3.2.6.1 for motivation).
- The additional levy of 90 c/m^3 on subsurface abstraction has not been factored into the economic calculations (see section 3.2.6.1 for motivation).
- The mix of activities within the various economic sectors is similar for the Middle Vaal- and the Vaal Barrage catchment. A study to adapt the user cost model for the Vaal Barrage is required if more accurate values are required.
- The ingress of water from Blesbokspruit into the Grootvlei mine workings is in the order of 50% of the volume pumped out of Grootvlei. This assumption is based on experience at the mine and should be investigated properly before any strategies that rely on this assumption are implemented.

Limitations for the study can be summarised as:

- The costs determined and used in the study are budget costs. These costs are furthermore dependent on the quantity and quality of the water to be used.
- The study focuses on the Vaal Barrage catchment. Additional economic benefits in the Middle Vaal, due to lower salinity in the Vaal River, were not included.
- Future development and changes in catchment management that will affect the Vaal Barrage catchment were not considered in the study.
- The minimum accuracy of the water and salt balance was set as 70%. The actual balances are in the accuracy range of 80% - 90%.
- The water and salt balance model is a static model calibrated for a 5-year moving average. The model is more accurate for average to dry 5-year periods and should not be used for very high rainfall 5-year periods, unless it is re-calibrated for high rainfall scenarios.
- The user cost model has a margin of error, e.g. an overestimation of 35% of salinity will result in costs being overestimated by 44% (see Table 3.2).

CHAPTER 4

CONCEPTUAL STRATEGIES FOR REDUCING THE SALT LOAD TO THE VAAL BARRAGE

4.1 INTRODUCTION TO STRATEGIES

The strategies outlined below approach the problem of reducing the salt load into the Vaal Barrage from a number of different perspectives. The aim of the eight strategies is to provide possible alternatives for cost-effective reduction of salt load, some of which can be used in conjunction with others. The conclusions from this section is discussed in Chapter 5, which provides a summary of the most promising treatment philosophy substantiated by budget costs of treatment and savings to downstream users and gives recommendations for further research.

Strategies 6 and 7 investigate the use of a channel to by-pass the wetland in the Blesbokspruit. It is believed that a large portion of the water in Grootvlei mine is caused by ingress from Blesbokspruit. The ingress of water from the Blesbokspruit is only addressed in strategies 6 and 7 and is not taken into consideration for the other strategies. Unlike the first five strategies that are based on technically viable options, strategies 6 and 7 require more investigations to proof their technical feasibility.

4.2 STRATEGY 1

4.2.1 Introduction

It is clear from the figures given in Table 2.2 above, that although the project was set up with regional treatment in mind, the contribution of Grootvlei to the total salt load entering the Vaal Barrage is disproportionately large (~80% of the total of the four mines). Strategy 1 was therefore set up to compare eight possible desalinating processes in order to determine the most promising process philosophy for the cost-effective reduction of the current salt load, discharged from Grootvlei to the Blesbokspruit and ultimately the Vaal River and Barrage.

4.2.2 Costs and Benefits

It should be remembered that the treatment costs given are budget costs and as such are subject to many variables. For example the price of dosing chemicals, membranes, electricity, labour etc. is likely to fluctuate over time and the contribution of these components to the overall treatment cost varies from process to process. In addition it should also be remembered that each mining effluent is different and that it is highly unlikely that any one process will be the most cost effective in the treatment of all waters.

The information given in Table 4.1 has been extracted from Appendix A.9. The total *cost* given in c/m^3 of product water, is a combination of the operating costs and the repayment of capital. The total *income* given in c/m^3 is an indication of the potential income that can be obtained per cubic metre of product water produced and includes for both the sale of water

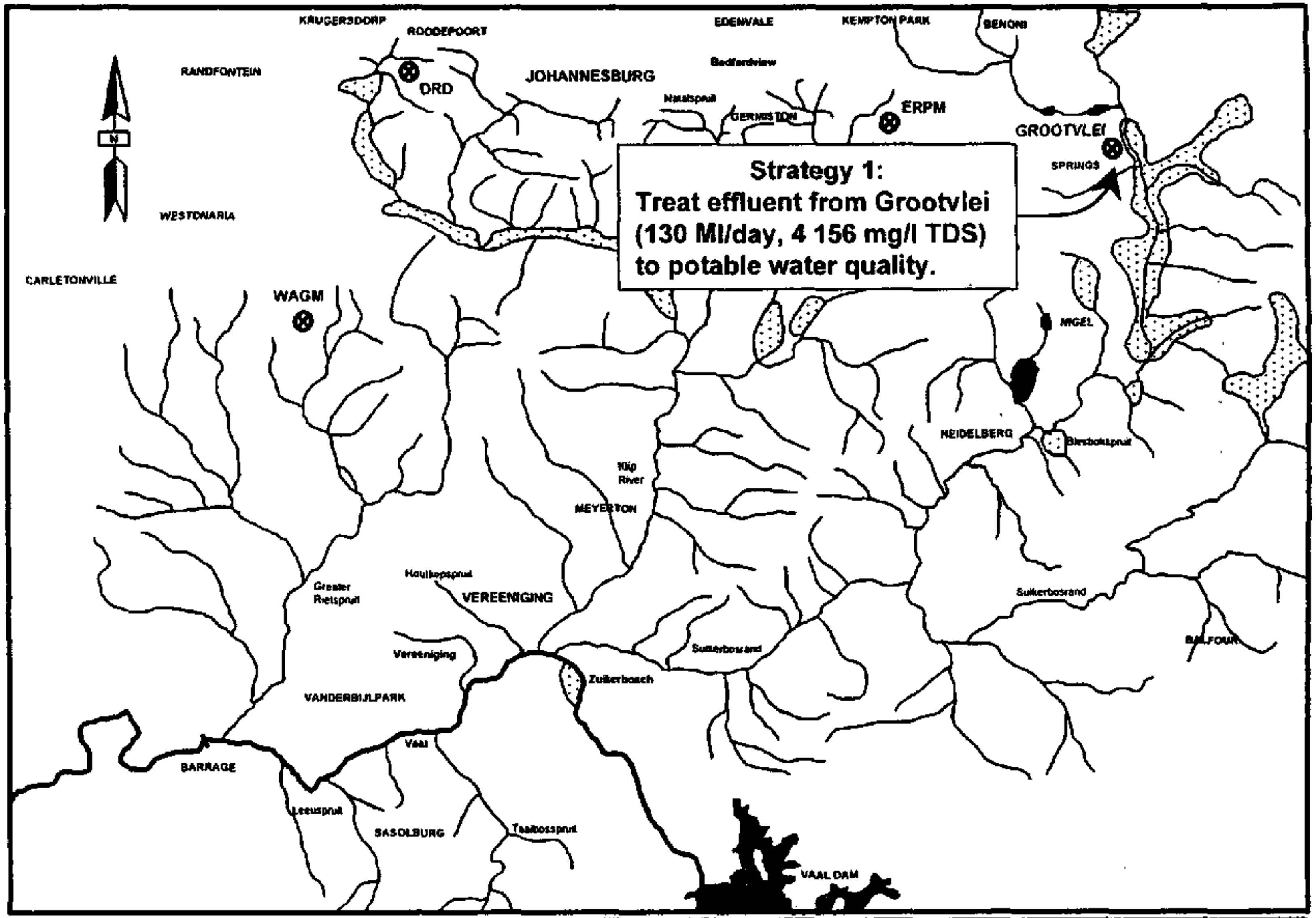


Fig 4.1 : Strategy 1 - Treatment of Grootvlei effluent.

and the sale of by-products. It should be noted that since the Grootvlei effluent is high in monovalent ions it is not possible to produce potable water using either the SAVMIN process or the Biosulphate process on their own. Although the water produced is not potable, it is still of considerably better quality than the raw effluent. However, the sale of this "service" quality water has not been included in the income from sale of water or by-products. The sale of elemental sulphur has also not been included in the income derived from sale of by-products for the Biosulphate process. (As noted in Chapter 3, the uncertainty surrounding the quality of elemental sulphur produced is problematic in terms of estimating an income from its sale.)

Table 4.1: Strategy 1 Unit Costs

Process	Inflow to plant (Ml/d)	Total cost per m^3 of product water (c/m^3)	Income per m^3 product water, from sale of water (c/m^3)	Income per m^3 product water, from sale of by-products (c/m^3)	Total income per m^3 product water, from sale of by-products (c/m^3)
AQUA-K	130	484	200	217	417
ASTROP	130	606	200	30	230
Biosulphate	130	157	0	0	0
EDR	130	461	200	0	200
GYP-CIX	130	607	200	38	238
RO	130	582	200	0	200
SAVMIN	130	340	0	27	27
SPARRO	130	434	200	29	229

The figures are quoted in c/m^3 so as to enable an equitable comparison between processes with differing water recoveries and in the case of the ASTROP, EDR, GYP-CIX, RO and SPARRO processes, the treatment cost includes for the treatment of brine via enhanced spray evaporation. (See Appendix A.6.)

The processes listed above can generally be separated into three groups: those that produce only potable water; those that produce only by-products and those that produce both potable water and by-products. In spite of the variation in treatment costs in c/m^3 it is apparent that those processes which produce both potable water and by-products are more likely to achieve higher cost recovery.

It is evident that although the AQUA-K process is the fourth most expensive in terms of $cost/m^3$, it is also the process which has the highest income from the sale of by-products. In fact, the income derived from sale of by-products for the AQUA-K process is greater than the income from the sale of potable water and significantly higher than the income achieved by any other process from the sale of by-products.

Interestingly, the cost of each process bears little or no correlation to the potential total income achievable.

Table 4.2 shows a cost benefit comparison which is broken down into direct costs (and benefits) and indirect benefits. The direct cost (or benefit) is then added to the indirect benefit to generate a total cost (or total benefit). The direct costs include the operating and capital repayment costs per annum and the direct benefits include for income derived from the sale of by-products (including potable water if applicable). The direct cost (or benefit) column gives an indication of the self-sustainability of the process.

Table 4.2: Strategy 1 Total Costs

Process	Direct costs (R x10^6/a)	Direct benefits (R x10^6/a)	Direct cost or benefit (R x10^6/a)	Average 5-year cycle: Indirect benefits (R x10^6/a)	Average 5-year cycle: Total cost or benefit (R x10^6/a)	Dry 5-year cycle: Indirect benefit (R x10^6/a)	Dry 5-year cycle: Total cost or benefit (R x10^6/a)
AQUA-K	-221	190	-31	28	-3	38	8
ASTROP	-259	98	-161	28	-133	38	-122
Biosulphate	-74	0	-74	15	-59	20	-54
EDR	-175	76	-99	28	-71	38	-61
GYP-CIX	-202	79	-123	28	-95	38	-84
RO	-235	81	-154	28	-126	38	-116
SAVMIN	-158	13	-145	19	-126	24	-121
SPARRO	-191	101	-91	28	-62	38	-52

It might be argued that indirect benefits have no place in this discussion, as although they improve the overall economical viability of all scenarios, the bottom-line of the polluting firm remains negatively impacted in nearly all cases. This situation would clearly not be acceptable to management.

It must nevertheless be borne in mind that any polluting activity carries a cost, and the price must ultimately be paid, whether by the polluter himself, or by downstream users who have to cope with reduced water quality. The Polluter Pays Principle holds that anyone who pollutes should be responsible for all costs associated with it. These may take the form of direct costs (the cost of clean-up) or indirect costs (pollution charges). Various economic instruments exist whereby indirect costs can be equitable passed on to polluters. In all cases the costs of coping with the effects of pollution would find their way onto the bottom-line of the polluting firm.

This topic is discussed more fully under Section 4.10, but the important issue to be noted here is that these economic costs can never be ignored if a full picture of the costs of pollution is to be obtained.

The indirect benefit is estimated using the user savings model and indicates both the savings to industry and individual users per annum resulting from treatment. Treatment costs are not expected to be subject to seasonal variations, although it is conceded that de-watering patterns vary on a seasonal basis and hence treatment volumes may fluctuate slightly. However, the variation in user costs will be more pronounced both on a seasonal basis and also according to dam levels and river flows. For this reason, the driest five-year cycle in the hundred year period prior to 1996 was considered and compared with an average five-year cycle over the same period, since TDS concentrations are higher both in winter and during dry cycles. In summary, the benefits of treatment are greater during dry periods and both the average and driest five-year cycles are shown for comparison.

The figures in Table 4.2 above show that none of the processes considered are currently self-sustainable (the figures given are intentionally conservative in this regard and process developments and refinements are on-going), although there is considerable variation with regard to the degree of potential self-sustainability. They also show that during a dry five-year cycle, the AQUA-K process is the only process that gives a positive benefit. The reason for this, as already mentioned, stems from the income derived from the sale of by-products, which further offsets the costs of treatment. It should be remembered that the production and subsequent sale of by-products also has risks. The risks associated with price fluctuation are probably more pronounced with the sale of by-products than with the sale of potable water. Also, it is possible that the production of a particular by-product may directly influence the sale price of that product since supply would have increased with demand remaining relatively constant.

The indirect benefit figures for the Biosulphate and SAVMIN process reflect a situation in which the product water is not potable and is discharged to the Blesbokspruit.

4.2.3 Conclusions

The above tables tend to indicate that, *ceteris paribus*, the AQUA-K process comes closest to being self-sustainable in terms of its operation. With the current trend towards the reduction of pumping and other subsidies, it is no longer sufficient to assume that funds will be available indefinitely for the treatment of decant water or effluents discharged from mines. It must be stressed that the above tables refer specifically to the effluent currently being discharged at Grootvlei and must not be generalised to apply to all high sulphate waters. The figures tabled above indicate that in order to treat high sulphate water without incurring continual annual costs, it is vital to adopt the correct process philosophy. Contrary to what is widely believed, a problem of this nature cannot be solved cost-effectively merely by the production and sale of potable water, with the concomitant removal of calcium sulphate. The costs of the SPARRO process indicate this. The process philosophy must be taken one step further to include not just the removal of compounds but their combination with other species which may or may not be present in the original effluent. The methodology adopted must therefore be one of separation possibly followed by re-combination to ultimately produce high value products. If potable water is produced in the process this should really be considered as another by-product, the demand for which is relatively consistent and this generally indicates a stable price.

It should be remembered that the user savings are those for the upper Vaal (i.e. between the Vaal Dam and the Vaal Barrage). The influence on user costs in the middle Vaal has not been included and indications are that during an average year, a total benefit will be realised from treatment and not a total cost as occurs if just the upper Vaal is used.

4.3 STRATEGY 2

4.3.1 Introduction

The quality of the effluent produced by ERPM is similar to that produced by Grootvlei (see Appendix A.7.) although the flow is considerably less at 16 Ml/d. (Recent estimates suggest that this flow is currently 22 Ml/d. A flow of 16 Ml/d has however been used in all calculations in this document). The two mines are both situated on the East Rand and are approximately 20 km apart. In this strategy therefore it is suggested that the effluent produced by ERPM be pumped to Grootvlei so that the combined flow of 146 Ml/d can be treated in one desalination plant. Since the quality of the combined flow is similar to that produced by Grootvlei, for brevity, only the AQUA-K process was considered since the combined water quality is very similar to the effluent from only Grootvlei and hence the process selection criteria will be similar.

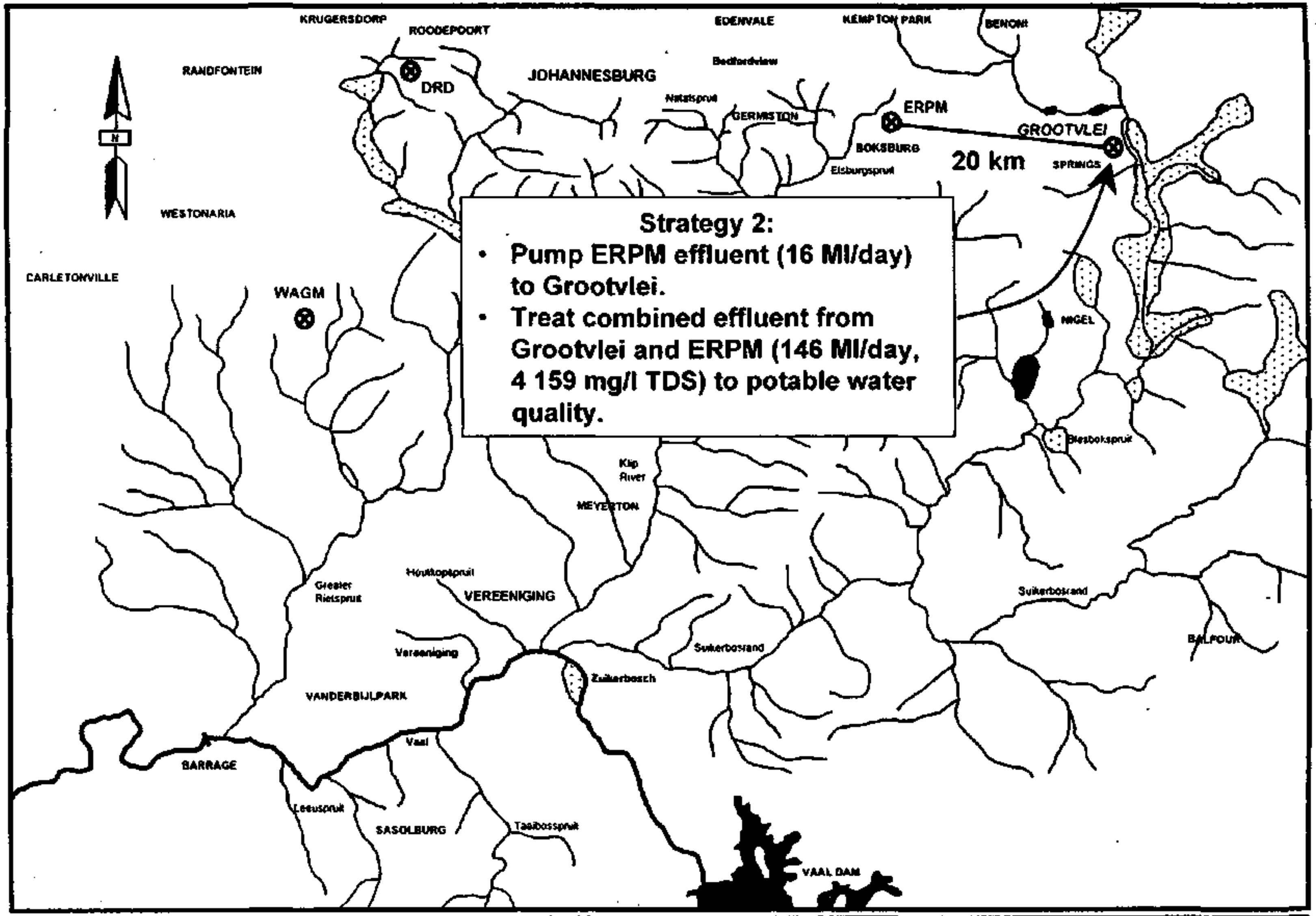


Fig 4.2 : Strategy 2 - Treatment of combined effluent from Grootvlei and ERPM.

4.3.2 Costs and Benefits

The unit costs shown in the table below are similar to those given for Strategy 1. The inclusion of the capital, operating and maintenance costs of the proposed 20 km pipeline with a design capacity of 16 Ml/d is small compared with the capital and operating costs of desalination. As with all the capital costs, a real interest rate of 8% is used over a repayment period of 20 years.

Table 4.3: Strategy 2 Unit Costs

Process	Inflow to plant (Ml/d)	Total cost per m^3 of product water (c/m^3)	Income per m^3 product water, from sale of water (c/m^3)	Income per m^3 product water, from sale of by-products (c/m^3)	Total income per m^3 product water, from sale of by-products (c/m^3)
AQUA-K	146	489	200	217	417

The economies of scale achieved by increasing the capacity of the desalination plant from 130 Ml/d to 146 Ml/d are not significant and to some extent are offset by the capital, operating and maintenance costs of the proposed pipeline.

Table 4.4: Strategy 2 Total Costs

Process	Direct costs (R x10^6/a)	Direct benefits (R x10^6/a)	Direct cost or benefit (R x10^6/a)	Average 5-year cycle		Dry 5-year cycle	
				Indirect benefits (R x10^6/a)	Total cost or benefit (R x10^6/a)	Indirect benefit (R x10^6/a)	Total cost or benefit (R x10^6/a)
AQUA-K	-250	213	-37	32	-5	43	6

The direct costs and direct benefits shown in the Table 4.4 are almost proportional to the size of the plant for relatively small increases or decreases in plant size. Hence, an increase in plant capacity from 130 Ml/d to 146 Ml/d increases the direct cost from R 31 x10^6/a to R 37 x10^6/a.

Although the direct cost is higher for strategy 2 than it is for strategy 1, the indirect benefit includes not only for the improved water quality downstream from treating the Grootvlei effluent but also the positive impact derived from the treatment of the ERPM effluent. These two mines contribute 91% of the total of the four mines in this study (ERPM, Grootvlei, DRD and WAGM). Thus, the total cost is greater, increasing from R 3 x10^6/a to R 5 x10^6/a in an average five-year cycle and for a dry five-year cycle the total benefit decreases from R 8 x10^6/a to R 6 x10^6/a.

4.3.3 Conclusions

The additional cost of treating a greater volume, including a reticulation component, is not outweighed by the additional benefits to downstream users. This implies that the treatment of the combined effluents discharged from Grootvlei and ERPM is not justified in terms of savings to downstream users. However, as with strategy 1, the AQUA-K process, while be more cost-effective than the other processes considered, but is still not self-sustaining because an annual direct cost still exists. It is accepted that these costs are conservative but it would appear that greater innovation is required to reduce this direct cost still further and ultimately ensure an annual *positive* cash flow with minimal risk or at least a break-even scenario. From the figures above it appears that although it is cost-effective to treat in a dry five-year period it is not cost-effective to treat in an average year. As with strategy 1, it should be borne in mind that the user savings are those for the upper Vaal (i.e. between the Vaal Dam and the Vaal Barrage). If the influence on user costs in the middle Vaal is included, indications are that even during an average year, a total benefit will be realised from treatment.

4.4 STRATEGY 3

4.4.1 Introduction

In keeping with the concept of regional treatment, the aim of strategy 3 was to assess the consequences of pumping the 7 Ml/d flow produced at DRD to WAGM (Randfontein Estates no 4 shaft) for combined treatment. The quality of the effluent produced at WAGM (40 Ml/d) is significantly better than that produced at DRD and hence the combined effluent is of a significantly better quality than that produced by Grootvlei. In particular the concentration of monovalent ions is below the limit required for potable water and hence the SAVMIN process can be classified as a full desalination process for the treatment of this water. The distance between the two mines is approximately 35 km.

4.4.2 Costs and Benefits

The total cost in c/m^3 of product water for the SAVMIN process is less than half of that for the AQUA-K process for the treatment of this effluent blend. The main reason for this is that chemical dosing forms a large part of the operating cost of the SAVMIN process and is related to the concentration of calcium sulphate in the raw water. In this blend the sulphate concentration is only 1 212 mg/l compared to 2 085 mg/l in the Grootvlei effluent. In addition, income can be derived from the sale of potable water. Although the cost of treatment is greater for the AQUA-K process, the income is also greater but not sufficient to offset the higher cost. This is shown below in Table 4.5.

Table 4.5: Strategy 3 Unit Costs

Process	Inflow to plant (Ml/d)	Total cost per m^3 of product water (c/m^3)	Income per m^3 product water, from sale of water (c/m^3)	Income per m^3 product water, from sale of by-products (c/m^3)	Total income per m^3 product water, from sale of by-products (c/m^3)
AQUA-K	47	452	200	63	263
SAVMIN	47	201	200	14	214

In 1997, Stewart Scott consulting engineers proposed a method of treating the effluent from WAGM alone (report to JCI Ltd). This involved a high lime process to remove uranium and heavy metals; softening, to reduce the high concentrations of calcium; and a side-stream nano-filtration plant for the reduction of sulphate to acceptable concentrations. The process included for rapid gravity filtration and chlorination and the overall capital and operating cost was comparable to that of the SAVMIN process treating the combined flow, the quality of which is poorer.

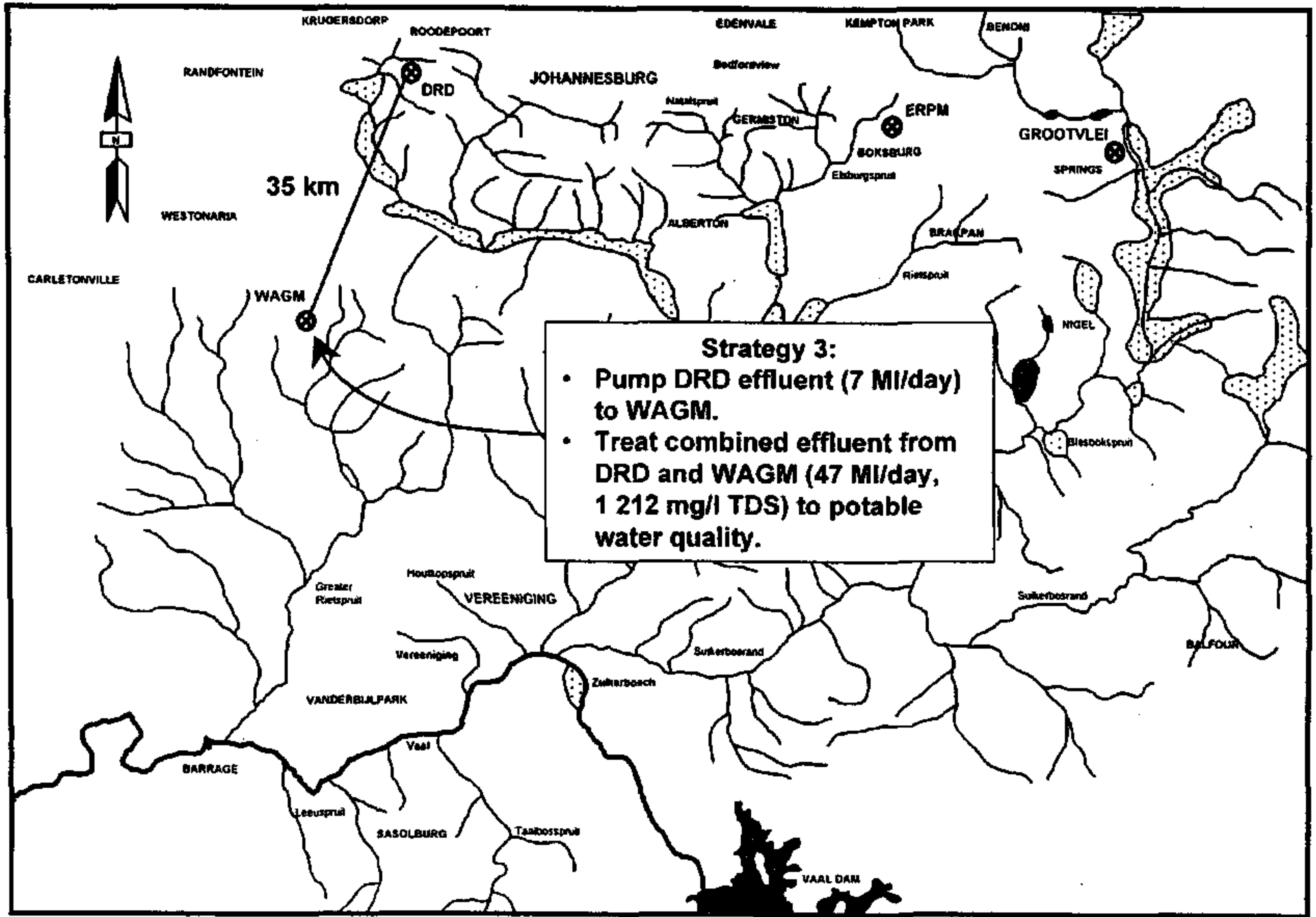


Fig 4.3 : Strategy 3 - Treatment of combined effluent from DRD and WAGM.

Table 4.6: Strategy 3 Total Costs

Process	Direct costs (R x10^6/a)	Direct benefits (R x10^6/a)	Direct cost or benefit (R x10^6/a)	Average 5-year cycle: Indirect benefits (R x10^6/a)	Average 5-year cycle: Total cost or benefit (R x10^6/a)	Dry 5-year cycle: Indirect benefit (R x10^6/a)	Dry 5-year cycle: Total cost or benefit (R x10^6/a)
AQUA-K	-74	43	-31	3	-28	4	-27
SAVMIN	-34	36	2	3	5	4	6

Table 4.6 shows that the treatment of the WAGM/DRD blend falls into the concentration range for which the sale of potable water alone can achieve full cost recovery (with the assistance of a possible 14 c/m^3 from the sale of gypsum). If the TDS of a high sulphate mining effluent falls below approximately 1 500 mg/l then, depending on the concentration of other constituents in the raw water (e.g. heavy metals, monovalent ions etc.) it is often possible to recover costs by designing a water producing plant rather than a plant that produces other products of value. The AQUA-K process is less cost-effective at the lower raw water concentration because although the total cost is reduced from 484 c/m^3 (in strategy 1) to 452 c/m^3, the income from sale of by-products is estimated to reduce from 217 c/m^3 to approximately 63 c/m^3. The reduction in total income from 417 c/m^3 to 263 c/m^3 makes the RO-based AQUA-K process uneconomical at lower TDS concentrations (< approximately 1 500 mg/l for a typical high sulphate mining water with comparatively low concentrations of monovalent ions).

4.4.3 Conclusions

The treatment of a blend between the 7 Ml/d effluent produced at DRD and the 40 Ml/d produced at WAGM (blend water qualities are given in appendix A.8.) is not only technically feasible but is also potentially profitable, even with the inclusion of the reticulation costs. Interestingly, it is not likely that a profit could be made, using any of the processes and costs described in this document, treating the DRD effluent in isolation. The profit from the treatment of the WAGM effluent in isolation should however, be greater. Hence, it is either possible to set up a different plant at each location and use the profit from the plant at WAGM to offset the losses at DRD or, as is proposed in this strategy, a blend can be treated, but with lower potential profit.

In terms of salt reduction to the Vaal Barrage the complete removal of both the 40 Ml/d produced at WAGM and the 7 Ml/d produced at DRD compares to less than an eighth of the salt load currently discharged from Grootvlei alone. This places perspective on the relative magnitudes shown in Table 2.2.

4.5 STRATEGY 4

4.5.1 Introduction

The purpose of strategy 4 was to determine the costs and benefits of combining all four flows and treating the resulting blend at Grootvlei. This entailed a combination of four different sizes and lengths of pipeline, the characteristics of which are shown in Figure 4.4 below.

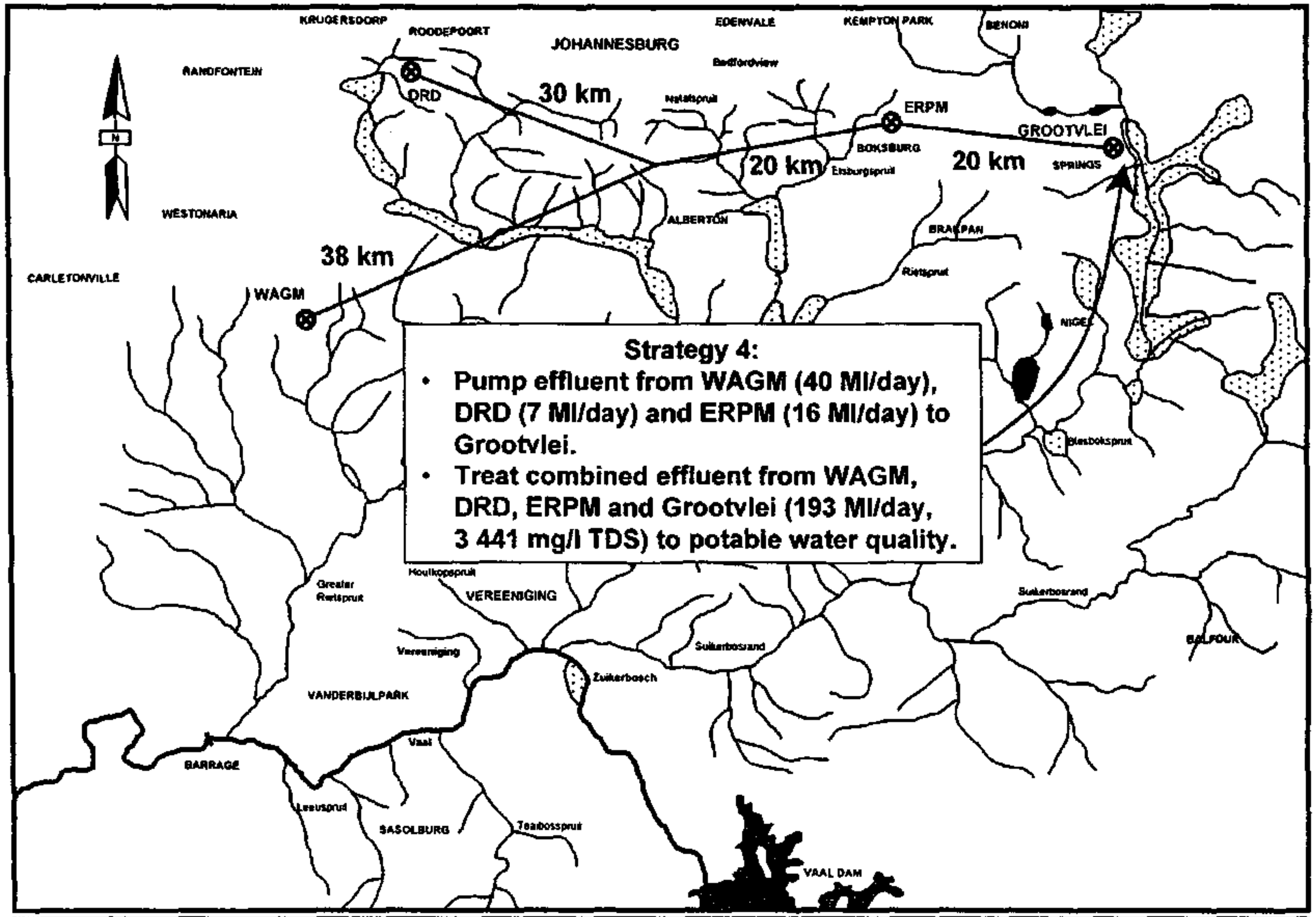


Fig 4.4 : Strategy 4 - Treatment of combined effluent from WAGM, DRD, ERPM and Grootvlei.

81% Of the salt load and 67% of the combined flow comes from Grootvlei and hence its characteristics are dominated by the characteristics of the Grootvlei effluent to produce a blended TDS of 3 441 mg/l (other blend characteristics given in Appendix A.8.4).

4.5.2 Costs and Benefits

Since the AQUA-K process had the lowest direct cost for strategy 1 it is the obvious choice *for the treatment of the blend from the four mines since the effluent quality is similar in* character to that produced at Grootvlei, although more dilute.

Table 4.7: Strategy 4 Unit Costs

Process	Inflow to plant (Ml/d)	Total cost per m^3 of product water (c/m^3)	Income per m^3 product water, from sale of water (c/m^3)	Income per m^3 product water, from sale of by-products (c/m^3)	Total income per m^3 product water, from sale of by-products (c/m^3)
AQUA-K	193	513	200	181	381

The unit costs shown above differ from those given in strategy 1 largely because of reticulation costs and a lower concentration of sulphate for the ultimate production of sodium sulphate for resale. Naturally for the purpose of this costing exercise it was assumed that the flow of product water of 185,3 Ml/d can be introduced to the Rand Water network in the far East Rand. However, it should be remembered that Rand Water is under no obligation to purchase all or any of the water and the assumed sale price of 200 c/m^3 is relatively optimistic since it compares to the current sale price of Rand Water.

Table 4.8: Strategy 4 Total Costs

Process	Direct costs (R x10^6/a)	Direct benefits (R x10^6/a)	Direct cost or benefit (R x10^6/a)	Average 5-year cycle		Dry 5-year cycle	
				Indirect benefits (R x10^6/a)	Total cost or benefit (R x10^6/a)	Indirect benefit (R x10^6/a)	Total cost or benefit (R x10^6/a)
AQUA-K	-347	258	-89	34	-55	47	-42

In order to reticulate the combined flow of 63 Ml/d to Grootvlei (making a total of 193 Ml/d to be treated) the direct cost, as expected, is the highest of any of the strategies. The sale of water and by-products does however offset this cost to some extent although the overall direct cost is R 89 x10^6/a.

This strategy involves the complete removal of approximately 664 t/d of salt from the system (recycling excluded) and hence the prevention of this salt from being washed into the Vaal River and Barrage. The indirect benefit is approximately R 34 x10^6/a during an average 5-year cycle and R 47 x10^6/a during a dry 5-year cycle, but the total *cost* is R 55 x10^6/a and R 42 x10^6/a respectively. It is interesting to note that for the treatment of Grootvlei alone there is a total *cost* of R 3 x10^6/a and a total *benefit* of R 8 x10^6/a for the average and dry 5-year cycles respectively. The reason for this is two-fold. Firstly, the cost of reticulation for the transfer of effluent from the other mines to Grootvlei increases the direct cost and secondly, the income is reduced from 417 c/m^3 to 381 c/m^3 because of the lower TDS being treated which contains less sulphate for re-sale as sodium sulphate.

4.5.3 Conclusions

The savings accrued from treating the combined flow of 193 Ml/d are not offset by the costs of reticulating all the flows to Grootvlei, particularly when the other three flows only represent 19% of the total load of the four mines. In addition, the risks of involving four separate mines which are geographically distant from each other and have differing expected life spans, would suggest that regional treatment in this case should be restricted to mines which are relatively close together and have similar life spans.

4.6 STRATEGY 5

4.6.1 Introduction

This strategy is based on the fact that during high river flows, which usually occur in summer, the TDS of river water is generally lower because of the dilution effect from rain. The lower TDS can be exploited to some extent, by allowing the discharge of certain brines or concentrates without significant impact on the biota in the river. In Australia permission has, on occasion, been granted to discharge a certain maximum flow and concentration to a river provided the flow in the river exceeds a specified quantity and quality. Once the river flow falls below this value or the quality deteriorates, discharge of the concentrate must cease immediately. This concept of "brine bleeding" however, is clearly only applicable under special circumstances. These include:

1. A relatively small mass of salt in the concentrate, relative to that present in the river.

2. A relatively small flow of concentrate relative, to the average wet weather flow in the river.

3. If the brine flow is large and continuous then the costs of brine storage prior to discharge should be low, if intermittent discharge to the river is planned.

The management of brines by bleeding, usually only applies to conventional membrane processes since the introduction of sludges and solids to a river, even during periods of high flow, is rarely considered acceptable.

As mentioned in Appendix A.6, the costs of brine storage and treatment are substantial and make up between 10% and 60% of the capital cost and between 2% and 17% of the operating cost. If, therefore, brine management can be handled in a more cost-effective manner, this may have the effect of increasing the viability of certain membrane processes. It should be noted however, that if the primary objective of desalination is to reduce the total salt load entering a river system, then the concept of brine bleeding is clearly not applicable if *all* the brine is discharged to the river. In this case, the total mass of salt discharged will remain unchanged (slightly less in practice because the product water will usually contain some salts if it is treated to conform to potable standards as opposed to demineralisation standards). The discharge flow however, will have been reduced by between 60% and 95% depending on the water recovery of the desalination process. This will in fact often increase the impact because the same mass of salt is contained in a reduced flow, yielding a higher concentration.

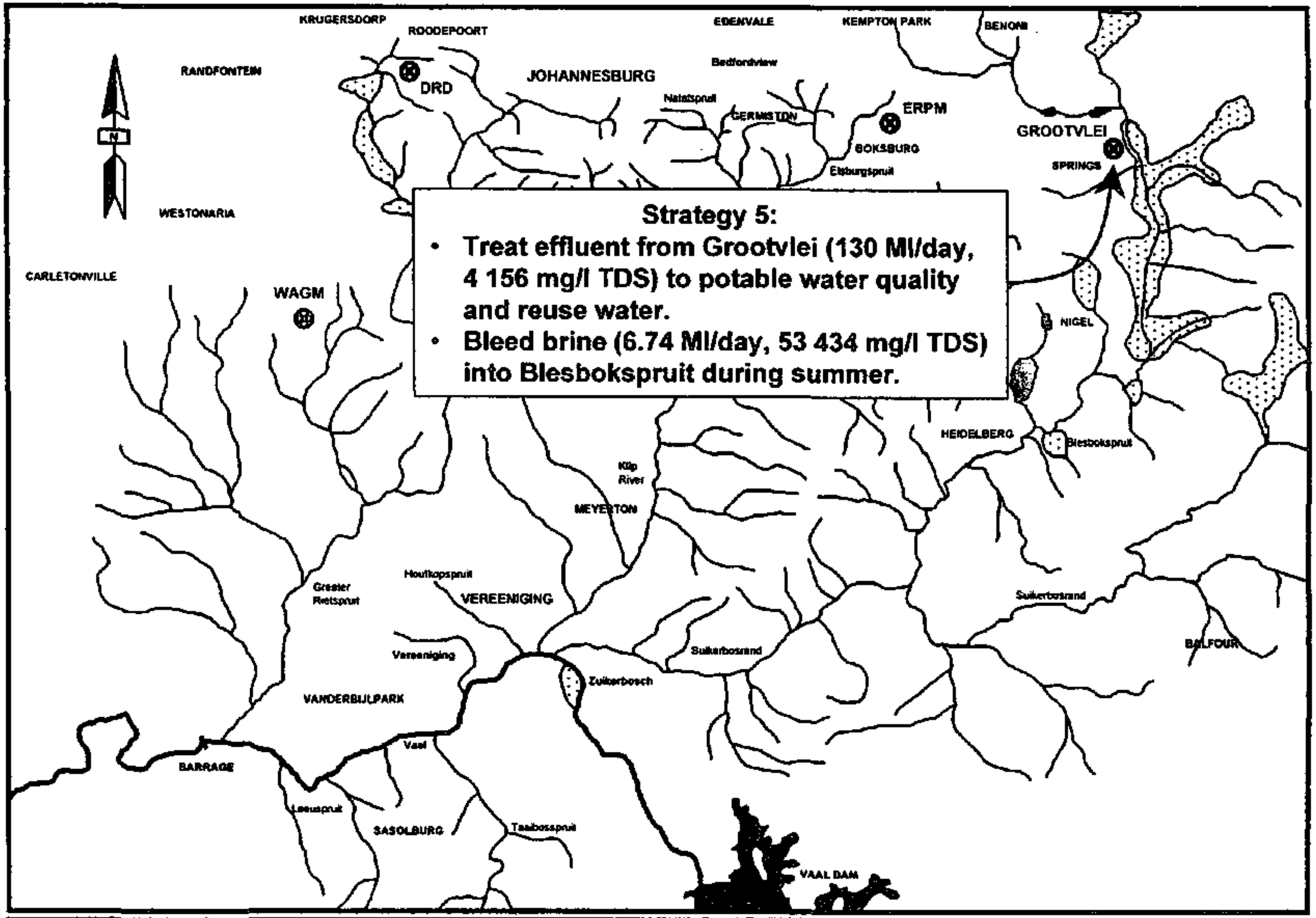


Fig 4.5 : Strategy 5 - Treat and reuse Grootvlei effluent and "bleed" brine into Blesbokspruit.

Generally speaking, there are more biological niches available to organisms that are continually exposed to a high concentration (e.g. the sea) than for those which are subjected to a large fluctuation between low concentrations and high concentrations. The magnitude of the relevant flows and loads will provide an indication of the severity of the impact, which can range from negligible to statistically significant.

If, however, the objective is to produce potable water at minimum cost while at the same time ensuring minimal impact to the receiving water body, then a form of brine bleeding can be applicable.

Kempster *et al.*, (1991) recommend a median sulphate concentration of 1 400 mg/l above which unacceptable impact will probably occur to biota in the river. The salt concentration currently being discharged from Grootvlei to the Blesbokspruit has a TDS of 4 156 mg/l and a sulphate concentration of 2 085 mg/l. Simplistically therefore, approximately half of the TDS is made up of sulphate. From Figure 4.6 below, it can be seen that the average summer flow of the Blesbokspruit is 131 Ml/d and the TDS is 345 mg/l upstream of Grootvlei. The discharge from Grootvlei mentioned above, results in a flow of 261 Ml/d with a TDS of 2 250 mg/l downstream of Grootvlei. This can be roughly approximated to 1 125 mg/l sulphate which is less than the value of 1 400 mg/l recommended by Kempster *et al.*, (1991). In terms of this definition, therefore, the sulphate concentration in the Blesbokspruit downstream of Grootvlei is not critical during average summer flows.

The winter situation however (see Figure 4.6) with regard to the sulphate concentration is not acceptable. When the reduced flow in the river (63.7 Ml/d) and increased TDS (467 mg/l) is combined with the discharge from Grootvlei, the resulting downstream TDS is approximately 2 943 mg/l which equates to a sulphate concentration of 1 471 mg/l. It is accepted for the purpose of this calculation that the variation in flow throughout a season is not substantial. However, if the daily or weekly river flows were used, it is possible that a different picture would emerge. Notwithstanding possible variations in flow, the TDS value of 2 943 mg/l is significant in that it is the worst average TDS currently being experienced in the Blesbokspruit during winter. Hence any brine bleeding strategy should not at any stage exceed this value since the objective is to reduce impacts on the Blesbokspruit.

Figure 4.6 shows that by using a maximum allowable TDS of 2 943 mg/l downstream of Grootvlei and using a brine concentration of 53 434 mg/l (see SPARRO concentration calculation spreadsheet, Appendix A.9.5.1), the overall downstream flow works out to be 137,7 Ml/d with the maximum acceptable brine flow of 6,74 Ml/d. The *actual* brine flow is 9,1 Ml/d for the SPARRO process which indicates that even in summer, discharging the brine on a *continuous* basis is unacceptable with regard to the resulting sulphate concentration. This means that if the brine is stored during winter and discharged on an intermittent basis during the summer, the resulting TDS and therefore sulphate concentrations will substantially exceed the current worst winter value. Brine bleeding therefore, cannot be considered as an option for the management of brine if the SPARRO process were used to treat the total discharge from Grootvlei of 130 Ml/d. It is possible that by only treating a portion of the total flow, the limit for the brine discharge could be achieved but then the reduction in salt load to the Vaal Barrage would also be substantially reduced.

For completeness, the following hypothetical situation is presented in which the concept of brine bleeding can be applied.

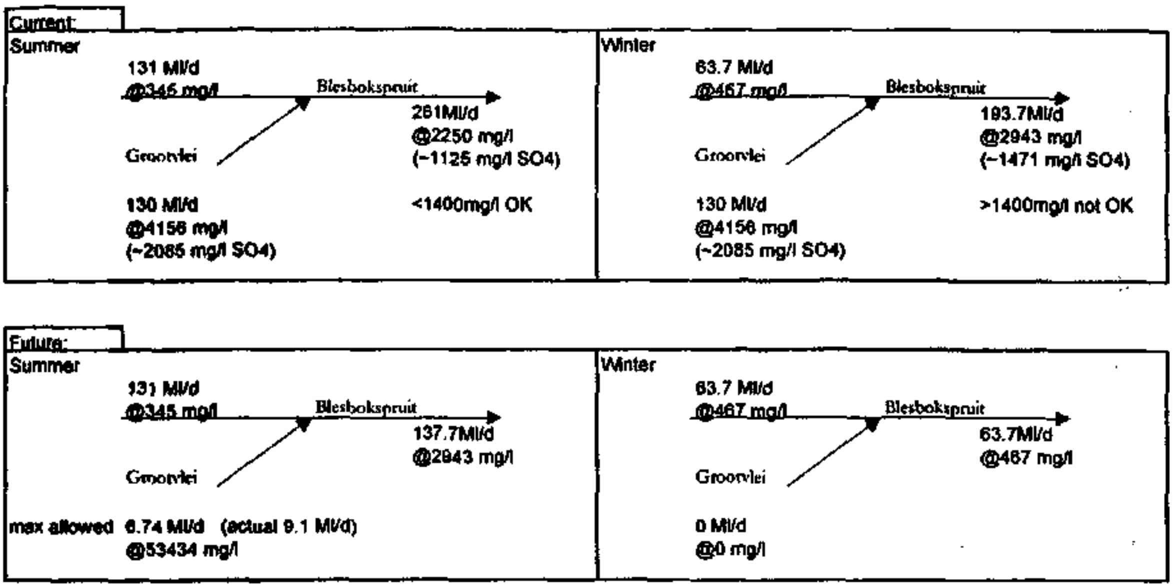


Figure 4.6: Schematic Diagrams of "Brine Bleeding" Scenarios

The surface flow of the Limpopo River is known to vary from 0 m^3/*sec* in winter to as much as 21 800 m^3/*sec* (the max recorded over the last 13 years). If a farmer required water for stock watering purposes but the water from his well was too saline, then it would be technically feasible to install an EDR plant to produce acceptable quality water. As long as permission were obtained, the brine from this plant could be introduced to the dry Limpopo River bed during winter and this brine would be washed away during the high flows in summer. The impact of a relatively small quantity of brine would be negligible compared to the large flow and absorption capacity of the Limpopo River once it is flowing.

The unit costs given in Table 4.9 are for the SPARRO process and show that the sale of by-products only makes up approximately 13% of the total income as compared to over 50% for the AQUA-K process.

Table 4.9: Strategy 5 Unit Costs

Process	Inflow to plant (Ml/d)	Total cost per m^3 of product water (c/m^3)	Income per m^3 product water, from sale of water (c/m^3)	Income per m^3 product water, from sale of by-products (c/m^3)	Total income per m^3 product water, from sale of by-products (c/m^3)
SPARRO	130	434	200	29	229

For the calculation of figures in Table 4.10, it is assumed that of the total brine flow of 9,1 Ml/d at a TDS of 52 434 mg/l, only 6,74 Ml/d is discharged to the Blesbokspruit and the remainder is treated further by enhanced evaporation. It should be noted that this discharge (6,74 Ml/d) can only take place in summer. In winter, because the salt load has been reduced from 540 t/d to 360 t/d and the flow has been reduced from 130 Ml/d to 6,74 Ml/d there is insufficient dilution to achieve an improvement on the current situation. The reason for this is the constraint that the maximum concentration in the river must not exceed the current average maximum, which occurs in winter.

Table 4.10: Strategy 5 Total Costs

Process	Direct costs (R x10^6/a)	Direct benefits (R x10^6/a)	Direct cost or benefit (R x10^6/a)	Average 5-year cycle: Indirect benefits (R x10^6/a)	Average 5-year cycle: Total cost or benefit (R x10^6/a)	Dry 5-year cycle: Indirect benefit (R x10^6/a)	Dry 5-year cycle: Total cost or benefit (R x10^6/a)
SPARRO	-191	101	-91	7	-84	9	-81

The indirect benefit of this strategy is low compared to that of other strategies, since a large portion of the brine flow is still discharged to the river during summer.

4.6.2 Conclusions

As far as Grootvlei is concerned the management of brine by bleeding is not an option since the salt load from de-watering is too high with respect to the normal flow and load in the Blesbokspruit. In conclusion therefore if the treatment process selected for Grootvlei produces a brine then this will have to be evaporated in an enhanced evaporation system or further treated by a crystallisor or another suitable method.

4.7 STRATEGY 6

4.7.1 Introduction

It has been suggested that up to 50% of the water pumped from Grootvlei originates from infiltration through the sediments of the Blesbokspruit. (A proposal to confirm this or otherwise has been submitted to the Water Research Commission by Pulles, Howard and de Lange in 1998). If this water could be prevented from seeping back into the area being de-watered by Grootvlei then the current discharge of up to 130 Ml/d could be reduced to as little as 65 Ml/d. In the absence of a detailed geohydrological study of the area surrounding Grootvlei, it is difficult to determine the origins of the water which drains into the mine workings. However, a study of the surface hydrology and water budget with an estimate of the evaporation and transpiration should allow an estimate of the seepage. For this strategy however, it was assumed that the quantity of water entering the workings of Grootvlei mine can be reduced from 130 Ml/d to 65 Ml/d by the construction of a concrete channel running parallel to the Blesbokspruit. The channel was sized to take a maximum flow of 65 Ml/d and was assumed to be 11 km in length. This was done in order to reticulate a portion of the flow upstream of Grootvlei past the mine and ultimately to a discharge point on the Blesbokspruit beyond where it could find its way back to the mineshaft.

If infiltration into the Grootvlei workings could be reduced then the costs of de-watering would also be reduced, providing an immediate benefit to the mine and a reduction in the size of the desalination plant. The costs of treating the reduced flow added to the costs of the channel were then compared with the benefits to downstream users as well as with the costs of other strategies.

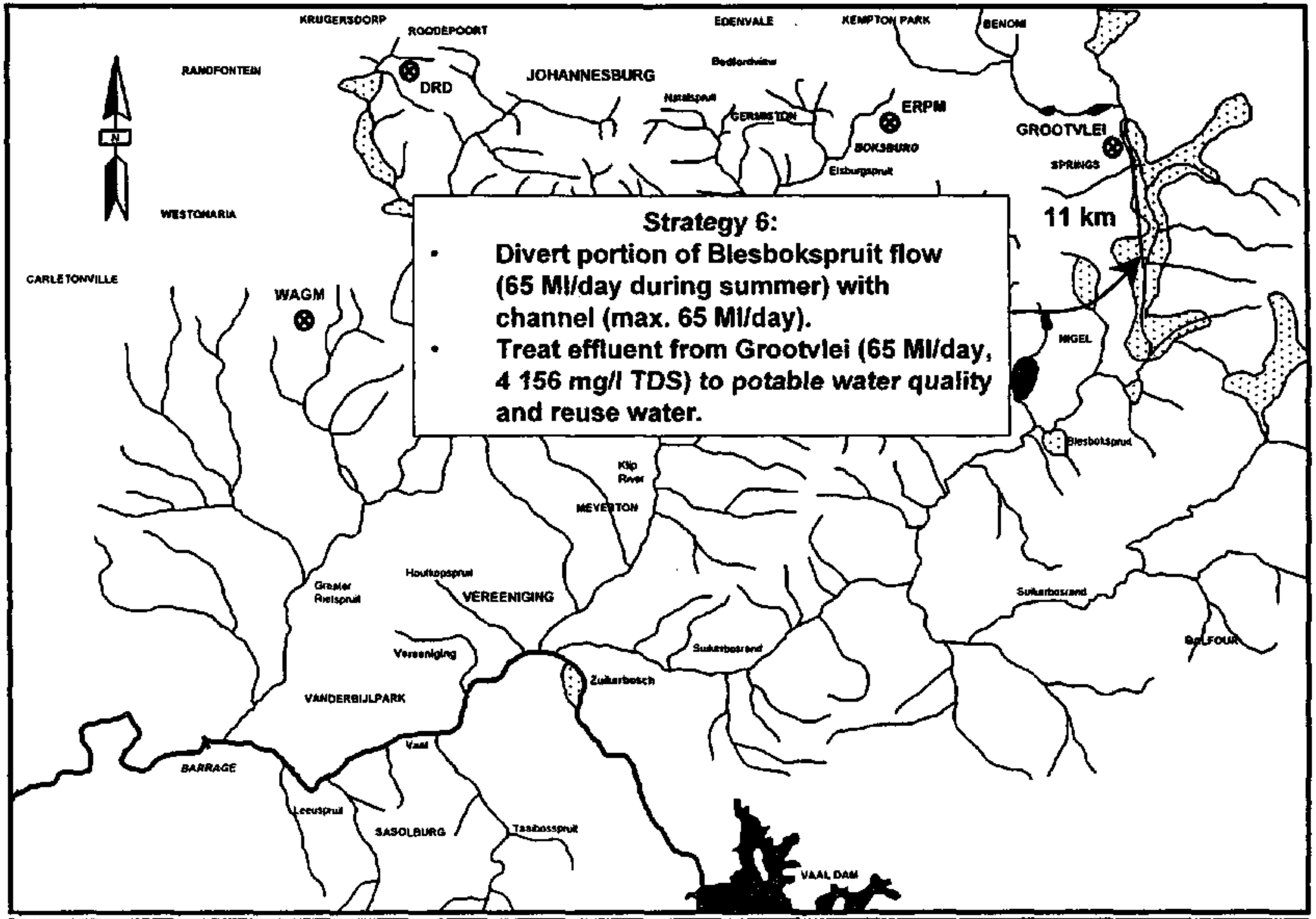


Fig 4.7 : Strategy 6 - Divert portion of Blesbokspruit and treat and reuse Grootvlei effluent.

The current average winter flow in the Blesbokspruit is 193.7 Ml/d while the average summer flow is 261 Ml/d. In winter therefore, 67% of the flow currently originates from Grootvlei and in summer 50%.

The reduced de-watered flow of 65 Ml/d is assumed to be treated using the AQUA-K process since it was demonstrated in Strategy 1 that this process might be the most cost-effective for high sulphate waters pending further investigation.

In summer, therefore, the flow in the region of the Blesbokspruit just upstream of the current discharge point of the potential 131 Ml/d with a TDS of 345 mg/l would be reduced to a flow of 66 Ml/d with a TDS of 345 mg/l (see Figure 4.8). The flow just downstream of the current discharge point would be reduced from 261 Ml/d at a TDS of 2 250 mg/l to a flow of 66 Ml/d at a TDS of 345 mg/l.

In other words the channel will convey its maximum capacity of 65 Ml/d in summer and no flow in winter.

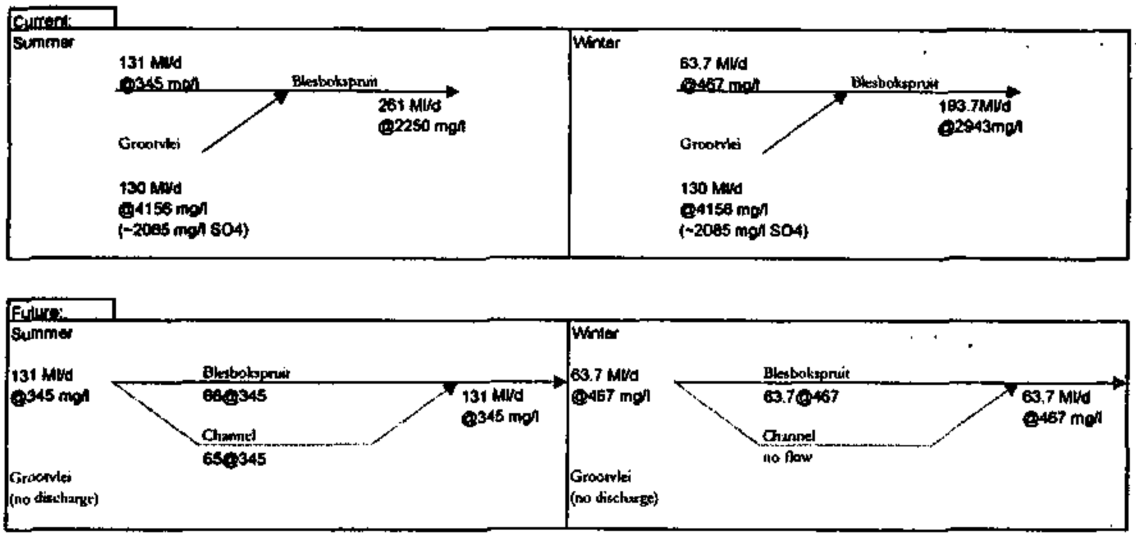


Figure 4.8: Schematic Diagrams of the Effect of Installing a 65 Ml/d Concrete Channel

4.7.2 Costs and Benefits

The total unit cost in c/m^3 of product water is marginally higher than that presented in strategy 1 as a result of the inclusion of the costs relating to the 11 km channel with a flow capacity of 65 Ml/d. Other unit costs are similar to those for strategy 1.

Table 4.11: Strategy 6 Unit Costs

Process	Inflow to plant (Ml/d)	Total cost per m^3 of product water (c/m^3)	Income per m^3 product water, from sale of water (c/m^3)	Income per m^3 product water, from sale of by-products (c/m^3)	Total income per m^3 product water, from sale of by-products (c/m^3)
AQUA-K	65	487	200	217	417

Table 4.12: Strategy 6 Total Costs

Process	Direct costs (R x10⁶/a)	Direct benefits (R x10⁶/a)	Direct cost or benefit (R x10⁶/a)	Average 5-year cycle		Dry 5-year cycle	
				Indirect benefits (R $x10^6$/a)	Total cost or benefit (R $x10^6$/a)	Indirect benefit (R $x10^6$/a)	Total cost or benefit (R $x10^6$/a)
AQUA-K	-111	95	-16	28	12	38	22

A reduction in the total flow from 130 to 65 Ml/d will, as expected, reduce the direct costs from R 31 $x10^6$/a to R 16 $x10^6$/a. The indirect benefits however, remain the same as those in strategy 1 since complete removal of the current discharge is catered for (recycling excluded). An additional direct benefit, which has not been included in the above figures, is the reduction in de-watering costs incurred by the mine.

4.7.3 Conclusions

The overall benefits of this strategy are greater than those for all other strategies apart from Strategy 8 (Strategy 8 however, cannot be compared directly with the other strategies. An explanation is given in the discussion of this strategy). It should be remembered however, that the costs and benefits of this strategy are based on the assumption that the installation of a channel will reduce the infiltration into the mine to approximately half of its current value (from 130 to 65 Ml/d).

4.8 STRATEGY 7

4.8.1 Introduction

This strategy was set up in order to compare strategy 6, which comprised the implementation of a treatment process *and* a by-pass channel, with a situation which comprised just a by-pass channel (albeit of a different size).

Strategy 7 (like strategy 6) assumes that a significant quantity of seepage takes place from the Blesbokspruit into the area de-watered by Grootvlei. The construction of a channel like that proposed in strategy 6 is assumed but this time with a maximum capacity of 130 Ml/d. The 65 Ml/d de-watered from Grootvlei is assumed **not** to be treated, but is discharged into the channel.

In summer the channel will convey 130 Ml/day of which 65 Ml/d is pumped from Grootvlei and the remainder (another 65 Ml/d) originates from upstream of Grootvlei. In winter, the channel will only convey the 65 Ml/d being de-watered from Grootvlei.

The costs of channels conveying maximum flows of 65 and 35 Ml/d were also calculated to enable a direct comparison to be made with strategy 6 (65 Ml/d) and also, to enable a decant flow to be conveyed away from the upper Blesbokspruit (35 Ml/d) should de-watering be discontinued.

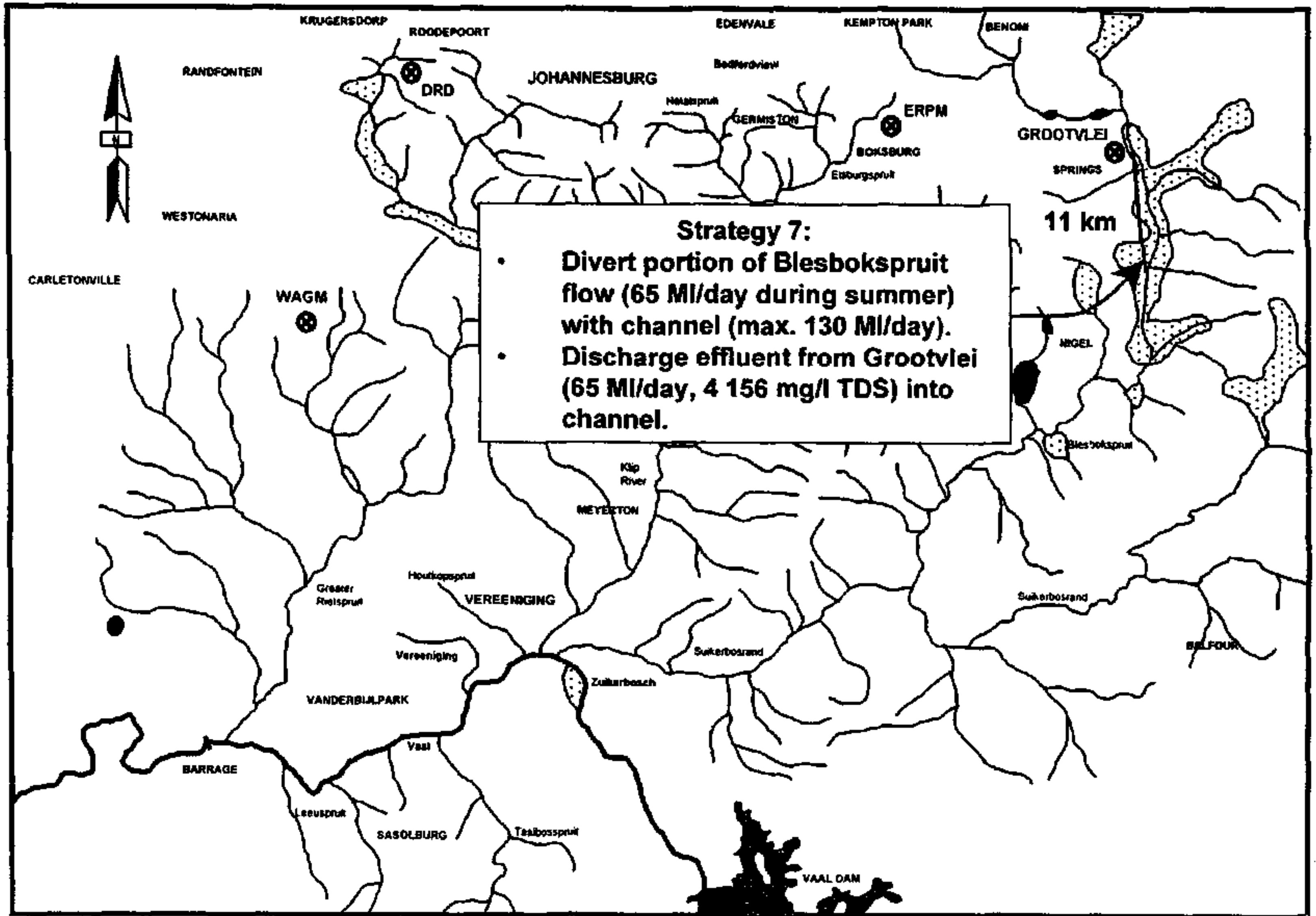


Fig 4.9 : Strategy 7 - Divert portion of Blesbokspruit and discharge Grootvlei effluent.

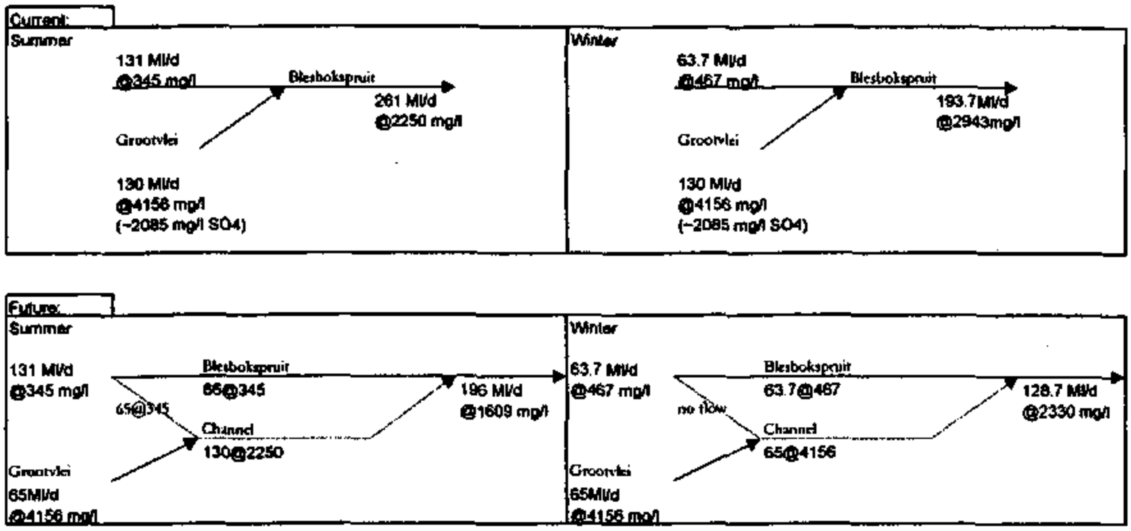


Figure 4.10: Schematic Diagrams of the Effect of Installing a 130 Ml/d Concrete Channel

4.8.2 Costs and Benefits

From the figures given in Table 4.13, it is immediately apparent that the costs involved in constructing and maintaining a channel are relatively low compared to the costs of desalination. However, as with strategy 6, it is assumed that de-watering volumes have been reduced from 130 Ml/d to 65 Ml/d and hence the salt load contribution by Grootvlei has also been reduced by approximately 50%. The indirect benefit therefore, is approximately half that of strategy 1. Further it should be noted that the direct benefits of reduction in de-watering costs have not been included.

Table 4.13: Strategy 7 Unit Costs

Process	Direct costs (R x10^6/a)	Direct benefits (R x10^6/a)	Direct cost or benefit (R x10^6/a)	Average 5-year cycle		Dry 5-year cycle	
				Indirect benefits (R x10^6/a)	Total cost or benefit (R x10^6/a)	Indirect benefit (R x10^6/a)	Total cost or benefit (R x10^6/a)
Channel 35 Ml/d	-0.49	0	-0.49	14.7	14.2	19.9	19.4
Channel 65 Ml/d	-0.73	0	-0.73	14.7	14.0	19.9	19.2
Channel 130 Ml/d	-1.22	0	-1.22	14.7	13.5	19.9	18.7

4.8.3 Conclusions

Although there are no direct benefits emanating from this strategy, the direct costs are extremely low and hence although the overall benefits are not as substantial as in other strategies, the cost of attaining these benefits are minimal.

The difference between the annual costs of constructing and maintaining a channel with a maximum capacity of 130 Ml/d and 35 Ml/d is relatively small if the cost is written off over 20 years as is the case here. It would appear therefore, that providing the construction of a channel has the desired effect of reducing the seepage of water into the Grootvlei workings then it can be considered as an economical option.

4.9 STRATEGY 8*

4.9.1 Introduction

This strategy proposes the complete transfer of the effluent de-watered from Grootvlei to the Kafferspruit, which drains northwards to the Klipspruit and the Bronkhorstspruit Dam. The transfer would be carried out using a suitably sized pipeline, separated into pressure and gravity sections. In order to accommodate different scenarios being implemented at Grootvlei the costs of the pipeline were calculated for flows of 130 Ml/d, 65 Ml/d and 35 Ml/d. The length of the pipeline was taken as 12 km. The indirect benefit is the benefit to users of the water abstracted between the Vaal Dam and the Vaal Barrage. However, it does not include for the cost accruing to users in the Kafferspruit, Klipspruit and in and below the Bronkhorstspruit Dam. The modelling of user costs for these rivers is beyond the scope of this project.

4.9.2 Costs and Benefits

The costs of constructing and maintaining a 130 Ml/d pipeline are relatively small when compared to the costs of desalination. However, as with all of the costs presented in this document, the repayment of capital is made over 20 years and assumes that de-watering patterns remain unchanged over that period. Although this strategy has no direct benefits, the substantial indirect benefit is derived from the complete removal of the current discharge at Grootvlei from the Vaal system. However, as stated above, the modelling of user costs accruing to the downstream users in the Kafferspruit and Klipspruit Rivers and in the Bronkhorstspruit Dam lie beyond the scope of this study. Clearly, an accurate comparison can only be made with the inclusion of such costs.

Table 4.14: Strategy 8 Unit Costs

Process	Direct costs	Direct benefits	Direct cost or benefit	Average 5-year cycle		Dry 5-year cycle	
				Indirect benefits	Total cost or benefit	Indirect benefit	Total cost or benefit
	(R x10^6/a)	(R x10^6/a)	(R x10^6/a)	(R x10^6/a)	(R x10^6/a)	(R x10^6/a)	(R x10^6/a)
Transfer 35 Ml/d	-2.20	0	-2.20	28.0	25.8	38.3	36.1
Transfer 65 Ml/d	-3.24	0	-3.24	28.0	24.8	38.3	35.1
Transfer 130 Ml/d	-5.04	0	-5.04	28.0	23.0	38.3	33.3

4.9.3 Conclusions

Inter-catchment transfer with regard to potable water is commonplace. However, the transfer of polluted water between catchments raises a number of issues and depends on the current and expected quality of the receiving water body. If the current TDS of the receiving water body is low, then it may be possible to introduce a portion of the high TDS flow without severe impact.

* *Note: Strategy 8 is not compared with the other strategies, due to reasons discussed in 4.9.1.*

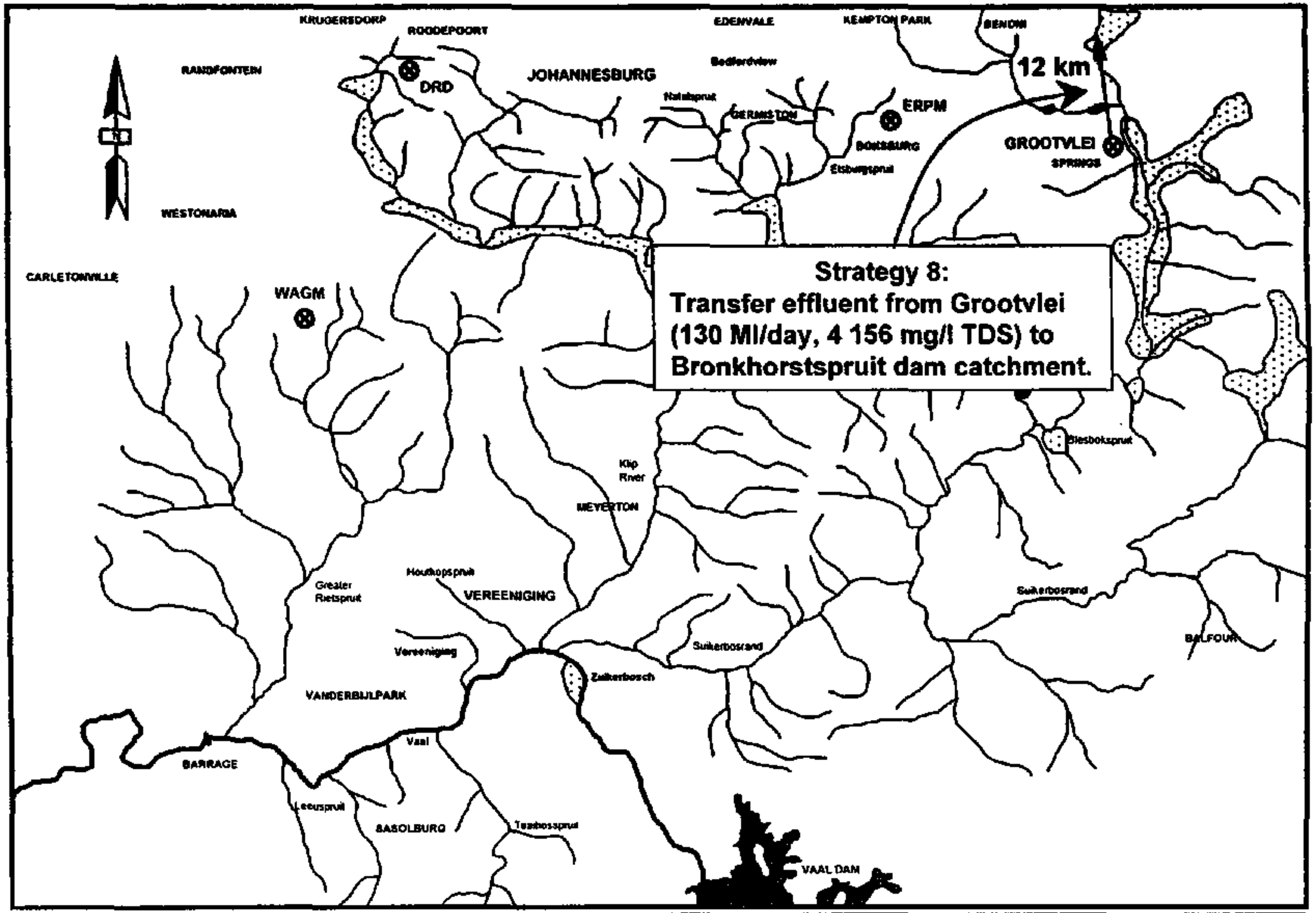


Fig 4.11 : Strategy 8 - Transfer Grootvlei effluent to Bronkshorstspruit dam catchment.

4.10 OTHER CONSIDERATIONS

4.10.1 Externalities

Any pollution that is generated in a production process must ultimately attract some costs. These costs could be incurred by cleaning up the pollution at source and returning unpolluted water to the system. In this case the costs of clean-up would be reflected in the bottom-line of the firm concerned.

Alternatively, the pollution could be passed on by including it, with return water. In this case, downstream users would pick up additional costs as they attempted to cope with water of lesser quality. These costs are still borne by the economy at large, although they may not be reflected in the bottom-line of the polluting firm. In economic terms, pollution handled this way is referred to as an externality of the polluting firm. It is part of the production process whose costs should have been included in the polluter's accounting system, but which have not.

To comply with the principle of economic equity, these costs should be reflected back to the polluter, or in economic terms, the externalities should be internalised. This concept has given rise to the Polluter Pays Principle, which holds *inter alia* that polluters should pay the full costs of their pollution.

If polluters do not clean up their pollution at source, but pass it on to other users, then in theory the payment for combating the pollution should be passed from the polluter to the subsequent user. Very often these other users are households, or large numbers of small enterprises, and effective and equitable compensation is not readily put in place. However, this in no way negates the need to keep the precepts of the Polluter Pays Principle in mind when making an economic evaluation, and various economic instruments exist which can assist with making a start in internalising externalities. These will be briefly discussed below.

4.10.2 Economic Instruments

A common feature of externalities is their unintended or incidental nature. Their producer may be aware of them but they do not enter his or her calculations. As long as productivity does not suffer, and no penalties are incurred, externalities will be regarded as an unfortunate by-product.

A solid case for internalising externalities can be found in the literature. In essence this amounts to levying a fee equivalent to the externality on the firm causing it. In practice, this does present difficulties of measurement and great scope for disagreement about the results of that measurement. Nevertheless, with this theoretical foundation, there is merit in considering economic instruments for environmental management.

These instruments can have the effect of motivating polluters to reduce their effluent, or of raising revenue, and take the form of:

- Effluent charges

  Effluent charges can be defined as levies on the discharge of pollutants to the air, water or land, usually based on the quantity and quality of the pollutant.

Charges may be considered as a price to be paid for pollution. Charges may have an incentive impact and a revenue raising impact. In many cases where charges have been introduced in other countries they have mainly had a revenue raising impact. These revenues can be used for collective treatment of emissions, research into new abatement technologies or for subsidisation.

Theoretically, charges can be differentiated from taxes. Charges are associated with return flows of goods or services whereas taxes are not. In practice this distinction is difficult to make, however, and the terms "charges", "taxes" and "levies" are often used interchangeably.

- Differential indirect taxes

  Indirect taxes (and specifically VAT) can be differentiated so as to lower the total prices of environmentally friendly products and/or raise the prices of others. The sole purpose of tax differentiation is its incentive impact, not the raising of revenue.

- Subsidies

  Subsidies, in the form of financial transfers of as tax concession, can be used as economic instruments although they can lead to economically inefficient situations. The main criticism against subsidies from the environmental perspective is that they focus mainly on repairing environmental damage and not on preventing it.

Pollution charges have as their main objective motivating polluters to reduce their pollution, which would have the effect of internalising their externalities. As externalities are internalised, pollution levels will drop and levies will be reduced until the externality is completely internalised, and downstream users will no longer suffer from upstream pollution activities. An effluent charge on return water could be coupled with a quality rebate to users downstream who abstract polluted water. Thus the costs brought about by polluted return streams are offset by rebates to users of polluted water. The system would be revenue neutral in that no excess revenue would be generated by the fiscus. When all externalities are completely internalised, then there would be no levies and no rebates.

CHAPTER 5

CONCLUSIONS, RECOMMENDATIONS AND FURTHER RESEARCH

5.1 CONCLUSIONS AND RECOMMENDATIONS

The assessment of the eight conceptual strategies in Chapter 4 according to costs and benefits is summarised in the Tables 5.1 – 5.2. The strategies can be ranked according to the total cost or benefit per 5-year average and 5-year dry cycle, as indicated in Tables 5.3 – 5.4 and Figure 5.1 – 5.2.

It has already been mentioned that strategy 8 was not included in the comparison of the different strategies. The reason for this is that although savings to downstream users in the Vaal system are included, the additional costs borne by users in the Kafferspruit, Klipspruit and Bronkhorstspruit dam system have *not* been included. The modelling of user costs in this catchment is beyond the scope of this study.

Table 5.1: Summary of Units Costs

Strategy	Process type	Inflow to plant (Ml/d)	Total cost per m^3 product water (c/m^3)	Income per m^3 product water, from sale of water (c/m^3)	Income per m^3 product water, from sale of by-products (c/m^3)	Total income per m^3 product water, from sale of by-products (c/m^3)
1	AQUA-K	130	484	200	217	417
1	ASTROP	130	606	200	30	230
1	Biosulphate	130	157	0	0	0
1	EDR	130	461	200	0	200
1	GYP-CIX	130	607	200	38	238
1	RO	130	582	200	0	200
1	SAVMIN	130	340	0	27	27
1	SPARRO	130	434	200	29	229
2	AQUA-K	146	146	489	217	417
3	AQUA-K	47	47	452	63	263
3	SAVMIN	47	47	201	14	214
4	AQUA-K	193	193	513	181	381
5	SPARRO	130	130	434	29	229
6	AQUA-K	65	65	487	217	417
7	None					
8	None					

For an average 5-year cycle, it would appear from the figures in Tables 5.1 - 5.3 and the graph in Figure 5.1, that the most cost-effective strategy in terms of total benefit is strategy 7 (installation of 130 Ml/d channel with no desalination). Clearly, this finding is dependent on the effectiveness of the proposed channel in reducing ingress into the Grootvlei workings. It is recommended that a study be undertaken to quantify more accurately the assumed seepage flow from the Blesbokspruit as a matter of urgency.

The next most promising strategy was strategy 6 (installation of 65 Ml/d channel with desalination). In this case, the AQUA-K process was used for desalination and the direct costs are reduced since the quantity of effluent required to be treated is approximately 50% of the current total. As with strategy 7, confirmation is required of the extent to which the quantity of de-watered effluent can be reduced by the installation of a channel to reduce ingress.

Strategy 6 is followed in order of effectiveness by strategies 3 (desalination of combined flow from DRD and WAGM using the SAVMIN process), 1 (desalination of Grootvlei only using the AQUA-K process) and 2(desalination of combined flow from ERPM and Grootvlei using the AQUA-K process).

Table 5.2: Summary of Total Costs

Strategy	Process	Direct cost ($Rx10^6/a$)	Direct benefit ($Rx10^6/a$)	Direct cost or benefit ($Rx10^6/a$)	Averge 5-year cycle		Dry 5-year cycle	
					Indirect benefit ($Rx10^6/a$)	Total cost or benefit ($Rx10^6/a$)	Indirect benefit ($Rx10^6/a$)	Total cost or benefit ($Rx10^6/a$)
1	AQUA-K	-221	190	-31	28	-3	38	8
1	ASTROP	-259	98	-161	28	-133	38	-122
1	Biosulphate	-74	0	-74	15	-59	20	-54
1	EDR	-175	76	-99	28	-71	38	-61
1	GYP-CIX	-202	79	-123	28	-95	38	-84
1	RO	-235	81	-154	28	-126	38	-116
1	SAVMIN	-158	13	-145	19	-126	24	-121
1	SPARRO	-191	101	-19	28	-62	38	-52
2	AQUA-K	-250	213	-37	32	-5	43	6
3	AQUA-K	-74	43	-31	3	-28	4	-27
3	SAVMIN	-34	36	2	3	5	1	3
4	AQUA-K	-347	258	-89	34	-55	47	-42
5	SPARRO	-191	101	-91	7	-84	9	-81
6	AQUA-K	-111	95	-16	28	12	38	22
7	Channel 35 Ml/d	-0.5	0	-0.5	14.7	14.2	19.9	19.4
7	Channel 65 Ml/d	-0.7	0	-0.7	14.7	14.0	19.9	19.2
7	Channel 130 Ml/d	-1.2	0	-1.2	14.7	13.5	19.9	18.7
8	Pipeline Transfer 35 Ml/d	-2.2	0	-2.2	28.0	25.8	38.3	36.1
8	Pipeline Transfer 65 Ml/d	-3.2	0	-3.2	28.0	24.8	38.3	35.1
8	Pipeline Transfer 130 Ml/d	-5.0	0	-5.0	28.0	23.0	38.3	33.3

Table 5.3: Strategies ranked according to Total cost/benefit for Average 5 year cycle

Rank	Strategy	Description	Treatment Process	Treatment flow (Ml/d)	Total cost or benefit ($Rx10^6/a$)
1	7	130 Ml/d channel only	None	0	14
2	6	65 Ml/d channel and treatment	AQUA-K	65	12
3	3	DRD and WAGM combined	SAVMIN	47	5
4	1	Grootvlei	AQUA-K	130	-3
5	2	Grootvlei and ERPM combined	AQUA-K	146	-5

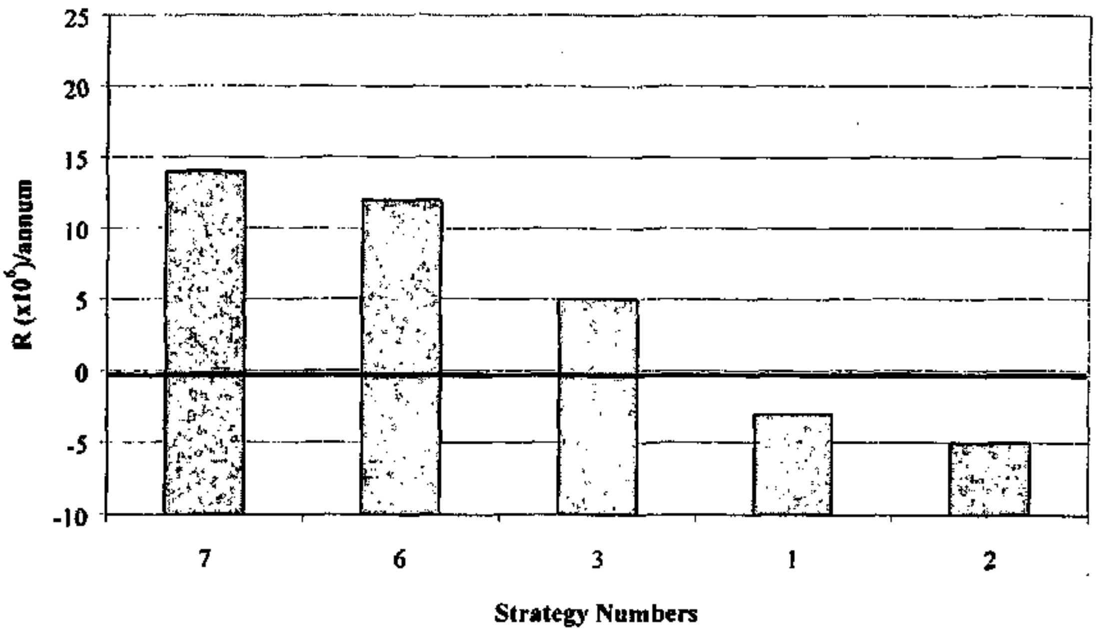


Figure 5.1: Graph of ranked strategies for Average 5-year cycle

For a dry 5-year cycle, the same 5 strategies out of the total of seven, emerge as the most promising. However, the order is different and reflects the sensitivity of the various strategies to the effects of reduced dilution experienced during dry periods.

From the figures in Table 5.1, 5.2 and 5.4 and the graph in Figure 5.2, that the most cost-effective strategy in terms of total benefit is strategy 6 (installation of 65 Ml/d channel with desalination using the AQUA-K process). This is followed by strategy 7 (installation of 130 Ml/d channel with no desalination) which again stresses the importance of reducing ingress as an effective method of combating salinity as well as reducing de-watering costs.

The next best strategies in order of their overall benefit in million Rand per annum, are strategies 1 (desalination of Grootvlei only using the AQUA-K process), 2 (desalination of combined flow from ERPM and Grootvlei using the AQUA-K process) and 3(desalination of combined flow from DRD and WAGM using the SAVMIN process).

The above conclusions relate specifically to the eight strategies discussed in Section 4.2. There are however, a number of more general conclusions which can be drawn from this study.

With regard to desalination the Budget costs indicate that the quality of the effluent to be treated has a significant bearing on the process philosophy adopted. For a typical calcium sulphate scaling gold mining effluent, if the TDS is below about 700 mg/l, full cost recovery can usually be obtained merely by the production and sale of potable water. However, should the TDS rise above about 4 000 mg/l, then processes which produce high value by-products, possibly in addition to potable water, are more likely to achieve higher cost recovery. To this end, conventional methods of desalination need to be modified to ensure that the production of by-products receives as much if not more attention, than the production of potable water. A study of the value of certain potential by-products therefore needs to be conducted prior to the selection of a particular design.

Table 5.4: Strategies ranked according to Total cost/benefit for Dry 5-year cycle

Rank	Strategy	Description	Treatment Process	Treatment flow (Ml/d)	Total cost or benefit ($Rx10^6/a$)
1	6	65 Ml/d channel and treatment	AQUA-K	65	22
2	7	130 Ml/d channel only	None	0	19
3	1	Grootvlei	AQUA-K	130	8
4	2	Grootvlei and ERPM combined	AQUA-K	146	6
5	3	DRD and WAGM combined	SAVMIN	47	3

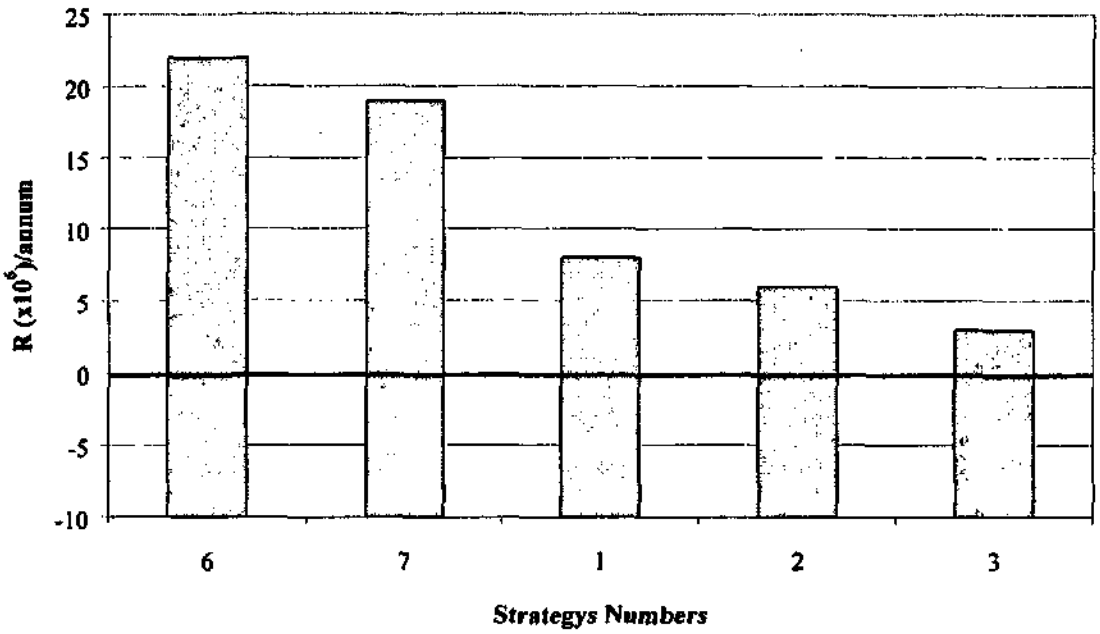


Figure 5.2: Graph of ranked strategies for Dry 5 year cycle

The "treatment" of brine has often been regarded as a necessary evil associated with desalination. However, certain processes now exist (e.g. AQUA-K) which not only incorporate the treatment of brine within the main process but also use a crystallisor to effect fractional separation. Brine disposal to the sea is only economically viable if the plant is to be located near the sea.

From the budget costs carried out on the various pipelines in this report, it appears that the cost of treating 130 Ml/d of the Grootvlei effluent is equivalent to reticulating that same flow a distance of between 70 and 380 km depending on the process selected. Although these figures are subject to change from ongoing innovation in the area of desalination, it is clear that if distances are relative short (i.e. less than 70 km) and flows are not too high, centralised treatment by the reticulation of flows to one plant can be cost-effective.

The importance of reducing the ingress of runoff and seepage into mine workings was highlighted in the report to the Grootvlei Joint Venture Committee (Sep. 1996). The finding of this report confirms that considerable savings can be realised by the reduction of ingress. In particular de-watering costs can be reduced and the flows which require desalination can be reduced, lowering the overall cost and liability. It is recommended that attention be focused on this aspect prior to the installation of any proposed desalination plant.

From this study it was found that data relating to water quality and quantities is generally scarce or in a form which cannot be readily used for planning. The importance of the continual collection of data both by individual mines and by abstractors and other effected parties cannot be underestimated. The continual collection of data will also require regular and proper maintenance of the data collection points.

From the economic model used to derive monetary savings to end users it was found that the highest burden of combating salinity is currently being carried by the household sector and not by industry as might be expected. The cost of pollution by a relatively small number of firms is therefore being carried by a large number of individuals and hence the unit cost is relatively small. The "polluter pays principle" suggests that one method of redressing this imbalance is to encourage the internalisation of pollution costs.

The "user savings" discussed in this study are economic costs in that they take into account the costs borne by users as opposed to polluters. A number of economic instruments in the form of effluent charges, taxes and subsides can be implemented in order to once again encourage the internalisation of externalities.

The proper management of the effluent from the gold mines under investigation is of national importance and should, therefore, receive the necessary attention. It is recommended that an active initiative is taken to develop and implement the conclusions and recommendations from this project. This initiative can be driven by, for example, a committee or forum that have the required authority to develop and implement strategic decisions for the Vaal Barrage catchment.

5.2 FURTHER RESEARCH

The assumptions and limitations, and conclusions and recommendations from the study highlighted certain areas where additional research is required. It is thus recommended that further research should be undertaken in the following areas:

- The feasibility of bypassing the Blesbokspruit wetland with a channel to minimise the ingress of water into the Grootvlei mine workings. This study will also have to determine the quantity, quality and location of the water ingress into the Grootvlei mine workings from the Blesbokspruit.

- The future water management of the Blesbokspruit should be defined to optimise and integrate the implementation of strategies from this study and proposed future development. The situation in the Blesbokspruit may change, due to effluent from future developments in this region, for example Welgedagt Sewage Treatment Works. It is thus important that the effect form future developments in the Blesbokspruit be assessed before implementation of strategies proposed in this study.

- A study to confirm and refine the user cost model used in this study is required. The original user cost model was developed for the Middle Vaal. This model was adapted for the Vaal Barrage based on the assumption that the mix of users in the Vaal Barrage catchment is similar to that in the study area used originally. This assumption needs to be confirmed or adjusted according to findings from a field study.

- The most feasible economic strategy to encourage the internalisation of externalities should be investigated before it is implemented.

APPENDIX A

MANAGEMENT OPTIONS AND TREATMENT PROCESSES

A.1 INTRODUCTION

This appendix begins by covering issues associated with management options and treatment options. The treatment options are initially discussed in general terms and thereafter the technologies are screened and those for which budget costs were derived, are discussed in more detail. Since a number of the screened processes produce brine, the next section discusses methods of brine "treatment" and gives budget costs for some of the methods.

The next section gives the raw water qualities emanating from the four mines. These qualities are subject to change depending on dewatering patterns and the flooding of mine workings. The characteristics of the blends of these waters are then given for the eight strategies and this is followed by budget cost estimates for each conceptual strategy.

A.2 MANAGEMENT OPTIONS

A.2.1. Contaminant Production

It is often possible to isolate specific areas on a mine-site which are major contributors to the total contaminant load. These include slimes dams and rock dumps amongst others. In the case of slimes dams, the pool can be minimised to reduce seepage through the underlying material into the ground water. Pool water is generally decanted into a "return water" dam, which itself is a source of pollution if it is not lined. Return water dams are often operated as storage facilities (i.e. their levels are maintained as high as possible) and hence, particularly during the rainy season these dams are likely to overflow which can provide yet another source of contamination.

As far as rock dumps are concerned, pollution potential is often related to the sulphide content of the material contained in the dump and its relative surface area. Oxidation of pyrite by micro-organisms of the genius *Thiobacillus* generates acids that can contribute to what is termed Acid Mine Drainage (AMD).

Ideal conditions for the growth of the species T. ferrooxidans and T. thiooxidands include CO_2, excess O_2 NH_4, P, S, Fe^{2+}, humid environments and temperatures between 29 and 32 degrees (Pulles *et al.* 1995). The possibility of limiting bacterial growth therefore exists by creating an environment that is not conducive to their survival.(Pulles *et al.* June 1995 WRC report 527/1/96)

A.2.2 Contaminant Transport

The migration of pollutants could also be retarded. For example specific sources of AMD could be captured and treated close to where they are generated. In this manner, the overall sulphate concentrations from all sources could be reduced to some extent, which would result in a reduced salt load entering the Barrage. In conjunction with this, methods of re-routing the flow path of uncontaminated fissure water in order to prevent contact with oxidised pyrite could be considered. This would require extensive groundwater modelling studies that would give a clearer picture of groundwater flow patterns and general subsurface geohydrological conditions.

Water decanted from slimes dams is often conveyed in open channels and not pipes. These channels, if not lined, are sources of seepage to the ground water and are often designed such that uncontaminated run-off from rainfall events can flow into these channels thereby contaminating a previously clean source of water.

A.2.3 Use Requirements

Different facilities on a mine require different qualities of water. For example, certain stages of mineral processing can tolerate very poor quality water whereas much better quality water is required for drinking underground or for use in making up chemicals. It is therefore essential that a minimum water quality be established for all major users on the mine and that as far as possible only water of this quality be supplied on a fitness-for-use basis. This would not have the effect of reducing the total salt load produced by the mine, but it would lead to the production of fewer, more concentrated, waste streams which have been recycled until quality is no longer sufficient for re-use. The re-use of effluent from sewage treatment plants is a good example of water that is generally not re-used and provided the presence of dissolved organics does not interfere with the function for which the water is required, it is often possible to re-use sewage effluent by blending it with another water.

A.2.4 Management structures

The management structure on a mine should incorporate a person to co-ordinate and monitor overall water usage if this is not currently taking place. The appointed person should, through use of water and salt balances, allocate water on a monthly basis and assess whether targets are being met. Interaction on a regional basis to encouraged regional solutions to discharge problems should also be encouraged such as the water forum in the Klerksdorp district.

A.3 TREATMENT OPTIONS

There are a number of treatment technologies which have been successfully employed to reduce salt loads in mining effluents. Clearly, the option chosen will depend on the raw water quality and the desired quality of the product water. A selection of some of the processes currently available for the treatment of mining effluents is given below accompanied by a general discussion of these processes. This is followed by a more detailed discussion of the processes selected for the various strategies outlined in this report with an indication of the costs of implementation and operation.

A.3.1 General Discussion of Treatment technologies

A.3.1.1 Full Desalination processes

- Softening followed by conventional desalination

Because many mine waters are so close to saturation with respect to calcium sulphate, it would only be possible to operate a conventional desalination process, without the use of anti-scalents, at unacceptably low water recovery ratios - in this case at between 10 and 25 percent. Brine streams will therefore be unacceptably large. One way of overcoming this problem would be to reduce the scaling potential. This is usually done by removing calcium from the water (softening), so the solubility product of the calcium and sulphate will not be exceeded in the concentrating effect which occurs in a conventional desalination process. Removal of sulphate from the water would also have a similar effect.

Softening for the removal of calcium in this situation can be achieved by the addition of chemicals (lime/soda softening), by the use of ion exchange (cation exchange resin) or by nanofiltration (NF).

Nanofiltration is a pressure driven membrane process, similar to reverse osmosis (RO) except that it makes use of what could be simply described as "loose" membranes. Nanofiltration or softening membranes are designed to retain divalent ions (such as calcium, magnesium and sulphate) and allow monovalent ions (such as sodium and chloride) to pass through them. In this way the membranes are able to provide some selectivity in the desalting process, and in this case could remove up to about 80 percent of the sulphate, calcium and magnesium. However, for the reasons mentioned above, with many mining waters, calcium sulphate scaling would still become a major problem within the nanofiltration process. Thus unless large dosages of anti-scalent were used or some seeding technique (discussed below) was employed, the operation of the plant would be extremely inefficient.

Softening by the addition of lime and soda ash can be costly, because in order to achieve significant calcium removal to render the water suitable for operating at a concentration factor of 5 (80 percent water recovery), large dosages of soda ash are required. The use of cationic ion exchange resin (in the sodium form) can remove most of the cations in the water (mainly calcium and magnesium), and would replace the ions with sodium in solution.

Following the softening step, conventional desalination processes suitable for treating a moderately saline mine water, such as reverse osmosis (RO) or electrodialysis reversal (EDR) could be applied.

RO and EDR differ in the manner in which dissolved ionic species are removed from solution. In RO the natural osmotic pressure is reversed to effect the removal of dissolved salts from solution. A pressure greater than the osmotic pressure is applied to the feed water on one side of the semi-permeable RO membranes and this allows passage of only pure water while the ionic species and organics are concentrating in the feed water. RO uses polymeric semi-permeable membranes in tubular, spiral and hollow fibre configurations and typical operating pressures range from 15 - 30 bar for brackish waters and 60 - 70 bar for sea water.

EDR is an electrochemical process in which ionised substances are extracted from solution while unionised or partially ionised substances are retained in the product water. Typically, the feed water is passed through a stack of alternating cation-permeable membranes and anion-permeable membranes. The cation-permeable membranes will allow passage of positively charged ions in an attempt to move toward the negatively charged cathode. Similarly, the anion-permeable membrane will allow passage of negatively charged ions moving toward the positive anode. A membrane stack is typically positioned between a cathode and an anode, and it consists of numerous cell pairs comprising a cation-permeable membrane, a spacer, an anion-permeable membrane and another spacer. Since cations cannot pass through anion membranes and vice versa, alternate cells will contain concentrated solutions of negative and positive ions, while adjacent cells contain the feed water which becomes the demineralized product stream as a result of the extraction of charged ions through the cation and anion membranes into the brine stream.

Depending upon the quality of the pre-treated feed water to the RO or EDR system, it may be possible to produce a product water which could be blended with a small flow which bypasses the desalination step, in order to produce the desired final water quality. This "side-stream blending" option would reduce the overall capacity, and thus cost, of the desalination step.

- Direct Ion Exchange

Ion exchange could be applied to remove both the cations and anions from the water to produce a desalinated product water. Usually, for softening by ion exchange as mentioned above, the resin is in the sodium form and sodium is exchanged for the unwanted calcium on the resin. In the case of full desalination, the sodium ions would have to be removed as well, and therefore the resin used would be in the hydrogen form. Thus during regeneration, sulphuric acid is used to regenerate the cation resin, calcium is returned to solution and precipitation and scaling by calcium sulphate occurs. This can be overcome by using hydrochloric acid as the regenerant, but then the costs increase significantly.

Similarly on the anion resin, where sulphate is removed, the resin is usually in the hydroxide form and regeneration can be by lime or caustic soda. Lime, the cheapest regenerant, would result in scale formation due to the presence of calcium and sulphate.

These potential scaling problems have largely been overcome by the introduction of a calcium sulphate seeded regeneration process that has been developed in South Africa and tested at pilot and demonstration scale. The process is known as the GYP-CIX process which is an adaptation of conventional counter-current ion exchange and produces a solid gypsum by-product during the regeneration process.

Because the process does not offer a physical barrier for the water to pass through, the product water from the process would still require final disinfection and possible turbidity removal (filtration) to produce a potable product water. A further consideration is that because ion exchange can produce a low salinity water, the possibility of side-stream blending also exists.

- Direct membrane desalination using seeding techniques

Rather than reduce the calcium sulphate scaling potential of the water before feeding it to a reverse osmosis process, one option is to allow the scaling to take place within the process in a controlled manner. This is achieved by providing a calcium sulphate seed in the feed water to the RO unit which becomes a preferential site for scale formation, as the solubility product of the calcium sulphate is exceeded.

The Slurry Precipitation and Recycle Reverse Osmosis (SPARRO) process is a novel design developed in South Africa by the Chamber of Mines, from a seeded RO concept originated by a company in the USA. Two of the main advantages of the process are that it produces a high quality solid gypsum by-product (which could be sold) and can operate at very high water recovery ratios (greater than 90 percent), which reduces the requirements for brine disposal. The quality of the product water is related to the overall water recovery and this would have to be adjusted according to each raw mine water treated.

Another seeded RO process has been developed by Envig called the Advanced Seeded Tubular Reverse Osmosis Process (ASTROP) which is capable of achieving exceptionally high water recoveries and salt rejections. Like the SPARRO process the costs of softening prior to exposure to the membranes can be substantially reduced.

- Evaporative technologies

Solar evaporation of the mine water could not be considered as an option on the scale under consideration. However, final solar evaporation of a small volume of highly concentrated brine in well designed and lined evaporation ponds could be a consideration.

Thermal evaporation of the mine water to produce a very high quality distillate is theoretically also a possible approach. However, at the TDS concentration of the mine water (around 3000 to 4500 mg/l) such processes would not be economical. In addition, as has been described above, the concentrating effect by the ions remaining in solution would lead to calcium sulphate scaling. Thus the evaporative process would have to be able to cope with high masses of calcium sulphate precipitate.

There are processes available which can cope with calcium sulphate precipitation, by making use of seeding in a similar manner to that mentioned above.

Use of expensive thermal evaporative processes would normally be restricted to small volumes of highly concentrated brine produced by an upstream desalination process. The distillate produced by the evaporative process would be a high percentage of the feed flow rate (about 90 percent) and would be recycled to be combined with the product stream from the desalination process (increasing the overall water recovery). The remaining small volume of concentrate would be in the form of crystals or a highly concentrated slurry.

Provided the land area is not a constraint then enhanced spray evaporation can be employed to reduce the surface area required for conventional evaporation systems. However, this technology can only be applied in areas in which mean annual evaporation is relatively high compared to mean annual precipitation.

- Freeze desalination

An alternative to evaporation would be to desalinate the water using a freezing process. The principle behind this process is that ice crystals formed when water freezes are pure. Thus the process attempts to form ice crystals in a controlled fashion and then wash or rinse the other ions off the crystals to produce a highly pure ice product.

Because of the concentrating effect and the presence of calcium sulphate, the process needs to operate in a seeded mode as well.

Pilot plant work was carried out by the South African Chamber of Mines on this process, treating highly scaling ERPM mine water. As expected, the process is expensive, but the advantage for the mining industry was viewed as being a high purity ice product which could be transported underground to serve a dual purpose of cooling as well as providing a high quality water source.

A number of process problems were encountered in the test work and the process still requires considerable research work before it can be considered as a commercial process.

A.3.1.2 Partial Desalination

In contrast to the full desalination processes discussed above, another option is to employ a technology which is specifically designed to remove certain elements from the feed water while the remainder are left largely unaffected by the process. One of the advantages of these processes is that a full desalination process often provides over-kill at considerable expense while a partial desalination process can provide product water of a poorer, but still acceptable quality, at much lower cost.

Partial desalination techniques are generally divided into two categories. The first involves a chemical process or series of processes while the second involves one or more biologically mediated steps. The two categories are briefly discussed below.

- Chemical processes

An example of a partial desalination chemical process is the SAVMIN process. In this process, chemicals are added to the feed water in order to effect precipitation of certain metal hydroxides. In subsequent steps the calcium sulphate which leaves the first step in a meta-stable condition, is removed using Ettringite as a carrier between acidic and basic conditions. The process is currently unable to provide for the removal of mono valent ions, hence the classification as a partial desalination process. However, if the concentration of mono valent ions in the feed water is below that specified for potable water, then the process can be classified as a full desalination process.

Another chemical process which has recently been researched is the use of barium to produce barium sulphate. Barium sulphate is a very insoluble compound, and one way of removing sulphate from water is to precipitate it as barium sulphate. Because the natural concentrations of barium in the water are usually low, barium is added to the water to bring about the precipitation.

The source of barium that is usually proposed is barium carbonate. While the chemistry of the precipitation process is well known, the raw material, barium carbonate, is expensive. Thus the only way in which the process can be considered economically viable is if the barium sulphate formed is converted back to barium carbonate and then re-used.

This process has been researched in South Africa, but has not yet been tested at pilot scale, mainly due to the cost of the raw barium carbonate. Calculations have indicated that this process would only become economically viable when applied at a very large scale; mainly because of the process equipment required for the recovery and conversion of the barium sulphate back to barium carbonate - heating with coal in a rotary kiln etc.

An alternative to using barium carbonate as the raw material, would be to use barium sulphide. In this case the barium sulphate produced would be reduced by heating with coal to barium sulphide, as described above, and reused directly in the process.

As explained earlier, the barium sulphate precipitation process would only address the removal of the majority of the sulphate in solution, and therefore in this case could produce a product water with significantly reduced salinity suitable for direct discharge to the environment. However, if product water of potable standard is required then once again other downstream processes would be required.

An advantage of the barium sulphate process is that high removal efficiencies of sulphate, and in this case calcium, can theoretically be achieved, because of the low solubility of barium sulphate and calcium carbonate. Also, the process involves the net removal of ions from the environment.

A disadvantage of the process is the expected operating costs of providing the raw barium carbonate. However, the CSIR propose that as part of the pilot plant investigations, they undertake some laboratory work to establish the merits of recovering barium carbonate from the barium sulphate sludge. This would be a complicated minerals processing operation from which they expect to obtain barium carbonate for recycling, calcium oxide (unslaked lime) for re-use and elemental sulphur for sale.

Various other chemical processes are used for the treatment of mining effluents. These can range from simple lime addition to raise the pH to complex metal extraction processes.

- Biological processes

By the use of anaerobic bacteria it is possible to reduce sulphur from the oxidised form in the sulphate ion to hydrogen sulphide. The hydrogen sulphide produced can be oxidised in a subsequent aerobic process to elemental sulphur.

This process has been considerably researched and has not been applied at any significant scale to date in South Africa, mainly because the cost calculations indicated that a suitable source of organic carbon for the bacteria would make the process uneconomical.

Apart from possible high removal efficiencies of sulphate (up to about 90 percent is possible), an advantage of the process is that in the reducing environment of the anaerobic reactor and in the presence of the hydrogen sulphide, the metals (such as zinc and iron) would precipitate as insoluble sulphides and would be removed from the water as well.

A variation of this process is currently being developed by Rhodes University in conjunction with the Water Research Commission. Basically the process is a facultative pond system. In the anaerobic section of the pond a high rate, biological sulphate reduction process occurs. This process is enhanced by the use of raw sewage sludge as an energy source for the bacteria. The overall process involves precipitation of sulphides as iron sulphides (pyrites) which can be recovered from the process and used for the manufacture of sulphuric acid, and production of algae which create the opportunity of harvesting a second by-product. The process is still in the development stages and the construction of a pilot scale plant is planned.

Another variation of the process is a patented THIOPAQ sulphate removal and metals recovery system. The process basically consists of two biological processes complemented with solids separation steps. In the anaerobic stage, sulphate is converted to hydrogen sulphide by sulphate reducing bacteria. In order to make the reduction possible an electron donor is required in the form of hydrogen, ethanol or organic waste streams. Similarly, the sulphides that are formed react with dissolved metals to form metal sulphide precipitates. In the aerobic stage, excess sulphide is oxidised by aerobic bacteria into elemental sulphur.

This process is attractive in that it would produce very little side-waste streams, however, the cost of the organic substrate could possibly make the process uneconomical although this could be offset to some extent by the sale of elemental sulphur.

Another advantage of this process is that a full-scale plant (5 Ml/d) has been in operational in the Netherlands since 1992. If 90 percent removal of sulphate can be achieved, a significant reduction of the salt load entering the Barrage could be achieved. In addition, in the case where drinking water quality is the desired product, this process could possibly be considered as a form of a "softening" pre-treatment step ahead of a conventional desalination process.

A.3.1.3 Constructed Wetlands

Constructed wetlands have been used for the past 20 to 25 years and only recently they have found popularity for use in the treatment of acid mine drainage and domestic wastewater. The actual mechanism for constituent reduction in a wetland system is believed to occur along various pathways, among which, uptake through the root system of certain plant species, absorption and microbial degradation in the soils are typically predominant.

This type of technology is attractive in terms of ease of operation, lack of energy requirements, potential for ecological benefits.

A major disadvantage of wetland systems is that the area requirement could amount to several hectares of land. If dewatering patterns in the region change then reticulation costs have to be incurred in order to continue using the wetland. They are also not able to withstand fluctuations in flow and even during the winter sufficient flow must be allowed to pass through the system to ensure the survival of the plants and micro-organisms within the system.

A.4 SCREENING OF TECHNOLOGIES

As described above, there are a number of different unit processes which can be assembled in a variety of different configurations. For example, chemical softening can be followed by either conventional RO or EDR. The brine produced from these two processes can then be treated in a number of ways. Consequently, a large number of permutations and combinations can quickly be generated which makes direct comparison of processes difficult. It was necessary to select certain process which can be compared relatively easily on the basis of effectiveness and cost.

A.5 DESCRIPTION OF PROCESSES FOR WHICH BUDGET COSTS ARE DERIVED.

A.5.1 Conventional Reverse Osmosis

A.5.1.1 Introduction

The principle of Reverse Osmosis (RO) has already been described but since it forms the basis for the SPARRO®, ASTROP® and AQUA-K processes, it bears further mention.

RO is capable of removing contaminants and particles with diameters as small as 0.0001 μm. Consequently it can remove salts, hardness, pathogens, turbidity, synthetic organic compounds, pesticides and almost all other potable water contaminants. However, most dissolved gases such as hydrogen sulphide and carbon dioxide will pass through RO membranes.

In general the product flow across a membrane is proportional to the net pressure differential across the membrane. Salt flow across the membrane however, is proportional to the concentration difference and is not affected by the applied pressure.

A.5.1.2 Process Flow Diagram

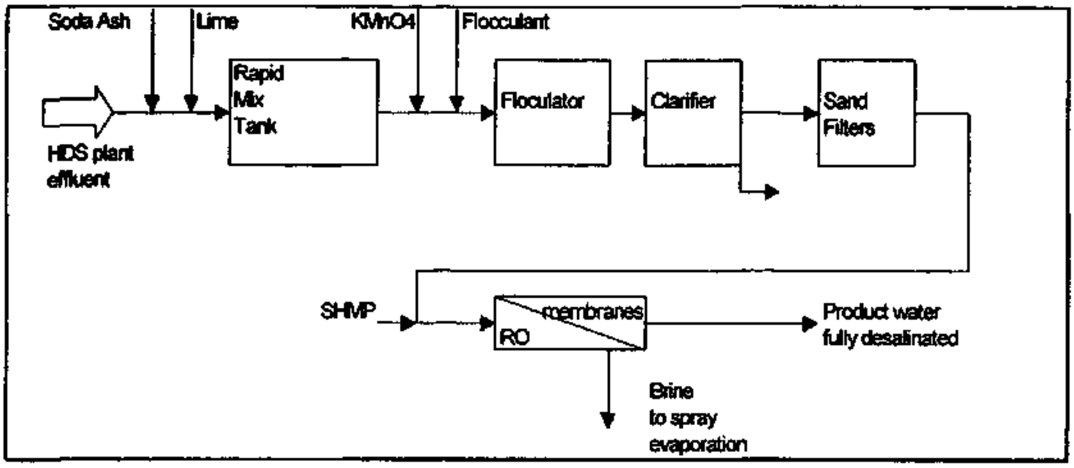


Figure A.1: Process Flow diagram.

A.5.1.3 Process Description

Fouling is of particular concern in RO systems and is as inevitable as death and taxes (Perry's Chemical Engineer's Handbook - 7th Edition). It is for this reason that considerable pre-treatment is required in order to remove colloidal material and certain chemical species which are sparingly soluble. Colloids and precipitants deposit on the membrane surface in spite of cross-flow and reduce the flux through the membrane over time. Precipitation of soluble salts is also problematic and occurs when the solubility product of a salt is exceeded. To prevent the formation of scale, either the anionic or cationic species must be removed from solution prior to the feed water being applied to the membranes. An alternative method of preventing precipitation is to acidify the feed water but this can cause degeneration of the membranes.
With reference to the Process Flow Diagram above, in order to effect the precipitation of calcium, magnesium and heavy metals, the pH is raised by the addition of soda ash and lime (in optimum proportions for effectiveness vs. cost). Freshly precipitated iron and manganese oxides can also contribute to membrane fouling and hence $KMnO_4$ is dosed in order to oxidise the iron and manganese to their higher, insoluble oxidation states. The resulting mixture is then clarified with the supernatant from the clarifier being filtered to remove any carryover. An anti-scalent such as sodium hexametaphosphate (SHMP) is then dosed to enable the system to be run at higher water recoveries by retarding or preventing precipitation of salts within the membranes. This is achieved by modifying the crystal structure of potential precipitants which interferes with crystal formation or retards precipitation kinetics.

If the Grootvlei effluent were fed to an RO plant the water recovery would be approximately 85% and the salt rejection 90%. These parameters however are strongly dependent on the extent of softening (using lime and/or soda ash) and the effectiveness of the anti-scalent dosed. The cost of membrane replacement requires that the silt density index (SDI) or an equivalent parameter, be monitored constantly to ensure that an acceptable feed quality is always maintained to the membranes. Cleaning cycles must also be carried out on a regular basis to maintain the flux through the membranes.

The product water is of a very high quality and in addition to being very low in TDS will be completely free of viruses and bacteria.

The brine should be relatively low in heavy metals if these were precipitated out during pre-treatment but the TDS concentration will be of the order of 25000 mg/l. The brine will probably require further concentration prior to final disposal (see Section A.6 for further details on brine treatment).

A.5.1.4 System Pros and Cons

Table A.1: System Pros and Cons.

Pros	Cons
High quality product water	Adequate pre-treatment to ensure reasonable water recovery is costly
Product water of a consistent quality	Produces a brine which still requires further treatment
Viruses and Bacteria removed	Membranes must be protected from failure in the pre-treatment system
Membrane modules can be removed and reassembled at another site if necessary	

A.5.2 Electrodialysis Reversal

A.5.2.1 Introduction

The purification of solvent in RO takes place by the selective transport of *solvent* through the membrane whereas in EDR, the purification of solvent takes place by the removal of undesirable *solute* through the membrane. This fundamental difference between the two processes means that particles have to be charged in order for them to migrate through an EDR membrane. Additionally, the smaller the charged particle the more easily it will move through the membrane which means that large organic particles, even if charged will tend to adhere to the membrane because they are too large to pass through. This causes membrane fouling. EDR has therefore not proved as attractive as RO for treating effluents which contain large amounts of microbiological contaminants and dissolved organic compounds. The chief function of the EDR process is therefore the removal of *inorganic ions* which leaves bacteria, viruses and neutral organics in the dilute stream.

A.5.2.2 Process Flow Diagram

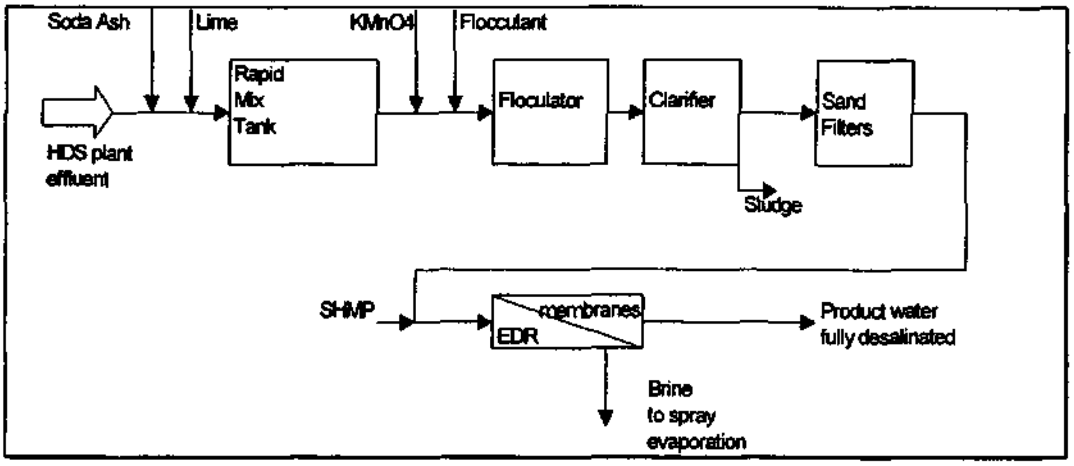


Figure A.2: Process Flow Diagram.

A.5.2.3 Process Description

The pre-treatment required for EDR is similar to that required for RO although the complete removal of suspended solids is more crucial in RO systems. Organic fouling is caused by the precipitation of large negatively charged anions on the anion-permeable membranes, while inorganic fouling is caused by the precipitation (scaling) of slightly soluble inorganic compounds (such as CaSO4 and CaCo3) in the brine compartments and the fixation of multivalent cations (such as Fe and Mn) on the cation-permeable membranes.

To prevent fouling therefore, $CaSO_4$ precipitation is encouraged by raising the pH to effect softening and $KMnO_4$ is dosed to oxidise iron and manganese. This is then followed by a flocculation step to remove suspended material and the supernatant is then passed through a sand filter.

The EDR process differs from ordinary ED in that the polarity of the electrodes is automatically reversed periodically (about three to four times per hour) and, by means of motor-operated valves, the fresh product water and the wastewater outlets are interchanged. This reversal of polarity has a profound effect on the ability of the process to control scale formation. Polarity reversal aids in breaking up and flushing out scale, slimes and other deposits from the cells. For this reason even high concentrations of $CaSO_4$ or the removal of Ca^{2+} ions above recognised saturation levels can be handled satisfactorily in the EDR system. This is due to the time lag in $CaSO_4$ precipitation. The upper design limit for the EDR system, without chemical addition is approximately 175% $CaSO_4$ saturation. With chemical addition to the concentrate stream, this limit can be extended to approximately 300%. Pilot plant operations at over 400% have been successfully demonstrated (Elyanow *et al*, 1981)

A.5.2.4 System Pros and Cons

Table A.2: System Pros and Cons.

Pros	Cons
High quality product water produced	Requires pre-treatment
Product water quality can be varied without structural adjustments to the system	Produces a brine which still requires further treatment
Monovalent ions removed	Bacteria, viruses and neutral ions are not removed
Pre-treatment requirements not as stringent as for RO	Water recovery usually lower than equivalent RO system
Can tolerate up to 175% CaSo4 saturation without scale formation	
Increasing range of separation applications with introduction of new membranes (e.g. water splitting)	

A.5.3 The GYP-CIX® process

A.5.3.1 Introduction

The GYP-CIX® process was developed in South Africa and is an ion exchange process optimised for the removal of $CaSO_4$.The process has been tested extensively and apart from the production of high quality gypsum, has demonstrated an ability to reduce radioactive elements such as uranium and radium to low levels.

A.5.3.2 Process Flow Diagram

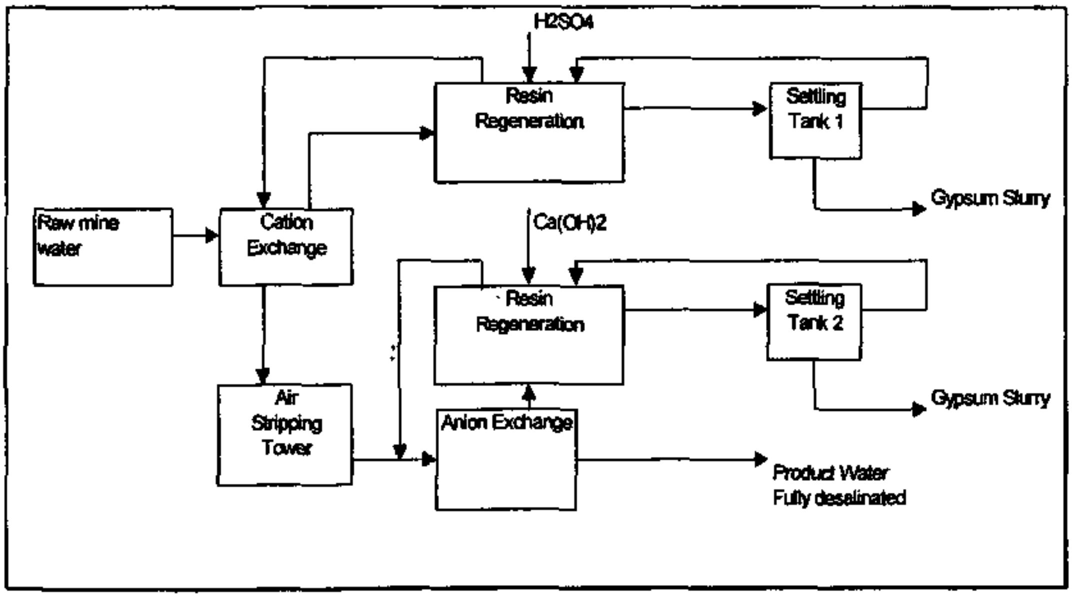


Figure A.3: Process Flow diagram.

A.5.3.3 Process Description

Unlike for the RO process, the GYP-GIX process requires comparatively little in the way of pre-treatment of the feed water prior to introduction to the cation exchange columns. It has been shown that filtration and pH adjustment are not necessary and that fouling of the resin from the presence of iron, silica and dissolved organics has been shown to have no adverse affects on the resin (Everett *et al*, 1994).

A counter-current configuration is used with the macroporous styrenic cation resin being regenerated using H_2SO_4 and a 10% loss of the resin expected through bead breakage per annum. The acrylic anion resin is regenerated with the use of lime, with an expected resin loss of 5% per annum.

Energy requirements for the process are relatively low but the need to use regenerant chemicals is considered by some to be disadvantageous, because it results in additional pollution load to the environment. However it must be remembered that the chemicals added for the pre-treatment required for other processes also constitute an addition of salts although a large portion are subsequently removed through precipitation.

The working capacity of the anion resin is approximately 85% and that of the cation resin is approximately 55%.

Some variations of the GYP-CIX process include the GYP-SOFT and GYP-GROW configurations. They operate on a similar principle but different resins and regenerants are used in order to produce different by-products. The GYP-GROW process for example, produces high value fertiliser as a by-product.

A.5.3.4 System Pros and Cons

Table A.3: System Pros and Cons.

Pros	Cons
Minimal pre-treatment required since filtration and pH adjustment are unnecessary	Water recoveries tend to be lower than RO-based processes and hence brine treatment volumes tend to be higher
Simple and reliable process	Regenerants constitute additional pollution load to the environment
High quality gypsum can be produced	
Tolerant of fluctuations in inflow quality	
Exchange beads less easily damaged than RO and EDR membranes	

A.5.4 The SPARRO® process

A.5.4.1 Introduction

The Slurry Precipitation and Recycle Reverse Osmosis (SPARRO) process was developed by the Chamber of Mines and is based on the concept of seeded RO. Rather than dosing anti-scalants in order to *retard* or *prevent* precipitation of calcium sulphate, the aim of seeded RO is to *promote* precipitation. As the concentrations of calcium and sulphate build up within the brine stream the solubility product of the calcium sulphate is exceeded and solid calcium sulphate precipitates. The concentration at which precipitation occurs in practice, is subject to the effects of ion pairing which is governed by the concentration of other ions in solution (e.g. Na^{+} and Mg^{2+}). In the seeded RO system the gypsum seed which is added to the feed water provides preferential sites for gypsum precipitation. This dramatically reduces the formation of scale on the membrane surfaces which presents the possibility of running the system at higher water recoveries with without expensive softening.

A.5.4.2 Process Flow Diagram

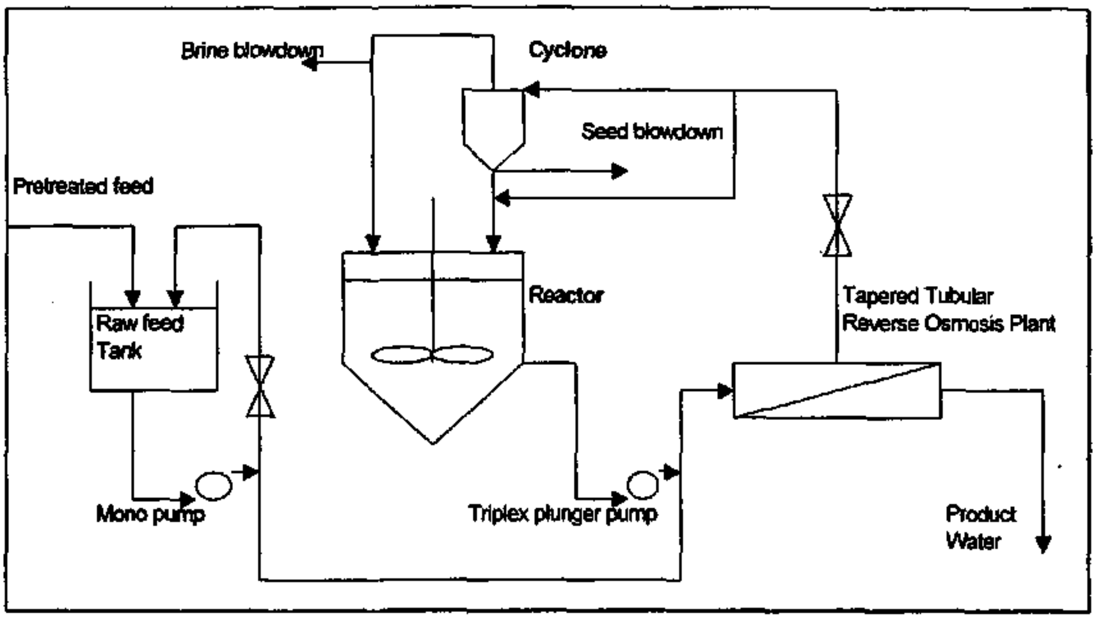


Figure A.4: Process Flow Diagram.

A.5.4.3 Process Description

The pre-treatment required for the SPARRO process involves the removal of colloids using flocculation, clarification and sand filtration. However, the softening, which forms part of the pre-treatment for the conventional RO process can be avoided which immediately reduces the high dosing costs required for softening. The reactor in the PFD above is operated to produce the required concentration of gypsum seed which is introduced to the feed stream via a separate pump. As the concentration inside the tubular membranes increases, the solubility product of the calcium sulphate will at some point be exceeded. Precipitation of calcium sulphate onto the seed crystals will then take place in the bulk liquid in preference to scale forming on other surfaces. Normal membrane fouling will still occur and must be dealt with by a cleaning cycle in the usual way.

A.5.4.4 System Pros and Cons

Table A.4: System Pros and Cons.

Pros	Cons
High quality of product water	Brine produced which requires further treatment
Product water of a consistent quality	Membranes must be protected from failure in filtration system
Viruses and Bacteria removed	Seed concentration dosed to feed water must be carefully monitored
Reduced pre-treatment costs compared to RO	
SHMP dosing not required	
Gypsum can be recovered	

A.5.5 The ASTROP® process

A.5.5.1 Introduction

The Advanced Seeded Tubular Reverse Osmosis Process (ASTROP), like the SPARRO process is based on the concept of seeded RO. The process was developed in South Africa and is in many respects similar to the SPARRO process in that gypsum seed is added to the feed water in order to promote the precipitation of calcium sulphate. The seed provides an alternative site for the precipitation of the calcium sulphate such that on concentration of the brine stream, membrane fouling can be reduced to acceptable levels and high water recoveries can be obtained without the dosing of expensive antiscalents.

The ASTROP system differs from the SPARRO process in that the product water from the tubular membranes serves as a feed water to a module of spiral wound membranes. The product from these membranes is the final product while the brine is recycled back to the seed reactor.

A.5.5.2 Process Flow Diagram

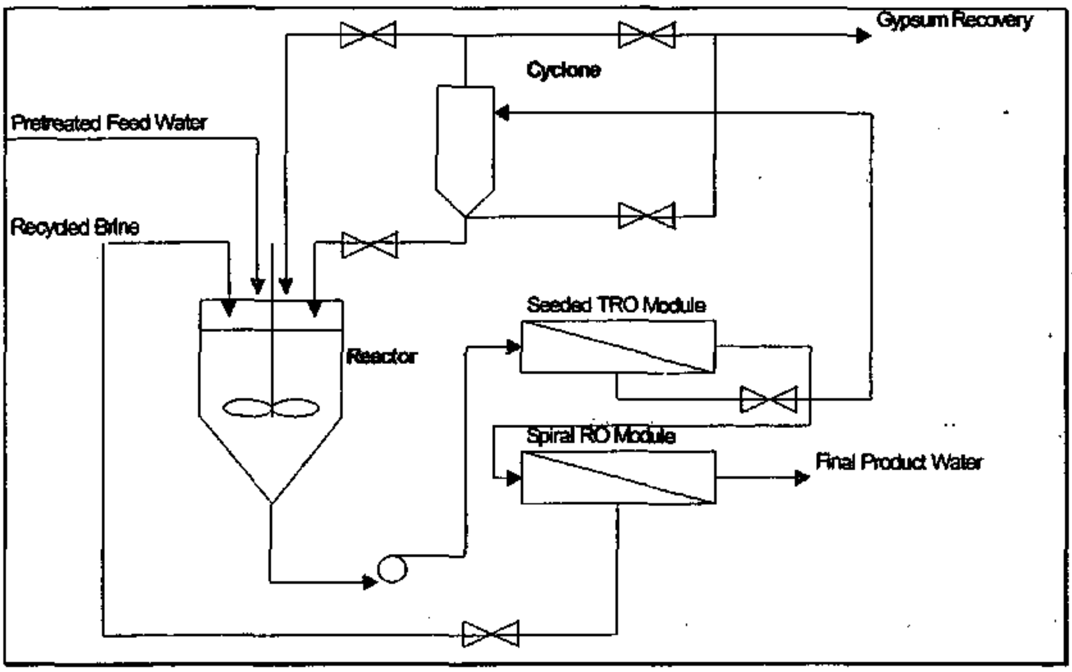


Figure A.5: Process Flow Diagram.

A.5.5.3 Process Description

The pre-treatment required for the ASTROP system involves the removal of suspended material via flocculation and filtration to prevent membrane fouling but softening to effect the removal of calcium is not required. A considerable saving can thus be realised compared to conventional RO since the dosing of lime and/or soda ash can raise the operating cost significantly.

The pre-treated feed water is introduced to the seed reactor, the concentration of which is maintained by wasting excess gypsum using a cyclone for solid-liquid separation. The quality of gypsum produced is dependent on the constituents of the feed water.

The use of two membrane types in series enables the process to achieve extremely high salt rejections and high water recoveries.

A.5.5.4 System Pros and Cons

Table A.5: System Pros and Cons.

Pros	Cons
Softening not required in pre-treatment	The brine produced requires further treatment
High and consistent quality of product water	Membranes must be protected from failure in clarification/filtration system
Bacteria and viruses removed	
Gypsum can be recovered and sold	
SHMP dosing not required	

A.5.6 The AQUA-K process

A.5.6.1 Introduction

This process incorporates conventional RO, with a low pressure and high pressure configuration in series. Although the process differs from conventional RO in that caustic soda is dosed instead of lime and a crystallisor forms part of the post treatment, the full process is essentially a package of well established unit processes. The basic process train was developed in Eastern Europe where several similar plants are currently in operation at military installation.

The process philosophy behind the development of this system recognises certain aspects not addressed in any of the other processes discussed in this report.

Firstly, the treatment of brine is acknowledged as being as important as the treatment of the feed water, since treatment of the feed water alone merely transfers the problem without necessarily solving it. Secondly, the process is set up not only to produce water but to produce by-products of high value in an attempt to achieve full cost recovery. The dosing regime is structured to produce not simply calcium sulphate but other products of higher value so that although the chemical dosing may appear more costly, these costs are to a large extent recovered from the sale of the compounds produced.

A.5.6.2 Process Flow Diagram

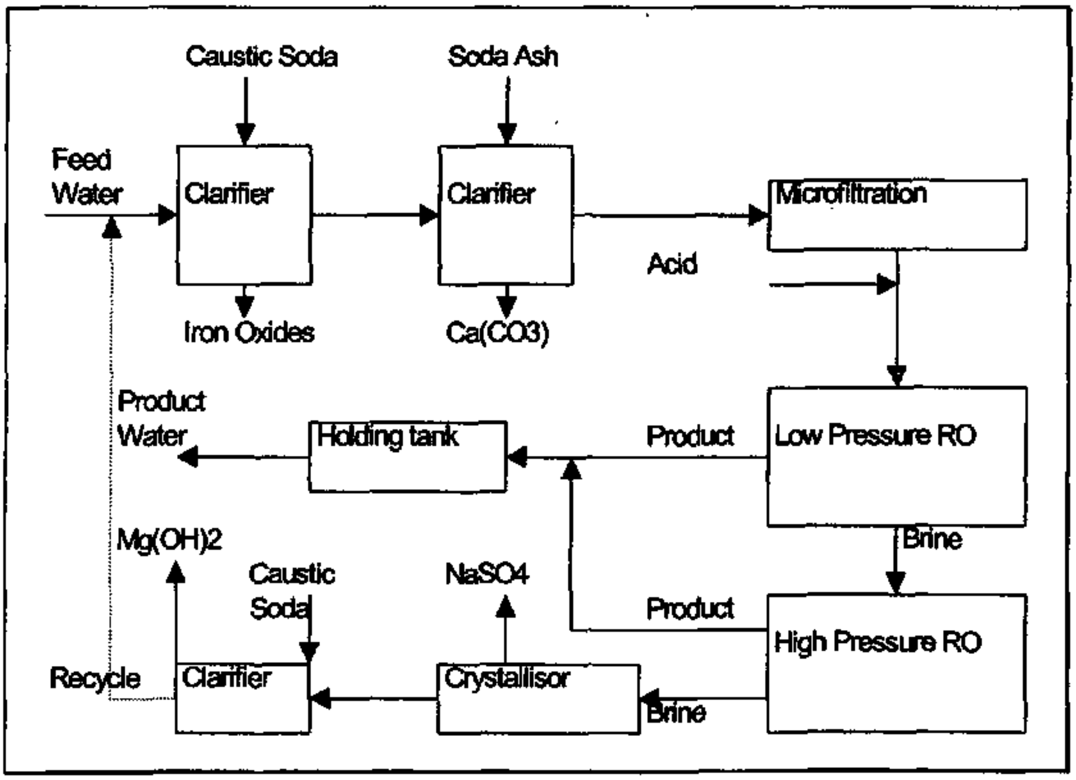


Figure A.6: Process Flow Diagram.

A.5.6.3 Process Description

If iron is present in the feed water caustic soda is dosed in order to remove the iron in the form of iron oxides. The sodium ions will remain in solution and ultimately form crystals when combined with sulphate ions. The next step is the addition of soda ash to maintain a pH of approximately 10. This will ensure almost total removal of calcium (as calcium carbonate) but minimal removal of magnesium which can continue through the process relatively unhindered. The supernatant is then passed through a micro filtration unit to ensure removal of any suspended material and to maintain a low SDI onto the membranes. Acid is then dosed to reduce the pH and the feed is then passed to a module of low pressure RO membranes. The product water from this step is stored in a holding tank while the brine is fed to a module of high pressure membranes. The product water from these membranes is stored in the same holding tank as the product water from the previous membranes. The brine is fed to a low temperature crystallisor which is optimised to produce sodium sulphate of high purity. The crystallisor reject is dosed with more caustic soda to enable high purity magnesium hydroxide to be precipitated. The supernatant from the clarifier is recycled to the beginning of the process such that no brine is produced which requires further treatment.

The modular nature of the process allows for easy modification and the brine treatment is relatively energy efficient compared to evaporator-type processes (which again tend to be geared towards the production of water rather than by-products).

A.5.6.4 System Pros and Cons

Table A.6: System Pros and Cons.

Pros	Cons
High and consistent quality of product water	Chemical dosing must be carefully monitored
Bacteria and viruses removed	Income subject to variation in price of by-products
Low overall cost of process	
Brine treatment an integral part of the process	
Sodium sulphate, magnesium hydroxide and calcium carbonate produced which can be sold	

A.5.7 The SAVMIN® process

A.5.7.1 Introduction

The SAVMIN process was jointly developed in South Africa and Australia specifically for the removal of sulphate from mining and industrial effluents. The process has the advantage of using conventional reactors operating at atmospheric pressure with an extremely efficient parallel cone settling system for solid liquid separation. Providing the concentration of mono valent ions in the feed water is not excessive, potable water can be produced as well as gypsum and calcium carbonate.

A.5.7.2 Process Flow Diagram

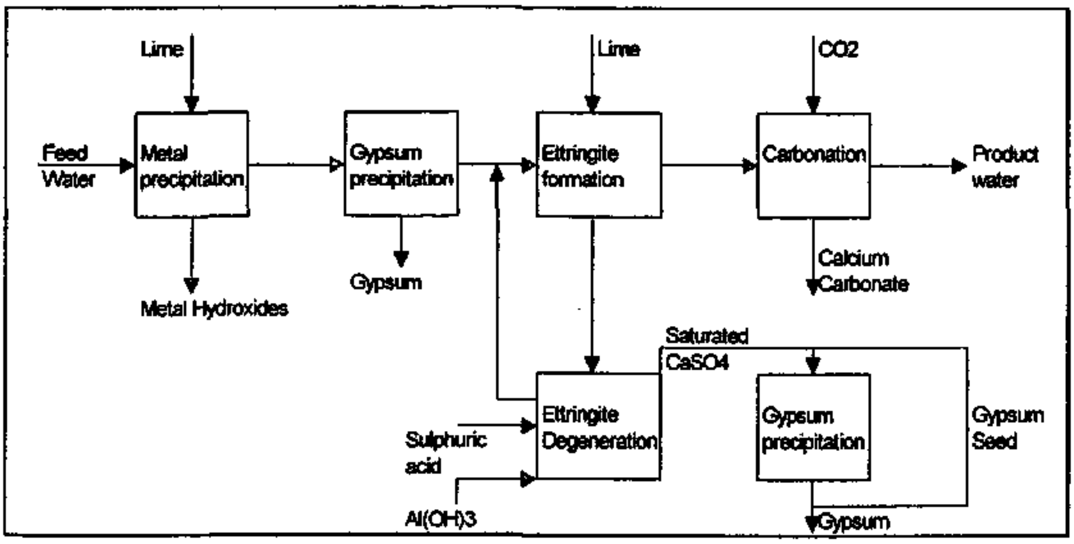


Figure A.7: Process Flow Diagram.

A.5.7.3 Process Description

Unlike with membrane processes, the SAVMIN process does not require any form of pre-treatment. The feed water is dosed with lime to raise the pH to approximately 12. In this environment, heavy metals and magnesium form insoluble hydroxides which are removed from the bulk solution. To promote the precipitation of the supersaturated calcium sulphate, a gypsum seed is introduced which, as in the seeded RO systems described above, provides a large surface area onto which precipitation will occur. The precipitated gypsum is removed in the under flow and the supernatant which is just saturated with respect to calcium sulphate is fed to the third stage of the process. In this stage further lime is added to maintain the pH between 11.4 and 12.4. Aluminium hydroxide is then dosed which at the high pH forms an insoluble precipitate known as ettringite. This precipitate contains calcium, aluminium, sulphate, oxygen and hydrogen, which is removed from the bulk solution and acidified in a separate reactor. On addition of acid, the ettringite degenerates into calcium and sulphate ions, aluminium hydroxide and water. The aluminium hydroxide is then removed by thickening/filtration and recycled to the ettringite precipitation reactor while the supernatant is transferred to another reactor which contains gypsum seed and promotes gypsum precipitation.

The bulk solution remaining from the third stage of the process is transferred to a separate reactor which receives a continuous dose of carbon dioxide. The reduction in pH together with the addition of carbonate species produces calcium carbonate which is removed as a precipitate. The resulting supernatant is the product water which would probably require filtration and stabilisation.

Mono valent ions are not removed by the process and hence the quality of the product water is dependent on the concentration of mono valent ions in the feed water. However, this disadvantage can often be overcome by blending the product water with a water which has a low concentration of monovalent ions.

A.5.7.4 System Pros and Cons

Table A.7: System Pros and Cons.

Pros	Cons
Process is relatively simple and no high pressure pumping equipment is required	Process cannot remove mono valent ions
Lime dosing for raising pH is cost-effective	Product water quality may vary slightly compared to product water from an RO-based process
Efficiency of parallel cone clarifier reduces residence times for solid liquid separation	Metal-rich sludge requires disposal
Gypsum is produced and can be sold	Aluminium concentration in the product water requires careful monitoring

A.5.8 The THIOPAQ® process

A.5.8.1 Introduction

This process is based on the biological reduction of sulphate to sulphide in an anaerobic environment followed by the oxidation of sulphide in an aerobic environment to produce elemental sulphur. Since sulphate contributes up to 50% of the total TDS in many mining effluents, the biological removal of sulphate can assist in the overall reduction in salts.

The Thiopaq process was developed in Europe where full scale plants are in operation but the anaerobic reduction of sulphate has received attention world-wide and considerable research has been carried out in South Africa (Maree *et al*,).

Mono valent ions are not removed by the process and sulphate removal varies from 85 to 91% so the process can only be considered as a partial desalination option.

The elemental sulphur produced by the aerobic stage and can be sold to offset capital and operating costs.

A.5.8.2 Process Flow Diagram

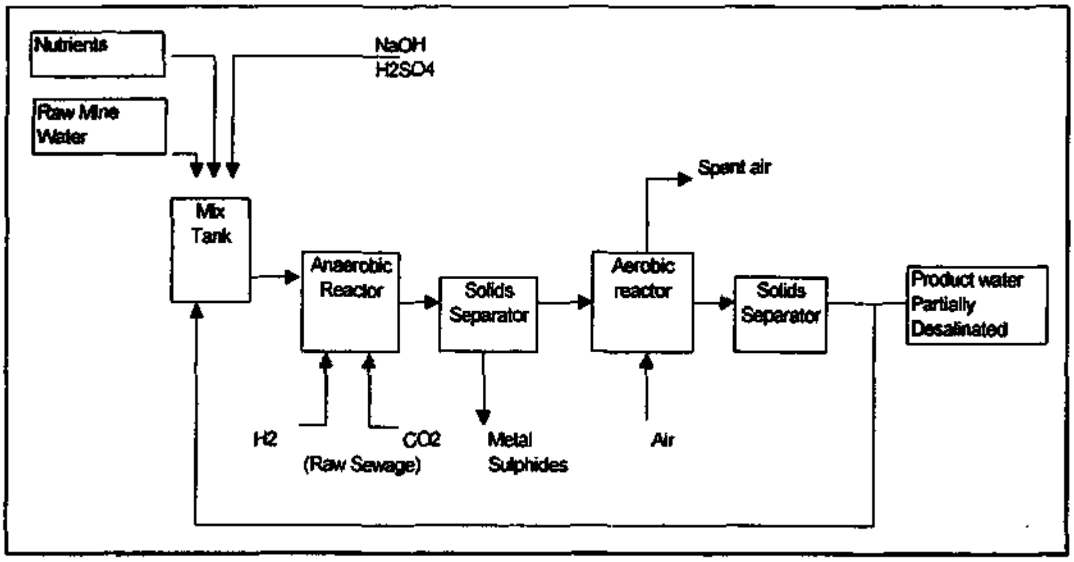


Figure A.8: Process Flow Diagram.

A.5.8.3 Process Description

No pre-treatment in the form of clarification and filtration is required for the Thiopaq process although it is necessary to dose nutrients for biological anabolism and to ensure that the pH of the feed is maintained by dosing either NaOH or H_2SO_4.

The anaerobic autotrophic bacteria require both a carbon and energy source to sustain their growth and carbon dioxide and hydrogen respectively are used. An alternative is to use fermented molasses if large quantities are available.

Insoluble metal sulphide precipitates are formed in the anaerobic reactor and are removed in the underflow of the solids separator. The dissolved hydrogen sulphide is then oxidised to form elemental sulphur (~88% pure has been obtained at pilot scale) which can be recovered and sold or processed further.

The product water is only partially desalinated since mono valent ions pass through the process unhindered. Calcium removal can be as high as 90%.

The process has the advantage of being relatively cheap to operate although this depends on the cost and availability of a suitable carbon and energy source.

A.5.8.4System Pros and Cons

Table A.8: System Pros and Cons.

Pros	Cons
Simple, robust process	Only partial desalination achieved for certain waste streams
Low operating costs if producer gas is readily available	Waste sludge is produced
The metal sulphides produced occupy a lower volume than metal hydroxides	

A.6 METHODS OF CONCENTRATE DISPOSAL

A.6.1 Introduction

There are a number of methods of 'treating' brine. These range from basic solid-liquid separation, in which a mixture of dry solids is obtained, to fractional crystallisation, in which specific compounds are targeted for removal. The economics of brine treatment are broadly dependent on:

- Area available
- Availability of a cheap energy source (e.g. steam)
- Contents of brine (valuable or not)
- Quantity to be treated
- Proximity to the sea or other suitable low impact disposal site

If the process selected for the treatment of the Grootvlei effluent produces a brine then it is immediately apparent that: the site is a considerable distance from the sea (BKS report to the Grootvlei JVC, Sept 1996 gives costs of a disposal pipeline to the sea) and the quantities to be treated could be large (between 8 and 26 Ml/d with a concentration of between 17000 and 53000 mg/l TDS).

However, there is possibly sufficient area available for a low operating cost evaporation system. This and other systems are discussed below as well as budget costs for some of the systems.

A.6.2 Evaporation ponds (unlined)

If a flow of 130 Ml/d of effluent were to be treated, a brine flow of between 9,1 Ml/d (105 l/s) and 39 Ml/d (451 l/s) could be expected depending on the process selected and the optimisation of parameters within the process. Clearly, these figures can be scaled down should the treated flow be less and thus the above figures would represent a worst case scenario. To place these brine flows in perspective a flow of 9,1 Ml/d would require a storage facility of approximately 100m^2 if the depth were 1m for storage for one day. In the case of the 39 Ml/d flow, a storage facility of approximately 200m^2 would be required if the depth were 1m. If the mean annual evaporation were say 1m, then simplistically, one days discharge would take a year to evaporate.

The above illustrates that the area required for the flows mentioned would be considerable and since the ponds are unlined the pollution potential from seepage into the ground water would be completely unacceptable.

In conclusion, the use of unlined evaporation ponds can only be considered for comparatively small brine flows in an area with a high mean annual evaporation and where the soil types do not permit significant seepage.

A.6.3 Evaporation ponds (lined)

In the discussion above, it was shown that the disadvantages of a system of unlined ponds for brine flows of between 9,1 and 39 Ml/d, are that the areas required are large and that a potential pollution problem exists from seepage.

Lining the ponds would increase the capital cost dramatically, but seepage would then be minimised. However, the area required would remain similar and hence, for the flows anticipated, lined evaporation ponds cannot be considered.

A.6.4 Lined ponds with enhanced spray evaporation

The advantage of enhanced spray evaporation over conventional evaporation ponds is that the area required can be reduced considerably since evaporation is far more efficient. However, the reduction in capital cost from a reduced area is to a large extent offset by the increased operating cost associated with pumping to supply the sprays. The faster accumulation of salts in the ponds requires that provision also be made for salt removal from the ponds. The problem of where to store the removed salts then arises.

To enable the costs of brine treatment to be included in the overall treatment costs given for the various processes in this document which produce brine, costing was carried out using enhanced spray evaporation as a method of brine treatment. The processes for which enhanced evaporation was assumed were: RO, EDR, GYP-CIX, SPARRO and ASTROP. The AQUA-K process, although RO-based, makes use of a crystallisor and The Biosulphate and SAVMIN processes produce sludges or precipitants which require dewatering.

The spray dryer discussed below is a modification of this method of separation.

A.6.5 Disposal via pipeline to the Indian Ocean

Since the brine concentration ranges from approximately 11000 to 53000 mg/l TDS and the concentration in the sea is approximately 35000 mg/l TDS ocean disposal is certainly possible if the treatment plant is located near the sea. However, the distance from the sea is too great to be considered as a method of brine disposal for Grootvlei. It has been suggested that if a pipeline were built, a number of industries which produce wastes suitable for sea disposal could contribute to the costs. This would certainly be beneficial as regards reducing salt discharges to the Vaal river but would require careful management to ensure precipitation of compounds did not occur in the pipeline. Toxic wastes could not be disposed of in this manner.

A table summarising the capital and operating costs of the above methods of disposal is given below.

Table A.9: Capital and operating costs of the above methods of disposal.

Brine evaporation system	Unit capital cost (R x10^6/Ml/d)	Unit operating cost (c/m^3)
Unlined evaporation ponds	4.0 – 5.5	2.5 – 2.9
Lined evaporation ponds	20.0 – 25.2	2.7 – 3.2
Lined ponds with enhanced spray evaporation	8.0 – 9.5	90.0 – 10.5
Crystallisors		
Spray dryers		
Pipeline to sea	28.25 (1) – 34.08 (2)	82.8 (1) – 119.0 (2)

(1) CSIR (1996)
(2) BKS (1996)

A.6.6 Crystallisors

As mentioned above, the AQUA-K process incorporates a crystallisor for the specific purpose of producing sodium sulphate. This crystallisor however, operates at a *low* temperature which differs from the system shown below which operates at a high temperature.

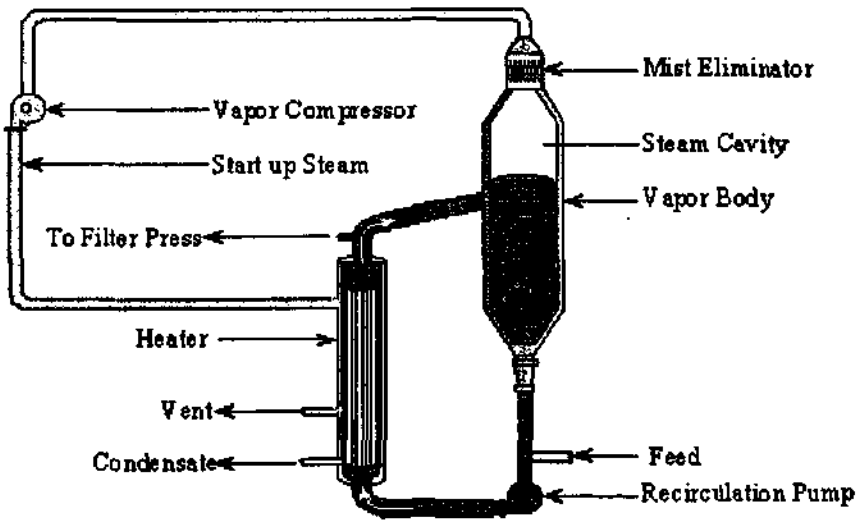


Figure A.9: Diagram of typical high temperature Crystallisor.

A crystallisor is able to reduce highly saturated wastewater to dry solids for disposal. High purity water is recovered from the crystallisor for recycling. A crystallisor may also recover specific salts from a mixed salt waste stream. The mechanism of crystallisation occurs by forced circulation evaporation which uses a mechanical vapour compressor or plant steam as the energy source.

A.6.7 Spray Dryers

If separation of the feed water into specific compounds is not required, then a spray dryer can be used.

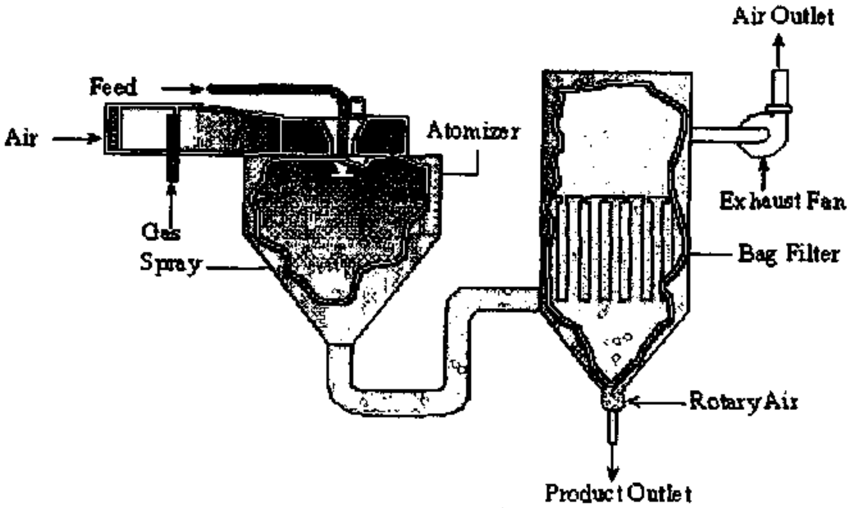


Figure A.10: Diagram of typical Spray Dryer.

The spray dryer transforms the slurry into a fine powder of mixed salts for disposal. This is achieved by atomising the wastewater slurry inside a hot chamber, which instantly vaporises the water droplets and leaves only dry salts behind. Clearly, the feed flow to the atomiser is limited and for large flows a number of atomisers operating in parallel would probably be required.

A.6.8 Calandria crystallisors

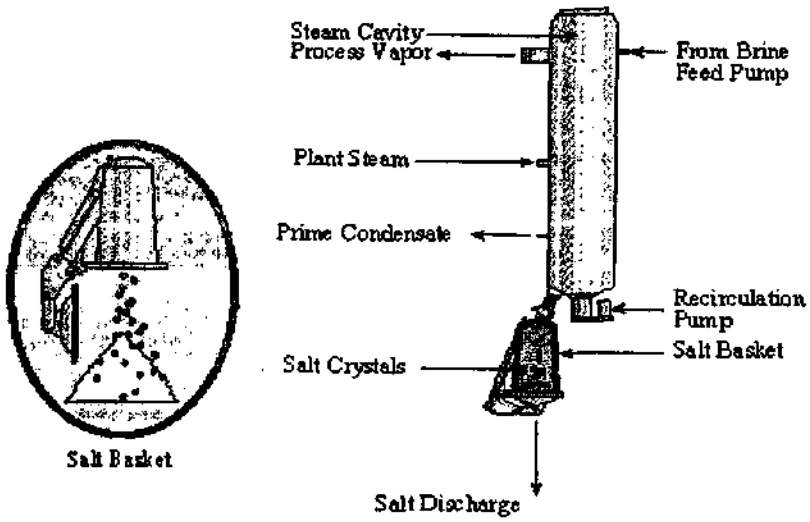


Figure A.11: Diagram of Calandria Crystallisor.

The calandria crystallisor reduces concentrated wastewater to dry solids for disposal. It is designed to concentrate certain brine chemistries to solids using a low-cost configuration which relies on steam as an energy source. The calandria operates in a continuous mode with salt crystals harvested in a batch process. A patented salt basket dewaters the concentrated brine and harvests the salt crystals without the added expense of a centrifuge or filter press.

A.7 RAW WATER DATA FOR GROOTVLEI, ERPM, WAGM AND DRD

A.7.1 Grootvlei

Table A.10: Grootvlei - Average results obtained from sampling after the HDS plant.

Contaminant	Treatment Plant Influent		DWAF water quality guidelines-Domestic use
	Probable design condition	Credible deviation condition (-20%)	
pH	9	10.8	6-9
TDS mg/l	4 156	4 987	450
Conductivity mS/m	342	410	70
Turbidity NTU	35.94	43	N/A
Total Hardness mg/l as $CaCO_3$	1 789	2 147	200
Ammonia mg/l	6	7.2	1
Calcium mg/l	523	628	32
Chloride mg/l	223	268	100
Magnesium mg/l	117	140	30
Potassium mg/l			50
Sodium mg/l	306	367	100
Sulphate mg/l	2 085	2 502	200
Nitrate mg/l			6
Alkalinity mg/l as $CaCO_3$	55	66	200
Copper mg/l			1
Zinc mg/l			3
Iron mg/l	7.91	9.49	0.1
Manganese mg/l	1.6	1.92	0.05
Fluoride mg/l	0.23	0.28	1
SS mg/l			N/A
Lead µg/l			10
Cadmium µg/l			5

A.7.2 ERPM

Table A.11: ERPM - Average results from February 1991 to September 1995. Effluent discharged to Elsburg spruit.

Contaminant	Treatment Plant Influent		DWAF water quality guidelines-Domestic use
	Probable design condition	Credible deviation condition (-20%)	
pH	7.8	9.4	6-9
TDS mg/l	4 184	5 021	450
Conductivity mS/m			70
Turbidity NTU			N/A
Total Hardness mg/l as $CaCO_3$	2727	3 272	200
Ammonia mg/l			1
Calcium mg/l	735	882	32
Chloride mg/l	79	95	100
Magnesium mg/l	212.3	255	30
Potassium mg/l			50
Sodium mg/l	195	234	100
Sulphate mg/l	2 200	2640	200
Nitrate mg/l			6
Alkalinity mg/l as $CaCO_3$	66.2	79.44	200
Copper mg/l			1
Zinc mg/l			3
Iron mg/l	15	18.00	0.1
Manganese mg/l	4.3	5.16	0.05
Fluoride mg/l	0.36	0.43	1
SS mg/l			N/A
Lead µg/l			10
Cadmium µg/l			5

A.7.3 WAGM (Randfontein Estates no 4#)

Table A.12: WAGM - Average discharge to Reitspruit during April and May 1997.

Contaminant	Treatment Plant Influent		DWAF water quality guidelines-Domestic use
	Probable design condition	Credible deviation condition (-20%)	
pH	6.3	7.6	6-9
TDS mg/l	812*	974	450
Conductivity mS/m	116	139	70
Turbidity NTU	17	20	N/A
Total Hardness mg/l as $CaCO_3$	498	598	200
Ammonia mg/l	2	2.4	1
Calcium mg/l	142	170	32
Chloride mg/l	20	24	100
Magnesium mg/l	35	42	30
Potassium mg/l	2.9	3	50
Sodium mg/l	34	41	100
Sulphate mg/l	577	692	200
Nitrate mg/l	3.5	4	6
Alkalinity mg/l as $CaCO_3$	12	14.4	200
Copper mg/l	0.1	0.12	1
Zinc mg/l	0.1	0.12	3
Iron mg/l	0.2	0.24	0.1
Manganese mg/l	1.8	2.16	0.05
Fluoride mg/l			1
SS mg/l			N/A
Lead µg/l			10
Cadmium µg/l			5

* This value was derived from a TDS/Conc ration of 7, calculated from historic data.

A.7.4 DRD

Table A.13: DRD - Average discharge quality to Klip river between September 1992 and May 1995.

Contaminant	Treatment Plant Influent		DWAF water quality guidelines- Domestic use
	Probable design condition	Credible deviation condition (-20%)	
pH	4.9	5.9	6-9
TDS mg/l	3 499*	4199	450
Conductivity mS/m	287.5	345	70
Turbidity NTU			N/A
Total Hardness mg/l as $CaCO_3$			200
Ammonia mg/l	8.7	10.4	1
Calcium mg/l			32
Chloride mg/l	50.1	60	100
Magnesium mg/l			30
Potassium mg/l			50
Sodium mg/l	128.3	154	100
Sulphate mg/l	2 112.3	2 535	200
Nitrate mg/l			6
Alkalinity mg/l as $CaCO_3$			200
Copper mg/l			1
Zinc mg/l			3
Iron mg/l			0.1
Manganese mg/l	5.7	6.84	0.05
Fluoride mg/l			1
SS mg/l	109.8	131.8	N/A
Lead µg/l			10
Cadmium µg/l			5

* This value was derived from a TDS/Conc ratio of 12.15, calculated from the Grootvlei data.

A.8 WATER BLEND DATA

Blends of waters were used for strategies 2, 3, and 4. The tables below show the characteristics of each blend (this does not apply to Strategy 1, although the characteristics are still given) and an estimate of the calcium carbonate and calcium sulphate precipitation potentials of the waters. These precipitation potentials were estimated using the Aquachem and Comwat programs which were specifically written for these types of waters and include the effects of ion pairing.

A.8.1 Strategy 1

Table A.14: Grootvlei effluent.

Parameter	Strategy 1		
	Aquachem	Comwat	Average
Total Ca (mg/l)	523	523	523
Total Mg (mg/l)	117	117	117
Total SO_4 (mg/l)	2 085	2 085	2 085
Total Cl (mg/l)	223	223	223
pH	9	9	9
Total Acidity (mg $CaCO_3$/l)	47	47.6	47.3
Total Alkalinity (mg $CaCO_3$/l)	55	55	55
Temperature	16	16	16
$CaCO_3$ precipitation pot. (mg/l)	28	17.5	22.8
$CaSO_4$ precipitation pot. (mg/l)	-90	-48.4	-69.2

A.8.2 Strategy 2

Table A.15: Blend of ERPM and Grootvlei effluents.

Parameter	Strategy 2		
	Aquachem	Comwat	Average
Total Ca (mg/l)	552	552.7	552.4
Total Mg (mg/l)	130	130.3	130.2
Total SO_4 (mg/l)	2 101	2 101.1	2 101.1
Total Cl (mg/l)	203	203	203
pH	8.9	8.9	9
Total Acidity (mg $CaCO_3$/l)	50	50.2	50.1
Total Alkalinity (mg $CaCO_3$/l)	57	56.6	56.8
Temperature	16	16	16
$CaCO_3$ precipitation pot. (mg/l)	7	24.2	15.6
$CaSO_4$ precipitation pot. (mg/l)	-58	-42.9	-50.5

A.8.3 Strategy 3

Table A.16: Blend of DRD and WAGM effluents.

Parameter	Strategy 3		
	Aquachem	Comwat	Average
Total Ca (mg/l)	230	231	230.5
Total Mg (mg/l)	30	29.8	29.9
Total SO_4 (mg/l)	806	807.3	806.7
Total Cl (mg/l)	24	24	24
pH	6.3	6.2	6.3
Total Acidity (mg $CaCO_3$/l)	45	44	44.5
Total Alkalinity (mg $CaCO_3$/l)	10	13.9	12.0
Temperature	16	16	16
$CaCO_3$ precipitation pot. (mg/l)	-28	-29.7	-28.9
$CaSO_4$ precipitation pot. (mg/l)	-587	-580.4	-583.7

A.8.4 Strategy 4

Table A.17: Blend of Grootvlei, ERPM, WAGM and DRD effluents.

Parameter	Strategy 4		
	Aquachem	Comwat	Average
Total Ca (mg/l)	459	457.4	458.2
Total Mg (mg/l)	101	101.3	101.2
Total SO_4 (mg/l)	1 727	1 720.6	1 723.8
Total Cl (mg/l)	152	152	152
pH	8.6	6.6	7.6
Total Acidity (mg $CaCO_3$/l)	48	104	76
Total Alkalinity (mg $CaCO_3$/l)	43	44.2	43.6
Temperature	16	16	16
$CaCO_3$ precipitation pot. (mg/l)	-28	-39.6	-33.8
$CaSO_4$ precipitation pot. (mg/l)	-216	-181.1	-198.6

A.8.5 Strategy 5

The water used in this strategy is from Grootvlei and hence has the same characteristics as the water in strategy 1.

A.8.6 Strategy 6

The water used in this strategy is from Grootvlei and hence has the same characteristics as the water in strategy 1.

A.8.7 Strategy 7

The water used in this strategy is from Grootvlei and hence has the same characteristics as the water in strategy 1.

A.8.8 Strategy 8

The water used in this strategy is from Grootvlei and hence has the same characteristics as the water in strategy 1.

A.9 BUDGET COST ESTIMATES FOR THE EIGHT CONCEPTUAL STRATEGIES

A.9.1 Strategy 1

A.9.1.1AQUA-K®

AQUA-K

PLANT PARAMETERS:		
Water Recovery (%)	96	
Salt Rejection(%)	95	
Inflow to plant (Ml/d)	130.0	
Inflow concentration (mg/l TDS)	4158.0	
Product flow (Ml/d)	124.8	
Product concentration (mg/l TDS)	218.5	
Brine Flow (Ml/d)	5.2	
Brine concentration (mg/l TDS)	98705.0	
UNIT COSTS:		
Unit cost of brine disposal(c/m^3)	0	Included elsewhere
Unit process op cost (c/m^3)	380	
Potable water cost (c/m3)	200	
By-product recovery factor	780	
FINANCIAL PARAMETERS:		
No of Years	20	
Interest rate	6%	

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs					
Pretreatment (included in desal)		0.00	0.00	0.00	0.00
Desalination	394.94	40.23	84.77	88.31	2118.36
Brine disposal (included in desal)		0.00	0.00	0.00	0.00
Op costs					
Desalination		180.31	380.00	395.83	9500.00
Brine disposal (included in desal)		0.00	0.00	0.00	0.00
Total Expenses (Op+Cap)	394.94	220.54	464.77	484.14	11618.36
Income:					
Sale of potable water		91.10	192.00	200.00	4800.00
Sale of By-products		98.82	208.28	216.94	5208.50
Total income		189.92	400.28	416.94	10008.50
Net Income (including brine disposal)		-30.61	-64.51	-67.20	-1612.86

Total Expenses (neglecting brine disposal)		220.54	464.77	484.14	11618.36
Net income (neglecting brine disposal)		-30.61	-64.51	-67.20	-1612.86

Total Expenses (Op only)		180.31	380.00	395.83	9500.00
Net Income (including brine disposal)		9.61	20.28	20.10	508.50

No of Years for Capital repayment	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
5	279	588	613	14712	
10	339	504	525	12601	Total Expenses
20	221	465	484	11619	
Interest Rate					
6%	221	465	484	11619	
16%	247	520	542	13010	Total Expenses
24%	278	583	607	14583	

Potable water cost (c/m3)	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
200	190	400	417	10007	
300	235	496	517	12407	Total Income
400	281	592	617	14807	
500	327	688	717	17207	
By-product recovery factor					
0	91	192	200	4800	
100	104	219	228	5467	Total Income
500	154	326	339	8137	
1000	218	459	478	11475	

Costs estimated from information supplied by Rand Water in conjunction with Aqua Technologies

A.9.1.2ASTROP®

ASTROP

PLANT PARAMETERS:	
Water Recovery (%)	90
Salt Rejection(%)	97
Inflow to plant (Ml/d)	130.0
Inflow concentration (mg/l TDS)	4150.0
Product flow (Ml/d)	117.0
Product concentration (mg/l TDS)	136.5
Brine Flow (Ml/d)	13.0
Brine concentration (mg/l TDS)	40313.2
UNIT COSTS:	
Unit cost of brine disposal(c/m^3)	102.69
Unit process op cost (c/m^3)	300
Potable water cost (c/m3)	200
Gypsum recovery (R/tonne)	100
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	8%

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs					
Pretreatment	34.54	3.52	7.41	8.24	74.14
Desalination	794.91	80.98	170.63	189.59	1706.29
Brine disposal	117.00	11.92	25.11	27.90	251.14
Op costs					
Desalination		157.53	332.00	368.89	3320.00
Brine disposal		4.88	10.28	11.43	102.85
Total Expenses (Op+Cap)	946.45	258.81	545.44	606.05	5454.43
Income:					
Sale of potable water		85.41	180.00	200.00	1800.00
Sale of Gypsum		12.67	26.70	29.67	267.00
Total Income		98.08	206.70	229.67	2067.00
Net Income (including brine disposal)		-160.73	-338.74	-376.38	-3387.43

Total Expenses (neglecting brine disposal)		242.02	510.04	566.72	5100.44
Net income (neglecting brine disposal)		-143.94	-303.34	-337.05	-3033.44

Total Expenses (Op only)		162.41	342.28	380.32	3422.85
Net income (including brine disposal)		-64.34	-135.59	-150.65	-1355.85

	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
No of Years for Capital repayment					
5	399	842	935	8416	Total Expenses
10	303	640	711	6395	
20	259	545	606	5454	
Interest Rate					
8%	259	545	606	5454	Total Expenses
16%	322	678	754	6787	
24%	393	828	920	8276	

	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
Potable water cost (c/m3)					
200	98	207	230	2067	Total Income
300	141	297	330	2967	
400	183	387	430	3867	
500	226	477	530	4767	
Gypsum recovery (R/tonne)					
0	85	180	200	1800	Total Income
100	98	207	230	2067	
500	149	314	348	3135	
1000	212	447	497	4470	

Costs estimated from information contained in paper
"Application of Seeded Reverse Osmosis in South Africa for the Recovery of Water from CaSO4 Scaling Water"
by GJG Juby, DJC Nel and MV van der Merwe 1996

A.9.1.3 BIOSULPHATE

Biosulphate

PLANT PARAMETERS:	
[illegible]	
UNIT COSTS:	
[illegible]	
FINANCIAL PARAMETERS:	
No of Years	20
Interest Rate	5%

Expenses:	Current Cost (c/kl)	Cap + Op Cost (c/kl)	Annual Cost (R)	Annual Cost (R) product	Annual Cost (R) brine
Cap costs					
Pretreatment (included in desal)		0.00	0.00	0.00	0.00
Desalination	285.82	24.87	54.81	56.87	5800.82
Sludge disposal (included in desal)		0.00	0.00	0.00	0.00
Op costs					
Desalination		46.98	99.00	100.00	9800.00
Sludge disposal (included in desal)		0.00	0.00	0.00	0.00
Total Expenses (Op + Cap)	[illegible]	73.55	155.01	156.87	15600.82
Income:					
Sale of potable water		0.00	0.00	0.00	0.00
Sale of Sulphur		0.00	0.00	0.00	0.00
Total Income		0.00	0.00	0.00	0.00
Net Income (including brine disposal)		-73.55	-155.01	-156.87	-15600.82

Total Expenses (neglecting brine disposal)		73.55	155.01	156.87	15600.82
Net Income (neglecting brine disposal)		-73.55	-155.01	-156.87	-15600.82

Total Expenses (Op only)		46.98	99.00	100.00	9800.00
Net Income (including brine disposal)		-46.98	-99.00	-100.00	-9800.00

No of Years for Capital repayment	Cap + Op Cost (c/kl)	Annual Cost (R)	Annual Cost (R)	Annual Cost (R) brine	
5	143	237	238	23672	
10	88	181	183	18000	⟺ Total Expenses
20	74	158	157	15581	
Interest Rate					
5%	74	158	157	15581	
10%	89	182	184	18178	⟺ Total Expenses
20%	119	233	233	23273	

Potable water cost (c/kl)	Cap + Op Cost (c/kl)	Annual Profit (R)	Annual Profit (R) product	Annual Cost (R) brine	
200	84	180	200	19800	
300	141	297	300	29700	⟺ Total Income
400	188	398	400	39600	
500	235	498	500	49500	
Sulphur recovery (R/tonne)					
0	6	6	6	6	
100	13	27	27	2670	⟺ Total Income
500	41	134	138	13360	
1000	127	267	278	26700	

Costs estimated from information contained in report number [illegible] "Investigation into Alternative Water Treatment Technologies for the Treatment of an Underground Mine Water discharged by Grootvlei Proprietary Mines LTD into the Blesbokspruit" by JJ Schoeman, D Whyte, J Maree, N Murray and A Steyn August 1996

A.9.1.4 EDR

EDR

PLANT PARAMETERS:	
Water Recovery (%)	80
Salt Rejection(%)	85
Inflow to plant (Ml/d)	130.0
Inflow concentration (mg/l TDS)	4158.0
Product flow (Ml/d)	104.0
Product concentration (mg/l TDS)	779.3
Brine Flow (Ml/d)	26.0
Brine concentration (mg/l TDS)	[illegible]
UNIT COSTS:	
Unit cost of brine disposal(c/m^3)	[illegible]
Unit process op cost (c/m^3)	214
Potable water cost (c/m3)	200
Gypsum recovery (R/tonne)	0
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	6%

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs					
Pretreatment	87.50	8.93	20.93	26.16	104.64
Desalination	282.50	29.79	62.79	78.48	313.92
Brine disposal	234.00	23.83	50.23	62.79	251.14
Op costs					
Desalination		101.54	214.00	267.50	1070.00
Brine disposal		9.76	20.57	25.71	102.86
Total Expenses (Op + Cap)	624.00	174.88	368.51	460.64	1842.56
Income:					
Sale of potable water		75.92	160.00	200.00	800.00
Sale of Gypsum		0.00	0.00	0.00	0.00
Total Income		75.92	160.00	200.00	800.00
Net income (including brine disposal)		-98.94	-208.51	-260.64	-1042.56

Total Expenses (neglecting brine disposal)		141.27	297.71	372.14	1488.57
Net income (neglecting brine disposal)		-65.35	-137.71	-172.14	-688.57

Total Expenses (Op only)		111.30	234.57	293.21	1172.85
Net income (including brine disposal)		-35.38	-74.57	-93.21	-372.85

	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
No of Years for Capital repayment					
5	268	564	705	2820	
10	204	431	538	2153	Total Expenses
20	175	369	461	1843	
Interest Rate					
6%	175	369	461	1843	
16%	217	456	570	2282	Total Expenses
24%	263	555	693	2773	

	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
Potable water cost (c/m3)					
200	76	160	200	800	
300	114	240	300	1200	Total Income
400	152	320	400	1600	
500	190	400	500	2000	
Gypsum recovery (R/tonne)					
0	76	160	200	800	
100	88	187	233	934	Total Income
500	139	294	367	1468	
1000	203	427	534	2135	

Costs estimated from information contained in report number JC 022 6000 6C01 "Investigation into Alternative Water Treatment Technologies for the Treatment of an Underground Mine Water discharged by Grootvlei Proprietary Mines LTD into the Blesbokspruit" by JJ Schoeman, D Whyte, J Maree, K Murray and A Steyn. August 1996

A.9.1.5 GYP-CIX®

GYP-CIX

PLANT PARAMETERS:	
[illegible]	[illegible]
UNIT COSTS:	
[illegible]	[illegible]
FINANCIAL PARAMETERS:	
[illegible]	[illegible]

	Current Cost (mR)	Cap + Op Cost (mR)	Annual Cost (existing plant)	Annual Cost (product)	Annual Cost (brine)
Expenses:					
Cap costs					
Pretreatment	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Desalination	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Brine disposal	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Op costs					
Desalination		[illegible]	[illegible]	[illegible]	[illegible]
Brine disposal		[illegible]	[illegible]	[illegible]	[illegible]
Total Expenses	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Income:					
Sale of potable water		[illegible]	[illegible]	[illegible]	[illegible]
Sale of Gypsum		[illegible]	[illegible]	[illegible]	[illegible]
Total Income		[illegible]	[illegible]	[illegible]	[illegible]
Net Income (including brine disposal)		[illegible]	[illegible]	[illegible]	[illegible]

Total Expenses (neglecting brine disposal)		[illegible]	[illegible]	[illegible]	[illegible]
Net Income (neglecting brine disposal)		[illegible]	[illegible]	[illegible]	[illegible]

Total Expenses (Op only)		[illegible]	[illegible]	[illegible]	[illegible]
Net Income (including brine disposal)		[illegible]	[illegible]	[illegible]	[illegible]

Total Expenses

Total Expenses

Total Income

Total Income

A.9.1.6 RO

RO

PLANT PARAMETERS:	
[illegible]	[illegible]
UNIT COSTS:	
[illegible]	[illegible]
FINANCIAL PARAMETERS:	
No of Years	30
Interest rate	[illegible]

	Current Cost	Cap + Op	Annual	Annual	Annual
Expenses:					
Cap costs					
[illegible]	91.88	9.33	19.88	23.13	131.00
[illegible]	119.38	12.16	25.82	30.14	170.61
Brine disposal	[illegible]	17.86	37.62	44.32	251.14
Op costs					
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Brine disposal		7.32	15.43	18.16	[illegible]
Total Expenses (Cap + Op)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Income:					
Sale of potable water		[illegible]	170.00	200.00	1130.33
Sale of by-product		0.00	0.00	0.00	0.00
Total Income		[illegible]	170.00	200.00	1130.33
Net Income (including brine disposal)		[illegible]	[illegible]	[illegible]	[illegible]

Total Expenses (neglecting brine disposal)		[illegible]	[illegible]	[illegible]	[illegible]
Net Income (neglecting brine disposal)		[illegible]	[illegible]	[illegible]	[illegible]

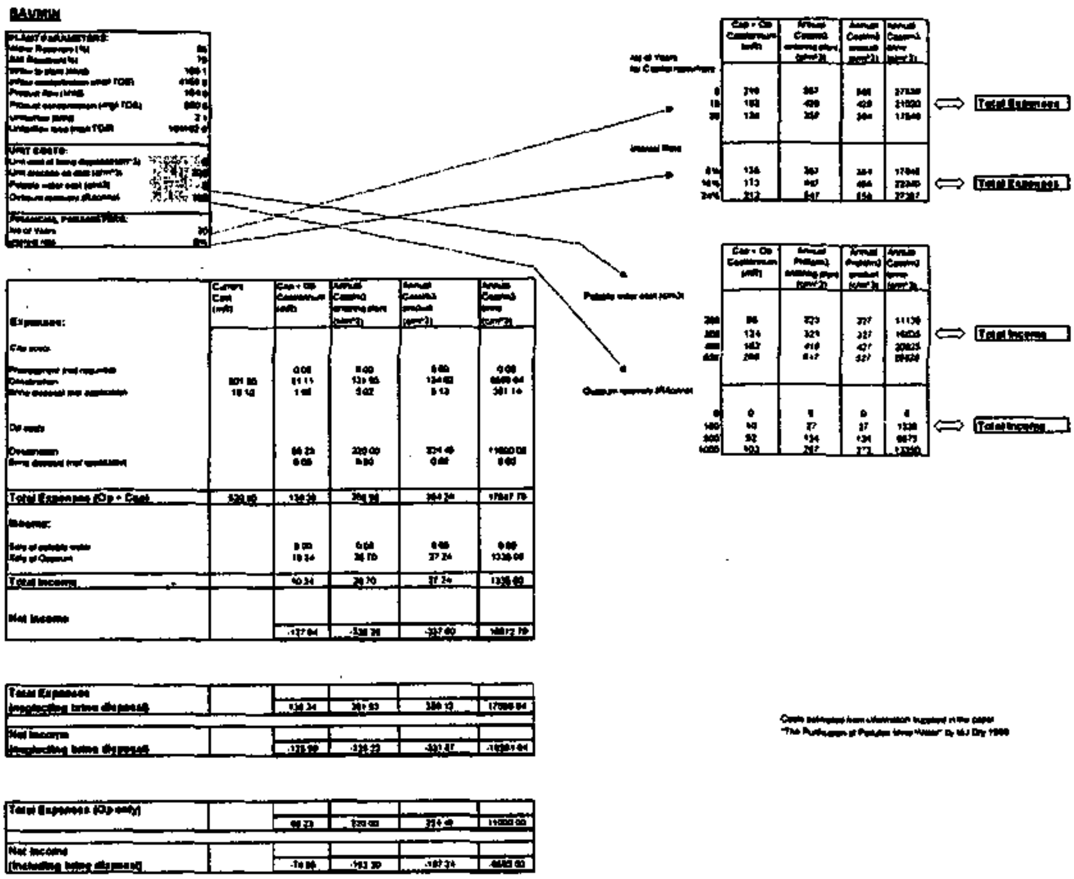
Total Expenses (Op only)		[illegible]	[illegible]	[illegible]	[illegible]
Net Income (including brine disposal)		[illegible]	[illegible]	[illegible]	[illegible]

	Cap + Op	Annual	Annual	Annual	
No of Years					
[illegible]	283	418	729	4106	Total Expenses
[illegible]	283	[illegible]	627	[illegible]	
30	[illegible]	498	582	[illegible]	
Interest Rate					
[illegible]	239	498	[illegible]	[illegible]	Total Expenses
[illegible]	[illegible]	548	640	[illegible]	
[illegible]	[illegible]	610	718	[illegible]	

	Cap + Op	Annual	Annual	Annual	
Potable water cost					
200	81	170	200	1133	Total Income
300	121	254	300	1700	
400	161	340	400	2267	
500	202	425	500	2833	
By-product recovery					
0	81	170	200	1133	Total Income
100	81	170	200	1133	
500	81	170	200	1133	
1000	81	170	200	1133	

Costs estimated from information contained in report number [illegible] "Investigation into Alternative Water Treatment Technologies for the Treatment of an Underground Mine Water discharged by [illegible] Mines LTD into the [illegible]" by [illegible] and [illegible]. August 1996

A.9.1.7SAVMIN®


Expenses:
Total Expenses
Income:
Total Income
Net Income
Total Expenses
Total Expenses
Total Income
Total Income

A.9.1.8SPARRO®

SPARRO

PLANT PARAMETERS:	
Water Recovery (%)	[illegible]
Salt Rejection (%)	[illegible]
Influent to plant (Ml/d)	130.0
Influent concentration (mg/l TDS)	4100.0
Product flow (Ml/d)	120.0
Product concentration (mg/l TDS)	446.6
Brine Flow (Ml/d)	0.1
Brine concentration (mg/l TDS)	83424.3
UNIT COSTS:	
Unit cost of brine disposal (c/m^3)	[illegible]
Unit income on sale (c/m^3)	[illegible]
Potable water cost (c/m3)	200
Gypsum recovery (R/tonne)	100
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	[illegible]

	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost (c/m3 entering plant (c/m^3)	Annual Cost (c/m3 product (c/m^3)	Annual Cost (c/m3 brine (c/m^3)
Expenses:					
Cap costs					
Pretreatment	34.54	3.82	7.41	7.81	108.92
Desalination	616.56	62.19	121.89	[illegible]	1872.32
Brine disposal	81.80	6.34	17.58	[illegible]	251.14
Op costs					
Desalination		113.87	240.36	250.25	3431.43
Brine disposal		3.42	7.30	7.74	[illegible]
Total Expenses (Op + Cap)	737.02	191.44	403.48	433.82	[illegible]
Income:					
Sale of potable water		88.28	180.00	200.00	2657.14
Sale of Gypsum		12.07	28.76	28.71	381.43
Total Income		100.83	212.76	228.71	3038.57
Net Income (including brine disposal)		-90.51	-190.72	-205.11	-2750.08

Total Expenses (neglecting brine disposal)		178.44	378.48	407.18	[illegible]
Net Income (neglecting brine disposal)		-78.75	[illegible]	-178.47	[illegible]

Total Expenses (Op only)		117.29	247.66	[illegible]	[illegible]
Net Income (including brine disposal)		-16.46	-34.70	[illegible]	[illegible]

	Cap + Op Cost/annum (mR)	Annual Cost (c/m3 entering plant (c/m^3)	Annual Cost (c/m3 product (c/m^3)	Annual Cost (c/m3 brine (c/m^3)	
No of Years for Capital repayment					
5	210	401	470	6016	Total Expenses
10	220	418	412	6796	
20	191	403	434	5784	
Interest Rate					
0%	181	403	434	5784	Total Expenses
10%	240	508	544	7220	
20%	294	620	687	[illegible]	

	Cap + Op Cost/annum (mR)	Annual Profit (c/m3 entering plant (c/m^3)	Annual Profit (c/m3 product (c/m^3)	Annual Cost (c/m3 brine (c/m^3)	
Potable water cost (c/m3)					
200	101	213	229	3039	Total Income
300	145	306	329	4361	
400	189	399	429	[illegible]	
500	233	492	529	7024	
Gypsum recovery (R/tonne)					
0	88	186	200	2657	Total Income
100	101	213	229	3039	
500	152	320	344	4564	
1000	215	453	487	6474	

Costs obtained from information contained in paper
"Application of Slurry Reverse Osmosis in South Africa for the Recovery of Water from CaSO4 Scaling Water"
by OJO Juby, JJC Nel and HW van der Merwe 1996

A.9.2 Strategy 2

A.9.2.1 AQUA-K®

AQUA-K

PLANT PARAMETERS:		
Water Recovery (%)	96	
Salt Rejection(%)	95	
Inflow to plant (Ml/d)	146.0	
Inflow concentration (mg/l TDS)	4156.0	
Product flow (Ml/d)	140.2	
Product concentration (mg/l TDS)	216.6	
Brine Flow (Ml/d)	5.8	
Brine concentration (mg/l TDS)	98776.2	
UNIT COSTS:		
Unit cost of brine disposal(c/m^3)	0	included elsewhere
Unit process op cost (c/m^3)	380	
Potable water cost (c/m3)	200	
By-product recovery factor	700	
FINANCIAL PARAMETERS:		
No of Years	20	
Interest rate	8%	

Expenses:		Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs.						
Pretreatment (included in desal)			0.00	0.00	0.00	0.00
Desalination		443.55	45.18	84.77	88.31	2119.36
Brine disposal (included in desal)			0.00	0.00	0.00	0.00
Pipe from ERPM to G (Ml/d)	18	20.30	2.07	3.48	4.04	96.97
Length of pipeline (km)	20					
Op costs.						
Desalination			202.50	380.00	395.83	9500.00
Brine disposal (included in desal)			0.00	0.00	0.00	0.00
Op+Main of pipeline			0.22	0.41	0.43	10.23
Total Expenses (Op+Cap)		463.84	249.96	469.06	488.61	11726.56
Income:						
Sale of potable water			102.32	192.00	200.00	4800.00
Sale of By-products			110.98	208.28	216.94	5206.50
Total Income			213.30	400.28	416.94	10006.50
Net income (including brine disposal)			-36.66	-68.80	-71.67	-1720.06

Total Expenses (neglecting brine disposal)		249.96	469.06	488.61	11726.56
Net income (neglecting brine disposal)		-36.66	-68.80	-71.67	-1720.06

Total Expenses (Op only)		202.50	380.00	395.83	9500.00
Net income (including brine disposal)		10.80	20.28	21.10	506.50

	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
No of Years for Capital repayment					
5	319	598	623	14950	
10	272	510	531	12753	⟺ **Total Expenses**
20	250	469	489	11727	
Interest Rate					
8%	250	469	489	11727	
16%	281	527	549	13180	⟺ **Total Expenses**
24%	318	592	617	14804	

	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
Potable water cost (c/m3)					
200	213	400	417	10007	
300	264	496	517	12407	⟺ **Total Income**
400	316	592	617	14807	
500	367	688	717	17207	
By-product recovery factor					
0	102	192	200	4800	
100	117	219	228	5467	⟺ **Total Income**
500	173	326	339	8137	
1000	245	459	478	11475	

Costs estimated from information supplied by Rand Water in conjunction with Aqua Technologies

A.9.3 Strategy 3

A.9.3.1AQUA-K®

AQUA-K

PLANT PARAMETERS:	
Water Recovery (%)	96
Salt Rejection(%)	95
Inflow to plant (Ml/d)	47.0
Inflow concentration (mg/l TDS)	1212.0
Product flow (Ml/d)	45.1
Product concentration (mg/l TDS	63.1
Brine Flow (Ml/d)	1.9
Brine concentration (mg/l TDS)	28785.0
UNIT COSTS:	
Unit cost of brine disposal(c/m^3)	0 Included elsewhere
Unit process op cost (c/m^3)	300
Potable water cost (c/m3)	200
By-product recovery factor	700
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	8%

Expenses:		Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs						
Pretreatment (included in desal)			0.00	0.00	0.00	0.00
Desalination		142.78	14.54	84.77	88.31	2119.38
Brine disposal (included in desal)			0.00	0.00	0.00	0.00
Pipe from DRD to Rand Est (Ml/d)	7	22.19	2.28	13.17	13.72	328.30
Length of pipeline (km)	35					
Op costs						
Desalination			57.47	335.00	348.96	8375.00
Brine disposal (included in desal)			0.00	0.00	0.00	0.00
Op+Main of pipeline			0.19	1.13	1.17	28.06
Total Expenses (Op+Cap)		164.97	74.48	434.07	452.15	10851.72
Income:						
Sale of potable water			32.94	192.00	200.00	4800.00
Sale of By-products			10.35	60.34	62.86	1508.35
Total income			43.29	252.34	262.86	6308.55
Net Income (including brine disposal)			-31.18	-181.73	-189.30	-4543.17

Total Expenses (neglecting brine disposal)		74.48	434.07	452.15	10851.72
Net Income (neglecting brine disposal)		-31.18	-181.73	-189.30	-4543.17

Total Expenses (Op only)		57.47	335.00	348.96	8375.00
Net income (including brine disposal)		-14.18	-82.66	-86.10	-2066.45

	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
No of Years for Capital repayment					
5	89	577	601	14424	
10	82	478	499	11968	⟺ Total Expenses
20	74	434	452	10852	
Interest Rate					
8%	74	434	452	10852	
16%	85	498	519	12458	⟺ Total Expenses
24%	98	570	594	14257	

	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
Potable water cost (c/m3)					
200	43	252	263	6309	
300	60	348	363	8709	⟺ Total Income
400	76	444	463	11109	
500	93	540	563	13509	
By-product recovery factor					
0	33	192	200	4800	
100	38	219	228	5487	⟺ Total Income
500	56	326	339	8137	
1000	79	459	478	11475	

Costs estimated from information supplied by Rand Water in conjunction with Aqua Technologies.

A.9.3.2SAVMIN®

SAVMIN

PLANT PARAMETERS:	
Water Recovery (%)	98
Salt Rejection(%)	79
Inflow to plant (Ml/d)	47 0
Inflow concentration (mg/l T	1212.0
Product flow (Ml/d)	46 1
Product concentration (mg/l	258 7
Underflow (Ml/d)	0 9
Underflow load (mg/l TDS)	######
UNIT COSTS:	
Unit cost of brine disposal(c	0
Unit process op cost (c/m^3	70
Potable water cost (c/m3)	200
Gypsum recovery (R/tonne)	700
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	8%

Expenses:		Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs						
Pretreatment (included in desal)			0.00	0 00	0 00	0 00
Desalination		181 42	18 48	107 71	109 91	5385 61
Brine disposal (included in desal)		8.46	0.86	5 02	5.13	251.14
Pipe from DRD to Rand Est	7	22 18	2.26	13 17	13 44	658 60
Length of pipeline (km)	35					
Op costs:						
Desalination			12 01	70 00	71.43	3500 00
Brine disposal			0 00	0 00	0 00	0.00
Op+Main of pipeline			0 19	1.12	1.15	56 11
Total Expenses (Op+Cap)		212 07	33 80	197 02	201 06	9851 46
Income:						
Sale of potable water			33 62	196 00	200.00	9800 00
Sale of Gypsum			2.29	13.35	13 62	667.50
Total income			35.91	209 35	213 62	10467 50
Net income (including brine disposal)			2.11	12 33	12.56	616.04

Total Expenses (neglecting brine disposal)		32.94	192.00	195 93	9600.32
Net income (neglecting brine disposal)		2 97	17.35	17 69	867 18

Total Expenses (Op only)		12.01	70 00	71.43	3500 00
Net income (including brine disposal)		23 90	139 35	142.19	6967.50

	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
No of Years for Capital repayment					
5	65	381	389	19037	
10	44	255	261	12767	⟺ Total Expenses
20	34	197	201	9851	
Interest Rate					
8%	34	197	201	9851	
16%	48	280	285	13981	⟺ Total Expenses
24%	64	372	379	18594	

	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
Potable water cost (c/m3)					
200	36	209	214	10468	
300	53	307	314	15368	⟺ Total Income
400	70	405	414	20268	
500	86	503	514	25168	
Gypsum recovery (R/tonne)					
0	34	196	200	9800	
100	36	209	214	10468	⟺ Total Income
500	45	263	268	13138	
1000	57	330	336	16475	

Costs estimated from information supplied in the paper "The Purification of Polluted Mine Water" by MJ Ory. 1998

A.9.4 Strategy 4

A.9.4.1 AQUA-K®

AQUA-K

PLANT PARAMETERS:	
Water Recovery (%)	96
Salt Rejection(%)	95
Inflow to plant (Ml/d)	47 0
Inflow concentration (mg/l T	1212 0
Product flow (Ml/d)	45 1
Product concentration (mg/l	83 1
Brine Flow (Ml/d)	1 9
Brine concentration (mg/l TI	#######
UNIT COSTS:	
Unit cost of brine disposal(c	0 (included elsewhere)
Unit process op cost (c/m^3	380
Potable water cost (c/m3)	200
By-product recovery factor	780
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	8%

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs					
Pretreatment (included in desal)		0.00	0.00	0.00	0.00
Desalination	142 79	14 54	84 77	88.31	2119 38
Brine disposal (included in desal)		0 00	0 00	0 00	0.00
Pipe from DRD to Rand Est T	22.18	2 26	13.17	13 72	329 30
Length of pipeline (km) 35					
Op costs					
Desalination		57 47	335 00	348 98	8375.00
Brine disposal (included in desal)		0 00	0.00	0.00	0 00
Op+Main of pipeline		0 19	1.12	1.17	28.05
Total Expenses (Op+Cap)	164 97	74.46	434 07	452 15	10851 72
Income:					
Sale of potable water		32 94	192.00	200 00	4800.00
Sale of By-products		10.35	60 34	62.86	1508.55
Total income		43.29	252 34	262 86	6308 58
Net income (including brine disposal)		-31.18	-181.73	-189 30	-4543 17

Total Expenses (neglecting brine disposal)		74 46	434 07	452 15	10851 72
Net income (neglecting brine disposal)		-31 18	-181 73	-189 30	-4543 17

Total Expenses (Op only)		57.47	335.00	348 98	8375.00
Net income (including brine disposal)		-14.18	-82 66	-86 19	-2066 45

	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
No of Years for Capital repayment					
5	96	577	601	14424	
10	82	479	499	11986	Total Expenses
20	74	434	452	10852	
Interest Rate					
8%	74	434	452	10852	
16%	85	498	519	12458	Total Expenses
24%	98	570	594	14252	

	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
Potable water cost (c/m3)					
200	43	252	263	6309	
300	60	348	363	8708	Total Income
400	76	444	463	11109	
500	93	540	563	13509	
By-product recovery factor					
0	33	192	200	4800	
100	38	219	228	5467	Total Income
500	56	328	339	8137	
1000	78	458	478	11475	

Costs estimated from information supplied by Rand Water in conjunction with Aqua Technologies

A.9.5 Strategy 5

A.9.5.1 SPARRO®

SPARRO

PLANT PARAMETERS:	
Water Recovery (%)	93
Salt Rejection(%)	90
Inflow to plant (Ml/d)	130.0
Inflow concentration (mg/l TD:	4156.0
Product flow (Ml/d)	120.8
Product concentration (mg/l T	446.9
Brine Flow (Ml/d)	9.1
Brine concentration (mg/l TDS	53434.3
UNIT COSTS:	
Unit cost of brine disposal(c/m	102.85
Unit process op cost (c/m^3)	240.2
Potable water cost (c/m3)	200
Gypsum recovery (R/tonne)	100
FINANCIAL PARAMETERS:	
No of Years	20
interest rate	6%

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs					
Pretreatment	34.54	3.52	7.41	7.97	105.82
Desalination	610.58	62.19	131.06	140.93	1872.32
Brine disposal	81.90	8.34	17.58	18.90	251.14
Op costs					
Desalination	-	113.97	240.20	258.28	3431.43
Brine disposal		3.42	7.20	7.74	102.85
Total Expenses (Op + Cap)	727.02	191.44	403.46	433.82	5763.66
Income:					
Sale of potable water		88.26	186.00	200.00	2657.14
Sale of Gypsum		12.67	26.70	28.71	381.43
Total Income		100.93	212.70	228.71	3038.57
Net income (including brine disposal)		-90.51	-190.76	-205.11	-2725.09

Total Expenses (neglecting brine disposal)		175.68	378.68	407.18	5409.88
Net income (neglecting brine disposal)		-76.76	-165.98	-178.47	-2371.09

Total Expenses (Op only)		117.39	247.40	266.02	3534.28
Net income (including brine disposal)		-16.46	-34.70	-37.31	-495.71

No of Years for Capital repayment	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
5	299	631	679	9016
10	226	476	512	6786
20	191	403	434	5764
Interest Rate				
6%	191	403	434	5764
16%	240	506	544	7226
24%	294	620	667	8860

⟺ **Total Expenses**

⟺ **Total Expenses**

Potable water cost (c/m3)	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
200	101	213	229	3039
300	145	306	329	4367
400	189	399	429	5696
500	233	492	529	7024
Gypsum recovery (R/tonne)				
0	88	186	200	2657
100	101	213	229	3039
500	152	320	344	4584
1000	215	453	487	6471

⟺ **Total Income**

⟺ **Total Income**

Costs estimated from information contained in paper
"Application of Seeded Reverse Osmosis in South Africa for the Recovery of Water from CaSO4 Scaling Water"
by GJG Juby, DJC Nel and MI van der Merwe 1996

A.9.6 Strategy 6

A.9.6.1 AQUA-K®

AQUA-K

PLANT PARAMETERS:		
Water Recovery (%)	96	
Salt Rejection (%)	95	
Inflow to plant (Ml/d)	65 0	
Inflow concentration (mg/l T	4156 0	
Product flow (Ml/d)	62 4	
Product concentration (mg/l	216 5	
Brine Flow (Ml/d)	2 6	
Brine concentration (mg/l TI	[illegible]	
UNIT COSTS:		
Unit cost of brine disposal(c	0	Included elsewhere
Unit process op cost (c/m^3	380	
Potable water cost (c/m3)	200	
By-product recovery factor	780	
FINANCIAL PARAMETERS:		
No of Years	20	
interest rate	6%	

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs					
Pretreatment (included in desal)		0 00	0 00	0 00	0 00
Desalination	198 27	20 11	84 77	88 31	2119 38
Brine disposal (included in desal)		0.00	0 00	0 00	0 00
Concrete channel	6 02	0.00	2 93	3 08	73 20
Op costs					
Desalination		90.75	380 00	399 02	9500 00
Brine disposal (included in desal)		0.00	0 00	0.00	0.00
Maintenance of channel		0 13	0 13	0.14	3 31
Total Expenses (Op+Cap)	204 29	110 99	467 83	484 14	11895 87
Income:					
Sale of potable water		45 55	192 00	200 00	4800 00
Sale of By-products		49 41	208 28	216 94	5208.50
Total income		94 96	400 28	416 94	10008 50
Net income (including brine disposal)		-16.03	-67 57	-70 39	-1689 37

Total Expenses *(neglecting brine disposal)*		*110 99*	*467 86*	*487.33*	*11895 87*
Net income (neglecting brine disposal)		-16 03	-67 57	-70 39	-1689 37

Total Expenses *(Op only)*		90 16	380 00	395.83	9500.00
Net income (including brine disposal)		4.81	20 28	20 10	508 50

No of Years for Capital repayment	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
5	141	598	621	14895
10	121	509	530	127211
20	111	468	487	11698
Interest Rate				
6%	111	468	487	11698
16%	125	525	547	13134
24%	140	590	614	14741

Total Expenses

Total Expenses

Potable water cost (c/m3)	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
200	95	400	417	10007
300	118	496	517	12407
400	141	592	617	14807
500	163	688	717	17207
By-product recovery factor				
0	46	192	200	4800
100	52	219	228	5467
500	77	326	339	8137
1000	109	459	478	11475

Total Income

Total Income

Costs estimated from information supplied by Rand Water in conjunction with Aqua Technologies

A.9.7 Strategy 7

A.9.7.1 35Ml/d Capacity Channel with no Desalination

Channel 35 Ml/d

PLANT PARAMETERS:		
Water Recovery (%)		
Salt Rejection(%)	0.0	
Inflow to plant (Ml/d)		
Inflow concentration (mg/l	0.0	
Product flow (Ml/d)	0.0	
Product concentration (mg/l TDS)		
Brine Flow (Ml/d)		
Brine concentration (mg/l TDS)		
UNIT COSTS:		
Unit cost of brine disposal(	0	Included elsewhere
Unit process op cost (c/m³	0	
Potable water cost (c/m3)	0	
By-product recovery factor	0	
FINANCIAL PARAMETERS:		
No of Years	20	
Interest rate	8%	

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs					
Pretreatment (included in desal)		0.00			
Desalination	0.00	0.00			
Brine disposal (included in desal)		0.00			
Concrete Channel 35Ml/d - 414	4.55	0.47			
Length (km) 11					
Op costs:					
Desalination		0.00			
Brine disposal (included in desal)		0.00			
Maintenance of Channel		0.02			
Total Expenses (Op+Cap)	4.55	0.49			
Income:					
Sale of potable water		0.00			
Sale of By-products		0.00			
Total Income		0.00			
Net income (including brine disposal)		-0.49			

Total Expenses (neglecting brine disposal)		0.49	0.00	0.00	0.00
Net income (neglecting brine disposal)		-0.49	0.00	0.00	0.00

Total Expenses (Op only)		0.00	0.00	0.00	0.00
Net income (including brine disposal)		0.00	0.00	0.00	0.00

No of Years for Capital repayment	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
5	1	0	0	0	Total Expenses
10	1	0	0	0	
20	0	0	0	0	
Interest Rate					
8%	0	0	0	0	Total Expenses
16%	1	0	0	0	
24%	1	0	0	0	

Potable water cost (c/m3)	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
200	0	0	0	0	Total Income
300	0	0	0	0	
400	0	0	0	0	
500	0	0	0	0	
By-product recovery factor					
0	0	0	0	0	Total Income
100	0	0	0	0	
500	0	0	0	0	
1000	0	0	0	0	

A.9.7.2 65Ml/d Capacity Channel with no Desalination

Channel 65 Ml/d

PLANT PARAMETERS:	
Water Recovery (%)	
Salt Rejection(%)	0.0
Inflow to plant (Ml/d)	
Inflow concentration (mg/l TDS)	0.0
Product flow (Ml/d)	0.0
Product concentration (mg/l TDS)	
Brine Flow (Ml/d)	
Brine concentration (mg/l TDS)	
UNIT COSTS:	
Unit cost of brine disposal(c/m^	0 (Included elsewhere)
Unit process op cost (c/m^3)	0
Potable water cost (c/m3)	0
By-product recovery factor	0
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	8%

Expenses:		Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs						
Pretreatment (included in desal)			0.00			
Desalination		0.00	0.00			
Brine disposal (included in desal)			0.00			
Concrete Channel 35MPa (R pe	620	8.82	0.70			
Length (km)	11					
Op costs						
Desalination			0.00			
Brine disposal (included in desal)			0.00			
Maintenance of Channel			0.03			
Total Expenses (Op+Cap)		8.82	0.73			
Income:						
Sale of potable water			0.00			
Sale of By-products			0.00			
Total income			0.00			
Net income (including brine disposal)			-0.73			

Total Expenses (neglecting brine disposal)		0.73	0.00	0.00	0.00
Net income (neglecting brine disposal)		-0.73	0.00	0.00	0.00

Total Expenses (Op only)		0.00	0.00	0.00	0.00
Net income (including brine disposal)		0.00	0.00	0.00	0.00

	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
No of Years for Capital repayment					
5	2	0	0	0	
10	1	0	0	0	⟺ Total Expenses
20	1	0	0	0	
Interest Rate					
8%	1	0	0	0	
16%	1	0	0	0	⟺ Total Expenses
24%	2	0	0	0	

	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
Potable water cost (c/m3)					
200	0	0	0	0	
300	0	0	0	0	⟺ Total Income
400	0	0	0	0	
500	0	0	0	0	
By-product recovery factor					
0	0	0	0	0	
100	0	0	0	0	⟺ Total Income
500	0	0	0	0	
1000	0	0	0	0	

A.9.7.3 130Ml/d Capacity Channel with no Desalination

Channel 130 Ml/d

PLANT PARAMETERS:	
Water Recovery (%)	
Salt Rejection(%)	0.0
Inflow to plant (Ml/d)	
Inflow concentration (mg/l TDS)	0.0
Product flow (Ml/d)	0.0
Product concentration (mg/l TDS)	
Brine Flow (Ml/d)	
Brine concentration (mg/l TDS)	
UNIT COSTS:	
Unit cost of brine disposal(c/m^3)	0 included elsewhere
Unit process op cost (c/m^3)	0
Potable water cost (c/m^3)	0
By-product recovery factor	0
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	8%

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs					
Pretreatment (included in desal)		0.00			
Desalination	0.00	0.00			
Brine disposal (included in desal)		0.00			
Concrete Channel 130Ml/d (R per ...) 1630	11.20	1.14			
Length (km) 11					
Op costs:					
Desalination		0.00			
Brine disposal (included in desal)		0.05			
Maintenance of Channel		0.03			
Total Expenses (Op+Cap)	11.20	1.22			
Income:					
Sale of potable water		0.00			
Sale of By-products		0.00			
Total Income		0.00			
Net Income (including brine disposal)		-1.22			

Total Expenses (neglecting brine disposal)		1.22	0.00	0.00	0.00
Net Income (neglecting brine disposal)		-1.22	0.00	0.00	0.00

Total Expenses (Op only)		0.00	0.00	0.00	0.00
Net Income (including brine disposal)		0.00	0.00	0.00	0.00

	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
No of Years for Capital repayment				
5	3	0	0	0
10	2	0	0	0
20	1	0	0	0
Interest Rate				
8%	1	0	0	0
16%	2	0	0	0
24%	2	0	0	0

Total Expenses

Total Expenses

	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Potable water cost (c/m3)				
200	0	0	0	0
300	0	0	0	0
400	0	0	0	0
600	0	0	0	0
By-product recovery factor				
0	0	0	0	0
100	0	0	0	0
500	0	0	0	0
1000	0	0	0	0

Total Income

Total Income

A.9.8 Strategy 8

A.9.8.1 35Ml/d Capacity Pipiline Transfer to Northern Catchment (No desalination)

Pipeline Transfer 35Ml/d

PLANT PARAMETERS:	
Water Recovery (%)	
Salt Rejection(%)	0 0
Inflow to plant (Ml/d)	
Inflow concentration (mg/l TDS)	0 0
Product flow (Ml/d)	0 0
Product concentration (mg/l TDS)	
Brine Flow (Ml/d)	
Brine concentration (mg/l TDS)	
UNIT COSTS:	
Unit cost of brine disposal(c/m^	0 Included elsewhere
Unit process op cost (c/m^3)	0
Potable water cost (c/m3)	0
By-product recovery factor	0
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	6%

Expenses:		Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs						
Pretreatment (included in desal)			0 00			
Desalination		0 00	0.00			
Brine disposal (included in desal)			0.00			
Pipe from g to Koffiefontei (Ml/c	35	19.01	1 94			
Length (km)	12					
Op costs						
Desalination			0 00			
Brine disposal (included in desal)			0 00			
Op+Main of pipeline			0 27			
Total Expenses (Op+Cap)		19 01	2 20			
Income:						
Sale of potable water			0 00			
Sale of By-products			0 00			
Total income			0 00			
Net Income (including brine disposal)			-2 20			

Total Expenses (neglecting brine disposal)		2 20	0.00	0 00	0 00
Net income (neglecting brine disposal)		-2 20	0 00	0 00	0.00

Total Expenses (Op only)		0 00	0 00	0 00	0 00
Net income (including brine disposal)		0 00	0 00	0 00	0 00

	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
No of Years for Capital repayment					
5	5	0	0	0	
10	3	0	0	0	⟺ Total Expenses
20	2	0	0	0	
Interest Rate					
6%	2	0	0	0	
10%	3	0	0	0	⟺ Total Expenses
24%	5	0	0	0	

	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
Potable water cost (c/m3)					
200	0	0	0	0	
300	0	0	0	0	⟺ Total income
400	0	0	0	0	
500	0	0	0	0	
By-product recovery factor					
0	0	0	0	0	
100	0	0	0	0	⟺ Total income
500	0	0	0	0	
1000	0	0	0	0	

A.9.8.265Ml/d Capacity Pipeline Transfer to Northern Catchment (No desalination)

Pipeline Transfer ##Ml/d

PLANT PARAMETERS:	
Water Recovery (%)	
Salt Rejection(%)	0.0
Inflow to plant (Ml/d)	
Inflow concentration (mg/l TDS)	0.0
Product flow (Ml/d)	0.0
Product concentration (mg/l TDS)	
Brine Flow (Ml/d)	
Brine concentration (mg/l TDS)	
UNIT COSTS:	
Unit cost of brine disposal (c/m^3)	0
Unit process op cost (c/m^3)	0
Potable water cost (c/m3)	0
By-product recovery factor	0
FINANCIAL PARAMETERS:	
No of Years	30
Interest rate	8%

included elsewhere

Expenses:		Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs						
Pretreatment (included in desal)			0.00			
Desalination		0.00	0.00			
Brine disposal (included in desal)			0.00			
Pipe from ## to Koffiefontein (Ml/d)	36	37.04	2.73			
Length (km)	42					
Op costs						
Desalination			0.00			
Brine disposal (included in desal)			0.00			
Op+Main of pipeline			0.40			
Total Expenses (Op+Cap)		37.04	3.24			
Income:						
Sale of potable water			0.00			
Sale of By-products			0.00			
Total Income			0.00			
Net income (including brine disposal)			-3.24			

Total Expenses (neglecting brine disposal)		3.24	0.00	0.00	0.00
Net income (neglecting brine disposal)		-3.24	0.00	0.00	0.00

Total Expenses (Op only)		0.00	0.00	0.00	0.00
Net income (including brine disposal)		0.00	0.00	0.00	0.00

No of Years for Capital repayment	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
5	7	[illegible]	[illegible]	[illegible]
10	5	[illegible]	[illegible]	[illegible]
20	3	0	[illegible]	[illegible]

⟺ Total Expenses

Interest Rate	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
5%	3	0	0	[illegible]
10%	3	0	[illegible]	0
20%	7	0	[illegible]	[illegible]

⟺ Total Expenses

Potable water cost (c/m3)	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
200	0	0	0	0
300	0	0	[illegible]	0
400	0	0	[illegible]	[illegible]
500	[illegible]	[illegible]	[illegible]	[illegible]

⟺ Total Income

By-product recovery factor	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
0	[illegible]	0	0	0
100	[illegible]	[illegible]	0	[illegible]
500	[illegible]	[illegible]	0	[illegible]
1000	[illegible]	0	0	0

⟺ Total Income

A.9.8.3 130Ml/d Capacity Pipeline transfer to Northern Catchment (No Desalination)

Pipeline Transfer 130Ml/d

PLANT PARAMETERS:		
Water Recovery (%)		
Salt Rejection(%)	0.0	
Inflow to plant (Ml/d)		
Inflow concentration (mg/l TDS)	0.0	
Product flow (Ml/d)	0.0	
Product concentration (mg/l TDS)		
Brine Flow (Ml/d)		
Brine concentration (mg/l TDS)		
UNIT COSTS:		
Unit cost of brine disposal(c/m^3	0	Included elsewhere
Unit process op cost (c/m^3)	0	
Potable water cost (c/m3)	0	
By-product recovery factor	0	
FINANCIAL PARAMETERS:		
No of Years	20	
Interest rate	8%	

Expenses:		Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs						
Pretreatment (included in desal)			0.00			
Desalination		0.00	0.00			
Brine disposal (included in desal)			0.00			
Pipe from g to Kaffersprui (Ml/d	130	40.12	4.09			
Length (km)	12					
Op costs						
Desalination			0.00			
Brine disposal (included in desal)			0.00			
Op+Main of pipeline			0.95			
Total Expenses (Op+Cap)		40.12	5.04			
Income:						
Sale of potable water			0.00			
Sale of By-products			0.00			
Total income			0.00			
Net income (including brine disposal)			-5.04			

Total Expenses (neglecting brine disposal)		5.04	0.00	0.00	0.00
Net income (neglecting brine disposal)		-5.04	0.00	0.00	0.00

Total Expenses (Op only)		0.00	0.00	0.00	0.00
Net income (including brine disposal)		0.00	0.00	0.00	0.00

	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
No of Years for Capital repayment				
5	11	0	0	0
10	7	0	0	0
20	5	0	0	0
Interest Rate				
8%	5	0	0	0
16%	8	0	0	0
24%	11	0	0	0

Total Expenses

Total Expenses

	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Potable water cost (c/m3)				
200	0	0	0	0
300	0	0	0	0
400	0	0	0	0
500	0	0	0	0
By-product recovery factor				
0	0	0	0	0
100	0	0	0	0
500	0	0	0	0
1000	0	0	0	0

Total income

Total income

A.10 EXAMPLE OF SPREADSHEETS USED FOR RE-BLEND AND DISCHARGE

The spreadsheets which follow are examples of those used to achieve a target discharge of 300 mg/l, 750 mg/l and 1500 mg/l. The ASTROP® estimations are shown since only the ASTROP® and the AQUA-K® processes are capable of achieving a target discharge of 300 mg/l when the product water is blended back into the main stream.

A.10.1 ASTROP® for re-blend to 300 mg/l

ASTROP

PLANT PARAMETERS:	
Water Recovery (%)	90
Salt Rejection(%)	97
Inflow to plant (Ml/d)	125.3
Inflow concentration (mg/l TDS)	4156.0
Product flow (Ml/d)	112.8
Product concentration (mg/l TDS)	138.5
Brine Flow (Ml/d)	12.5
Brine concentration (mg/l TDS)	40313.2
UNIT COSTS:	
Unit cost of brine disposal(c/m^3)	102.85
Unit process op cost (c/m^3)	332
Potable water cost (c/m3)	200
Gypsum recovery (R/tonne)	100
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	8%

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs					
Pretreatment	33.20	3.38	7.41	8.24	74.14
Desalination	767.49	78.17	170.96	189.95	1709.53
Brine disposal	112.75	11.48	25.11	27.90	251.14
Op costs					
Desalination		151.81	332.00	368.89	3320.00
Brine disposal		4.70	10.29	11.43	102.85
Total Expenses (Op+Cap)	913.53	249.56	545.77	606.41	5457.66
Income:					
Sale of potable water		82.31	180.00	200.00	1800.00
Sale of Gypsum		12.21	26.70	29.67	267.00
Total Income		94.52	206.70	229.67	2067.00
Net Income (including brine disposal)		-155.04	-339.07	-376.74	-3390.66

Total Expenses (neglecting brine disposal)		233.37	510.37	567.07	5103.67
Net Income (neglecting brine disposal)		-138.86	-303.67	-337.41	-3036.67

Total Expenses (Op only)		156.52	342.29	380.32	3422.85
Net Income (including brine disposal)		-62.00	-135.59	-150.66	-1355.85

No of Years for Capital repayment	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
5	385	843	936	8426	
10	293	640	711	6400	⟺ Total Expenses
20	250	546	606	5456	
Interest Rate					
8%	250	546	606	5458	
16%	311	679	755	6792	⟺ Total Expenses
24%	379	828	920	8283	

Potable water cost (c/m3)	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)	
200	95	207	230	2067	
300	136	297	330	2967	⟺ Total Income
400	177	387	430	3867	
500	218	477	530	4767	
Gypsum recovery (R/tonne)					
0	82	180	200	1800	
100	95	207	230	2067	⟺ Total Income
500	143	314	349	3135	
1000	204	447	497	4470	

Costs estimated from information contained in paper
"Application of Seeded Reverse Osmosis in South Africa for the Recovery of Water from CaSO4 Scaling Water"
by GJG Juby, DJC Nel and IW van der Merwe.1996

A.10.2 ASTROP® for re-blend to 750 mg/l

ASTROP

PLANT PARAMETERS:	
Water Recovery (%)	90
Salt Rejection(%)	97
Inflow to plant (Ml/d)	111.9
Inflow concentration (mg/l TDS)	4058.6
Product flow (Ml/d)	100.7
Product concentration (mg/l TDS)	139.8
Brine Flow (Ml/d)	11.2
Brine concentration (mg/l TDS)	40313.2
UNIT COSTS:	
Unit cost of brine disposal	102.00
Unit proceeds of gypsum	300
Potable water cost (c/m3)	200
Gypsum recovery (R/tonne)	600
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	6%

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
Cap costs					
Pretreatment	28.74	5.80	7.41	8.24	74.14
Desalination	488.60	70.24	171.84	191.05	1719.42
Brine disposal	100.73	10.30	25.11	27.90	251.14
Op costs					
Desalination		135.62	332.00	368.89	3320.00
Brine disposal		4.20	10.29	11.43	102.85
Total Expenses (Op+Cap)	606.07	223.35	546.78	607.51	5467.55
Income:					
Sale of potable water		73.53	180.00	200.00	1800.00
Sale of Gypsum		10.91	26.70	28.67	267.00
Total income		84.44	206.70	228.67	2067.00
Net income (including brine disposal)		-138.91	-340.08	-377.84	-3400.55

Total Expenses (neglecting brine disposal)		208.88	511.38	568.17	5113.58
Net income (neglecting brine disposal)		-124.45	-304.68	-338.51	-3046.58

Total Expenses (Op only)		139.82	342.29	380.33	3422.85
Net income (including brine disposal)		-55.38	-135.59	-150.66	-1355.85

No of Years for Capital repayment	Cap + Op Cost/annum (mR)	Annual Cost/m3 entering plant (c/m^3)	Annual Cost/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
5	345	846	939	8451
10	262	641	713	6415
20	223	547	608	5468
Interest Rate				
6%	223	547	608	5468
16%	278	681	757	6809
24%	338	831	923	8307

⟹ Total Expenses

⟹ Total Expenses

Potable water cost (c/m3)	Cap + Op Cost/annum (mR)	Annual Profit/m3 entering plant (c/m^3)	Annual Profit/m3 product (c/m^3)	Annual Cost/m3 brine (c/m^3)
200	84	207	230	2067
300	121	297	330	2967
400	158	387	430	3867
500	195	477	530	4767
Gypsum recovery (R/tonne)				
0	74	180	200	1800
100	84	207	230	2067
500	128	314	349	3135
1000	183	447	497	4470

⟹ Total Income

⟹ Total Income

Costs estimated from information contained in paper
"Application of Seeded Reverse Osmosis in South Africa for the Recovery of Water from CaSO4 Scaling Water"
by GJG Juby, OJC Nel and HV van der Merwe 1996

A.10.3 ASTROP® for re-blend to 1500 mg/l

ASTROP

PLANT PARAMETERS:	
Water Recovery (%)	90
Salt Rejection(%)	97
Inflow to plant (Ml/d)	89.0
Inflow concentration (mg/l TD	4156.0
Product flow (Ml/d)	80.1
Product concentration (mg/l	138.5
Brine Flow (Ml/d)	8.9
Brine concentration (mg/l TD	40313.3
UNIT COSTS:	
Unit cost of brine disposal c/k	102.86
Unit process op cost (c/m^3)	332
Potable water cost (c/m^3)	200
Gypsum recovery (R/tonne)	100
FINANCIAL PARAMETERS:	
No of Years	20
Interest rate	8%

Expenses:	Current Cost (mR)	Cap + Op Cost/annum (mR)	Annual Cost/m^3 entering plant (c/m^3)	Annual Cost/m^3 product (c/m^3)	Annual Cost/m^3 brine (c/m^3)
Cap costs					
Pretreatment	23.64	2.41	7.41	8.26	74.14
Desalination	554.63	56.48	173.87	193.30	1739.73
Brine disposal	80.06	8.15	25.11	27.90	251.14
Op costs					
Desalination		107.80	332.00	368.89	3320.00
Brine disposal		3.34	10.29	11.43	102.86
Total Expenses (Op+Cap)	658.32	178.19	548.79	609.76	5487.88
Income:					
Sale of potable water		58.45	180.00	200.00	1800.00
Sale of Gypsum		8.67	26.70	29.67	267.00
Total Income		67.12	206.70	229.67	2067.00
Net income (including brine disposal)		-111.08	-342.09	-380.10	-3420.88

Total Expenses (neglecting brine disposal)		166.70	513.39	570.43	5133.87
Net income (neglecting brine disposal)		-99.58	-306.69	-340.76	-3066.87

Total Expenses (Op only)		111.14	342.29	380.32	3422.86
Net income (including brine disposal)		-44.02	-135.59	-150.65	-1355.86

No of Years for Capital repayment	Cap + Op Cost/annum (mR)	Annual Cost/m^3 entering plant (c/m^3)	Annual Cost/m^3 product (c/m^3)	Annual Cost/m^3 brine (c/m^3)	
5	276	850	945	8501	Total Expenses
10	209	644	716	6444	
20	178	549	610	5488	
Interest Rate					
8%	178	549	610	5488	Total Expenses
16%	222	684	760	6843	
24%	271	836	929	8356	

Potable water cost (c/m3)	Cap + Op Cost/annum (mR)	Annual Profit/m^3 entering plant (c/m^3)	Annual Profit/m^3 product (c/m^3)	Annual Cost/m^3 brine (c/m^3)	
200	67	207	230	2067	Total Income
300	96	297	330	2967	
400	126	387	430	3867	
500	155	477	530	4767	
Gypsum recovery (R/tonne)					
0	58	180	200	1800	Total Income
100	67	207	230	2067	
500	102	314	348	3135	
1000	145	447	497	4470	

Costs estimated from information contained in paper
"Application of Seeded Reverse Osmosis in South Africa for the Recovery of Water from CaSO4 Scaling Water"
by GJG Juby, DJC Nel and W van der Merwe 1996

APPENDIX B

WATER AND SALT BALANCES WITH AQUABAT MODEL

The procedural steps that were followed to develop a water and salt balance model for this project correspond with the recommended steps in *Best Practice Guideline 1: Water and Salt Balances* (DWAF, 1999). The recommended steps were adapted for the large, complex Vaal Barrage system, which has an existing monitoring system with a substantial amount of data. An indication of these steps is illustrated as a flow diagram in Figure B.1 and will be discussed in more detail below.

B.1 OBJECTIVES

The overarching objectives of the project are discussed in Chapter 1. To achieve these objectives the project has been divided into three main sections, namely:

- Treatment / management options and costs
- Water and salt balances
- Costs to users

These different sections are discussed in detail in the various appendices and the second section is the focus of this appendix.

The main objectives of the water and salt balance are defined as follows:

- To develop a water and salt balance model for the Vaal Barrage region.
- The model must simulate water management strategies for both an average precipitation period and a dry period.
- The model must be able to simulate summer (October – March) and winter (April – September) seasons.
- Return flows and abstraction flows larger than 1 000 Ml/a should be included in the model.
- The model must be able to simulate the changes in water flow and quality in the main tributaries of the Vaal Barrage catchment, if a defined water management strategy is implemented.
- The model must be flexible so that it can be changed easily to simulate various different water management strategies, or "what-if" scenarios.
- The model must be able to do simulations relatively quickly, i.e. within a few minutes.
- The balances should have an accuracy of 70% - 80%.

All the objectives can be achieved with the aid of the software programme AQUABAT, developed by Pulles, Howard and de Lange Inc. The motivation for the use of the software is discussed in Chapter 3.

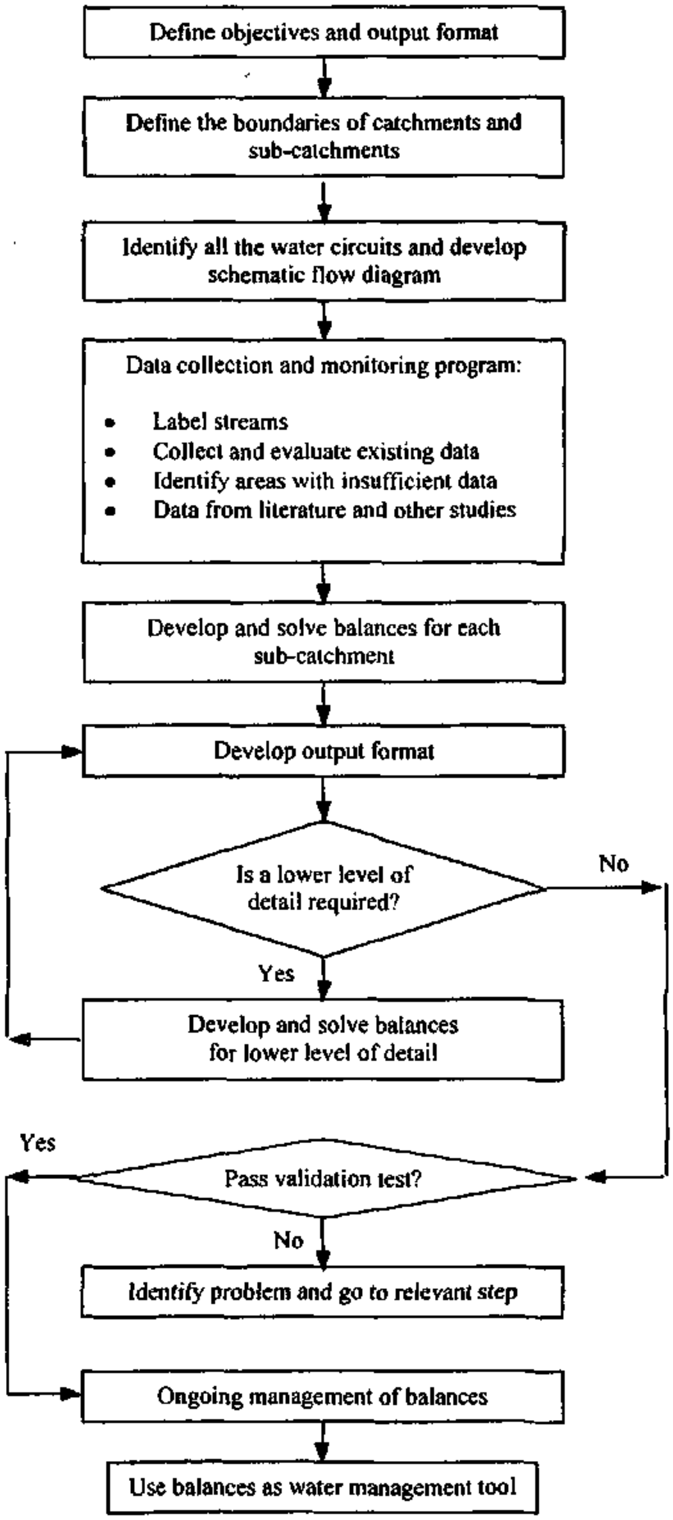


Figure B.1: Procedural steps to develop water and salt balance

The output format for the model was defined during this step and is presented in section B.6.

B.2 CATCHMENT AND SUB-CATCHMENTS BOUNDARIES

The Vaal-Barrage catchment encompasses the incremental catchment that drains into the Vaal River between the Vaal Dam and the Vaal Barrage (DWAF catchment numbers C 210 and C 220) and is illustrated in Figure B.2. This catchment of 8 651 km^2 is one of the most developed areas in South Africa and the streamflows are mainly influenced by industrial, mining and municipal return flows, abstractions, urban runoff and irrigation. The main tributaries are the Blesbokspruit, Suikerbosrand River, Klip River (which includes the Natalspruit and the Rietspruit), Greater Rietspruit and Taaibos River. The catchments and sub-catchments that were defined to develop the water and salt balance model correspond to the different tributaries of the main catchment and are indicated in Table B.1 and Figure B.2. Existing monitoring points influenced the boundaries of the sub-catchments. The catchments were classified as urban or rural for runoff water quality purposes.

Table B.1: Sub-catchments for water and salt balance model

Catchment	Sub-catchment	DWAF Monitoring Point	RWB Monitoring Point	Size (km^2)	Classification
	Blesbokspruit	C2H133	B10	1 502	Urban
	Upper Suikerbosrand River	C2H070	-	1669	Urban
Suikerbosrand River	Lower Suikerbosrand River	C2H004	S2	303	Urban
	Natalspruit	C2H135	N8	392	Urban
	Rietspruit	C2H136	R6	465	Urban
	Upper Klip River	-	K10	883	Urban
Klip River	Lower Klip River	C2H071	K19	532	Urban
Greater Rietspruit	Greater Rietspruit	C2H005	RV2	1123	Rural
Taaibosspruit	Taaibosspruit	C2H014	T1	831	Rural
Vaal River	Vaal River	C2R008	V17	941	Urban

B.3 WATER CIRCUITS AND FLOW DIAGRAM

To define all the relevant water circuits it was necessary to know all the main abstraction and return flows, namely flows that are in the range of 1 000 Ml/a or larger. This step and the next step, namely data collection, were executed in parallel. The relevant abstraction and return flows are indicated in Table B.2. Other relevant flows include:

- Releases from the Vaal Dam
- Diffuse sources, mainly seepage from mines
- Runoff
- Flow from the Vaal Barrage catchment to the middle Vaal River
- Evaporation
- Irrigation
- Bed losses

The flow diagram that was developed for these circuits is indicated in Figures B.3.a – f.

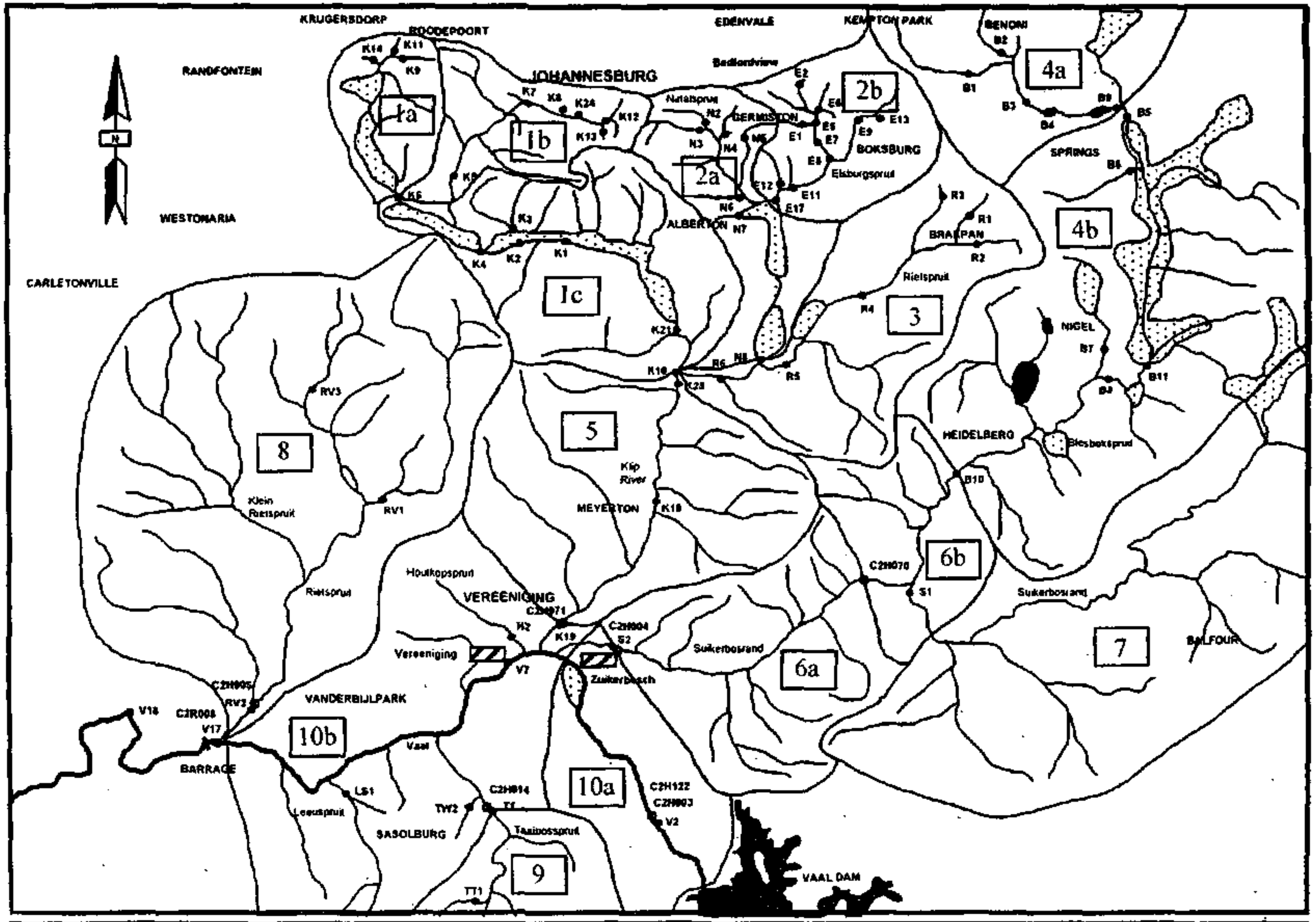


Fig B.2 : Sub-catchment boundaries and loction of monitoring points in Vaal Barrage catchment.

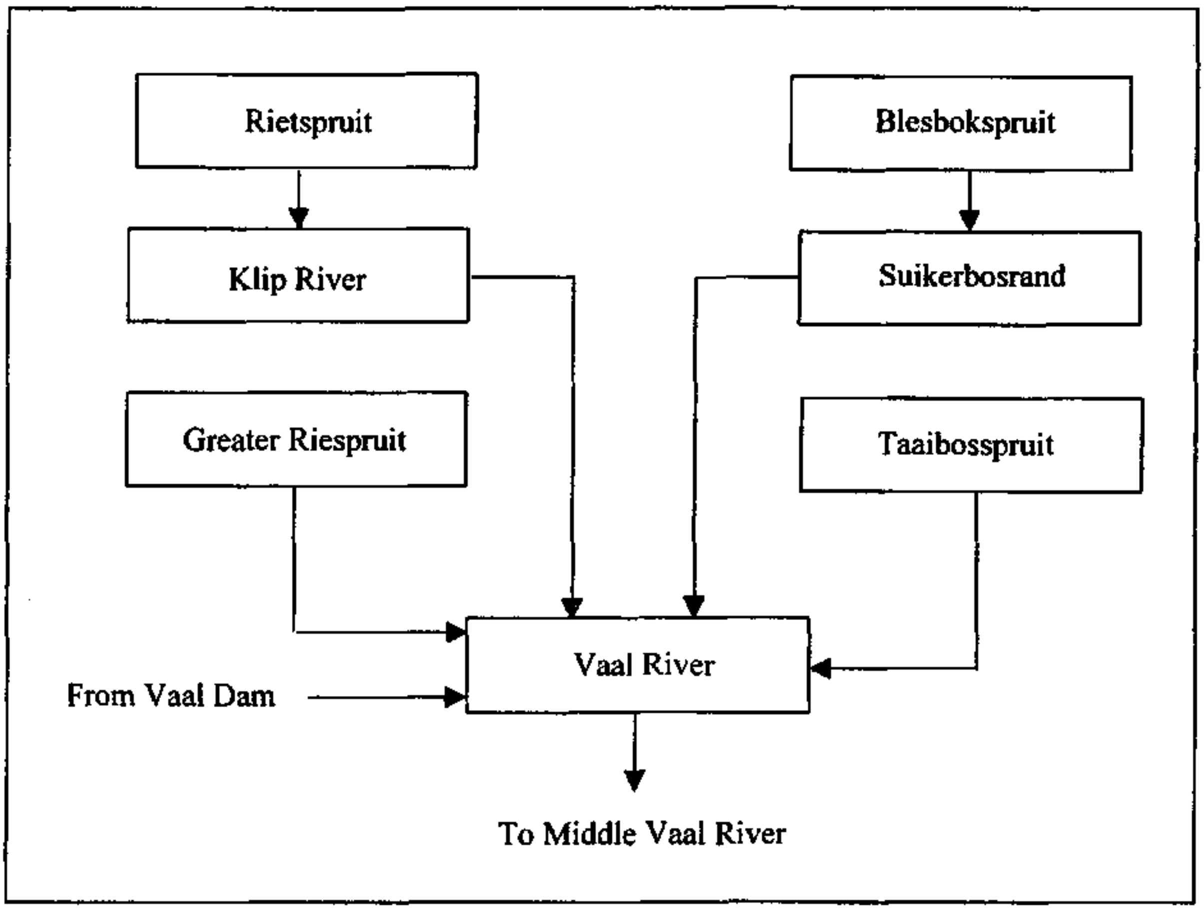


Figure B.3.a: Flow Diagram of Vaal Barrage Water Reticulation System - Total Catchment

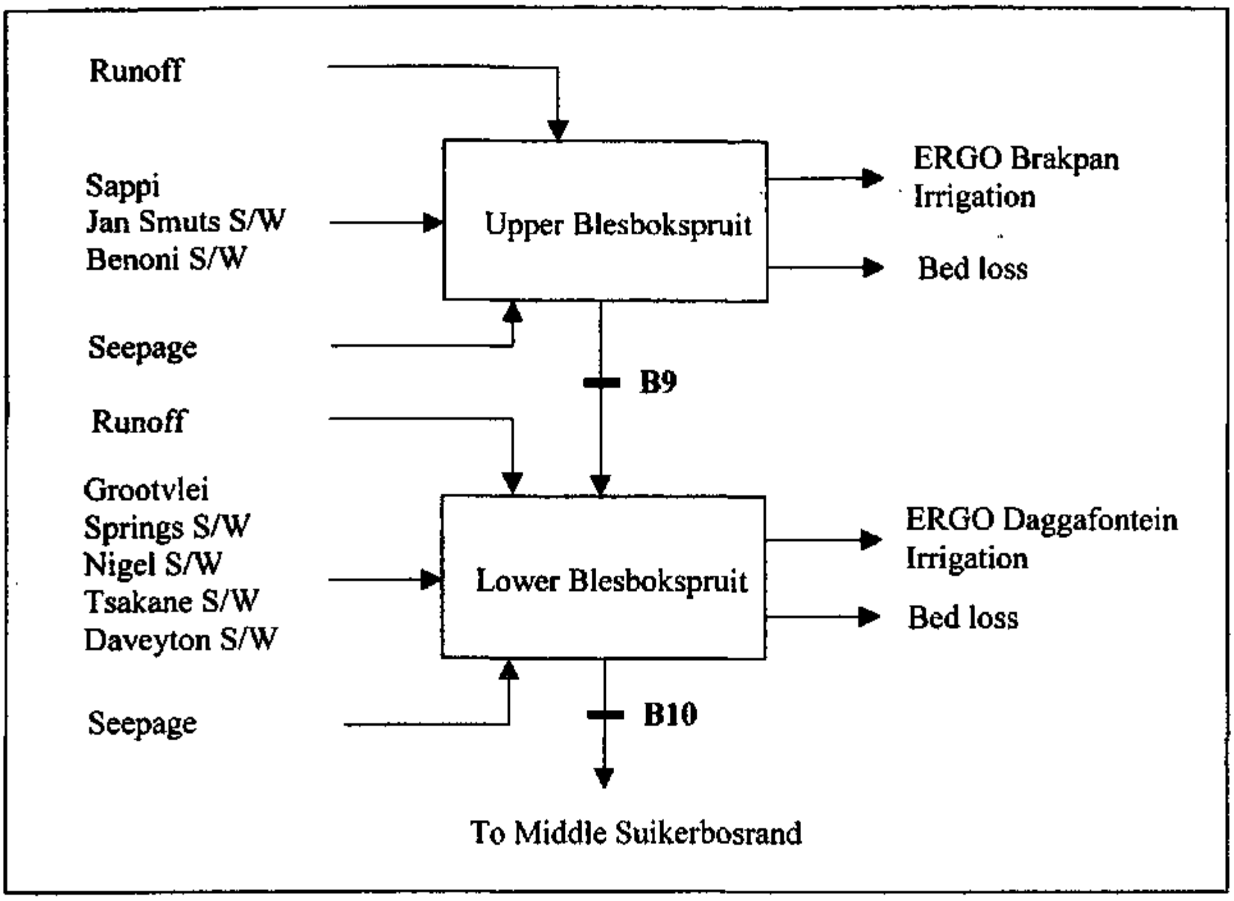


Figure B.3.b: Flow Diagram of Vaal Barrage Water Reticulation System - Blesbokspruit Catchment (Sub-catchments 4a and 4b)

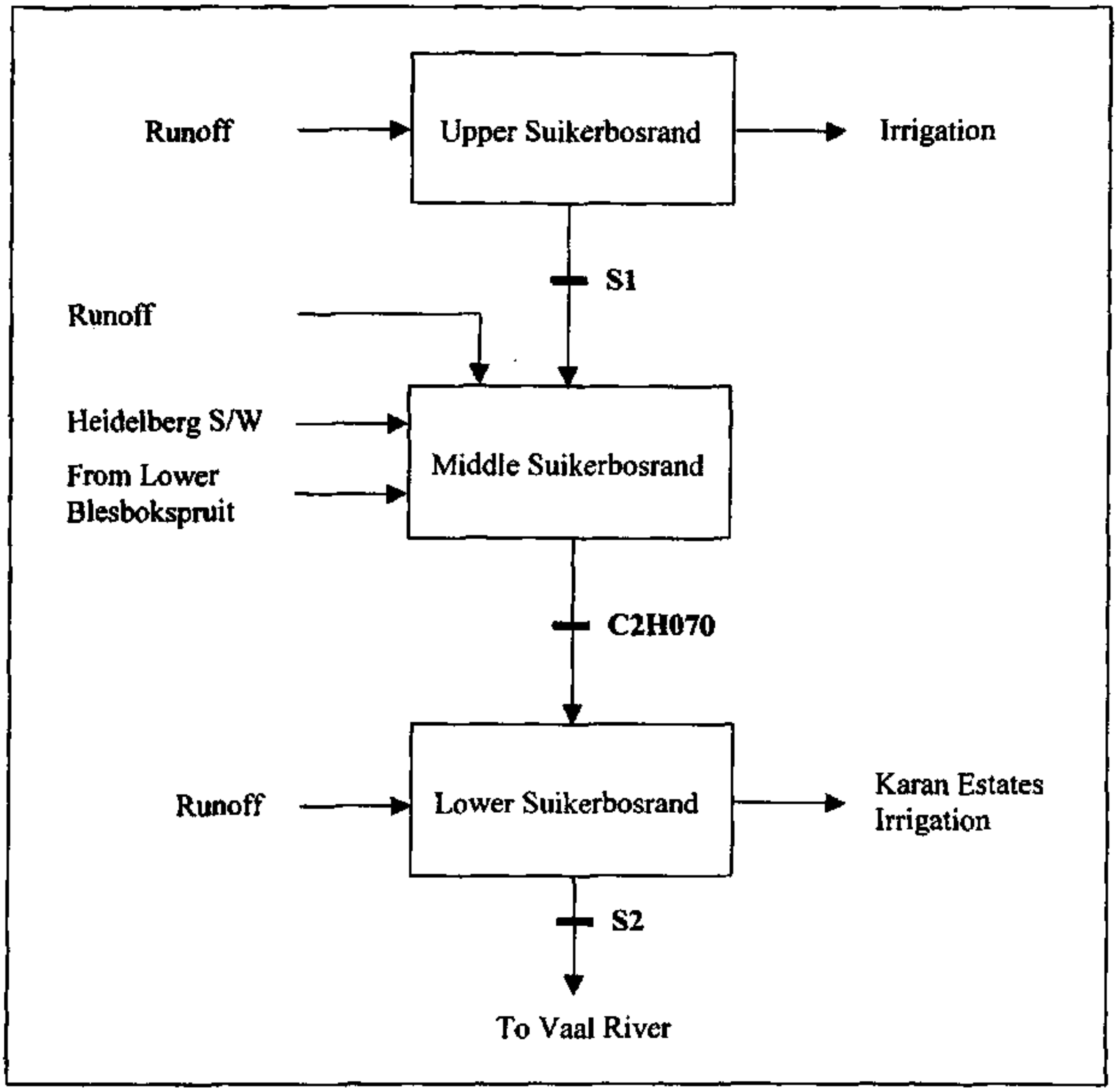


Figure B.3.c: Flow Diagram of Vaal Barrage Water Reticulation System - Suikerbosrand Catchment (Sub-catchments 6a, 6b and 7)

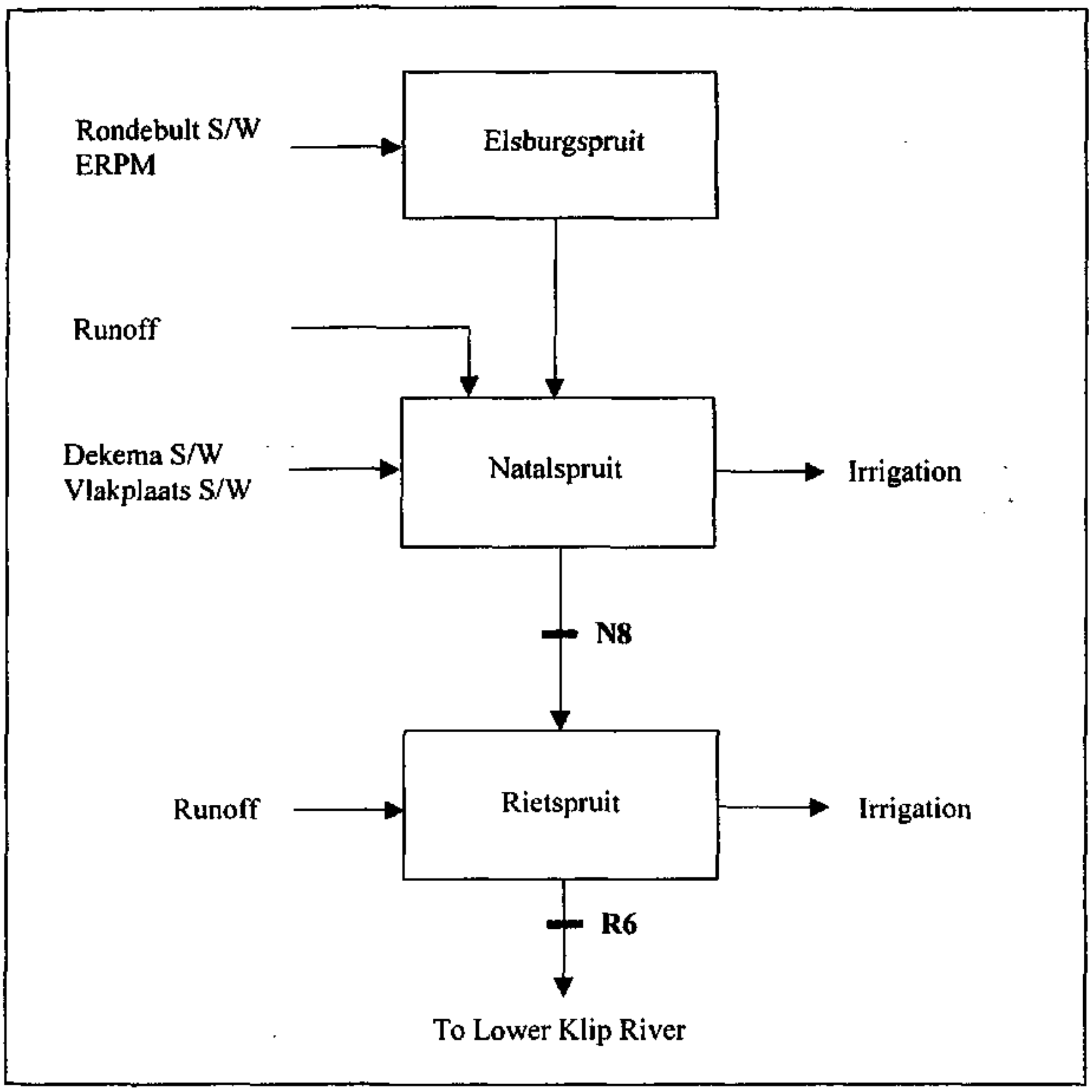


Figure B.3.d: Flow Diagram of Vaal Barrage Water Reticulation System - Rietspruit Catchment (Sub-catchments 2a, 2b and 3)

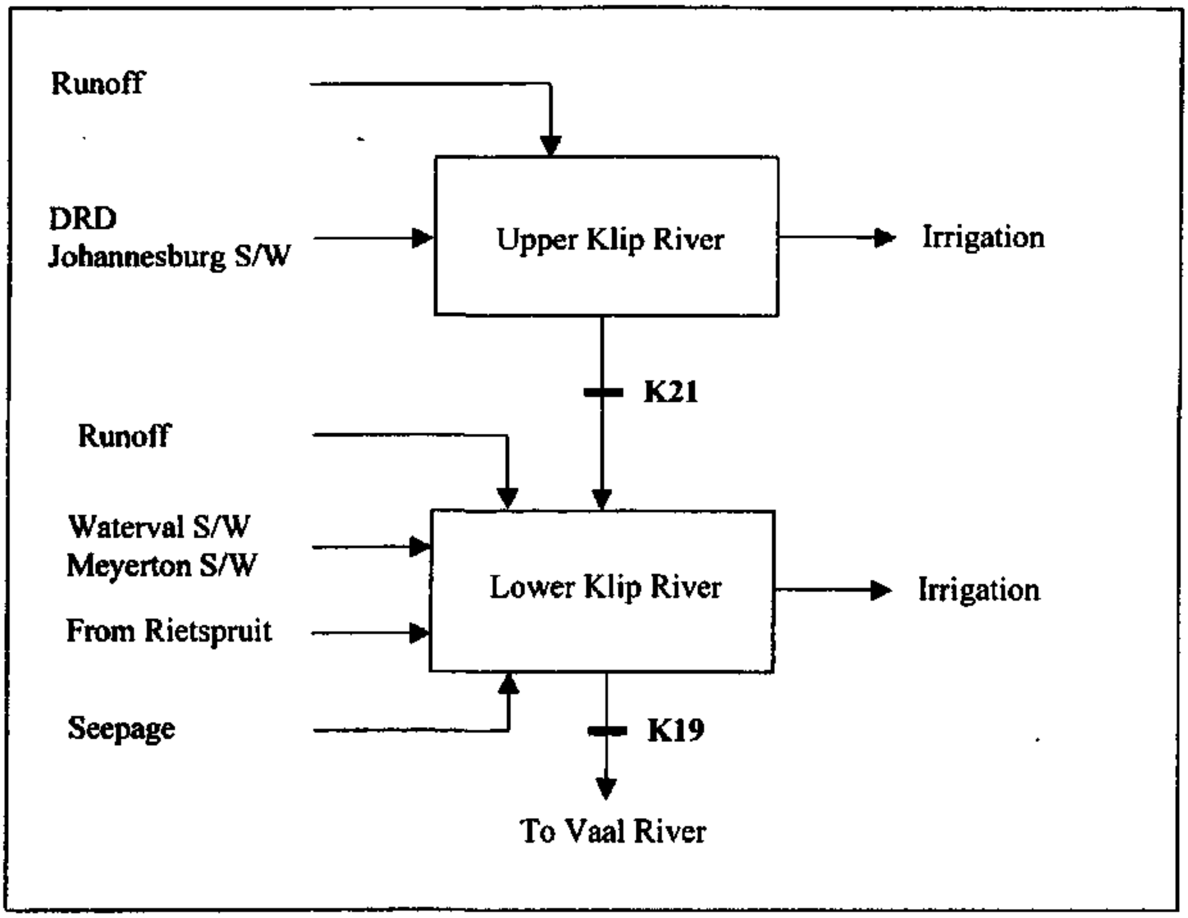


Figure B.3.e: Flow Diagram of Vaal Barrage Water Reticulation System - Klip River Catchment (Sub-catchments 1a, 1b, 1c and 5)

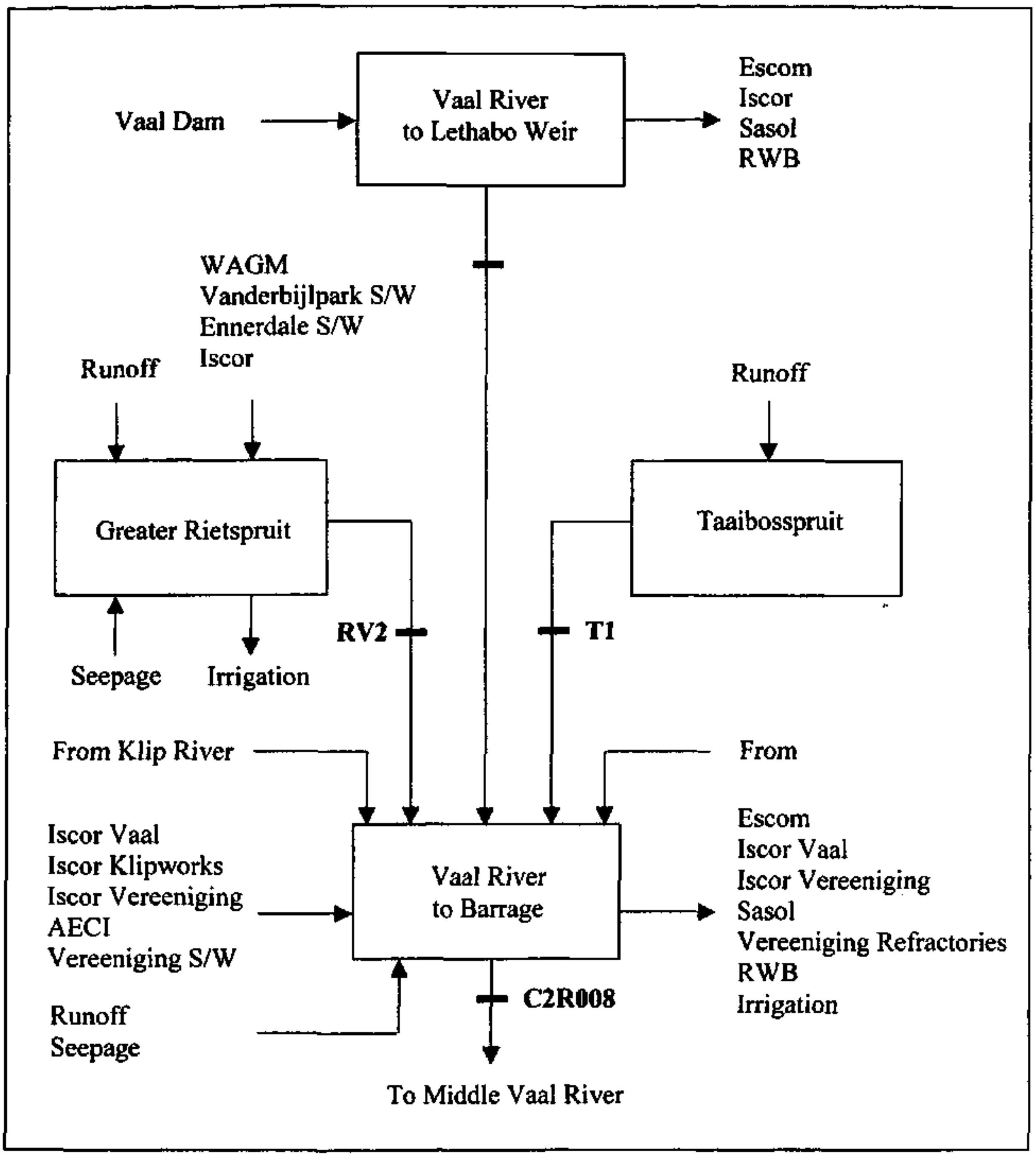


Figure B.3.f: Flow Diagram of Vaal Barrage Water Reticulation System - Vaal River Catchment (Sub-catchments 8, 9, 10a and 10b)

B.4 DATA COLLECTION AND MONITORING PROGRAMME

The following sources were used to collect all the required data and information:

- Water quality and quantity data:
  Department of Water Affairs and Forestry (DWAF)
  Rand Water (RW)
  Mines
  Municipalities
  In-house database

- Meteorological data:

  South African Weather Bureau

- Physical characteristics of the catchment area:

  Literature

B.4.1 Water quality and quantity data

The Vaal Barrage catchment has mainly two monitoring systems that are operated and managed separately by the Department of Water Affairs and Forestry (DWAF) and the Rand Water (RW). Both DWAF and RW have labeled the various monitoring points. The monitoring systems used to focus mainly on flow data, with substantial data available for almost eighty years, and it is only during the last thirty years that substantial water quality data is also collected.

The monitoring system of DWAF has two components, namely the monitoring of rivers and the monitoring of point abstractions and return flows. The main DWAF monitoring points in the river systems are indicated in Figure B.2, while the abstraction and return flows, in the range of 1 000 Ml/a or larger, monitored by DWAF are indicated in Table B.2. Data for the period 1990 – 1997 was assessed for suitability. As the data collection was done during 1997 large knowledge gaps were present in data for the period 1995 – 1997. It was decided that data for the period 1990 – 1994 would be used as the base case, and that flows for new facilities in operation during 1995 – 1997 would be included. Flows for defunct facilities were excluded. This water and salt balance model will be evaluated against monitored data for the period 1990 – 1994, taking into consideration the changes that were made.

The RW's monitoring points monitor mainly rivers and are indicated in Figure B.2.

Not all of the flow data is reliable and an indication of the aspects that influence the interpretation of the data are indicated in Table 3.

Runoff water quality for urban and rural areas were assumed to be 189 mg/l and 163 mg/l for urban and rural areas respectively during summer, and 254 mg/l and 182 mg/l for urban and rural areas respectively during winter (Pulles, 1994).

Table B.2.a: Main return flows in the Vaal Barrage catchment.

Catchment	Description	Summer			Winter		
		Flow (Ml/season)	TDS (mg/l)	TDS Load (t/season)	Flow (Ml/season)	TDS (mg/l)	TDS Load (t/season)
Blesbokspruit and Suikerbosrand	SAPPI	4 524	1 060	4 795	4 590	1 036	4 755
	Jan Smuts S/W	1 220	577	704	1 173	452	530
	JP Marais S/W (Benoni)	1 773	427	757	1 836	427	784
	Rynfield S/W (Benoni)	1 724	429	740	1 623	398	646
	Benoni S/W (Benoni)	1 837	673	1 236	1 865	594	1 108
	Grootvlei	23 400	4 156	97 250	23 400	4 156	97 250
	Springs S/W	1 666	621	1 035	1 933	611	1 181
	Nigel S/W	1 018	454	462	948	428	406
	Tsakane S/W	1 513	537	812	1 533	491	753
	Daveyton S/W	1 855	747	1 386	1 927	766	1 476
	Heidelberg S/W	1 110	484	537	993	480	477
Rietspruit	Rondebult S/W	4 722	1 056	4 986	5 289	984	5 204
	ERPM	2 880	4 285	12 341	2 880	4 082	11 756
	Dekama S/W	3 805	588	2 237	4 430	544	2 410
	Vlakplaats	10 003	501	5 012	11 101	497	5 517
Klip River	DRD	1 260	3 499	4 409	1 260	3 499	4 409
	Johannesburg S/W	65 966	383	25 277	68 795	485	33 372
	Waterval S/W	13 410	502	6 732	13 547	539	7 302
	Meyerton S/W	575	638	367	474	629	298
Greater Rietspruit	WAGM	7 200	814	5 861	7 200	810	5 832
	Vanderbijl S/W	871	548	477	1 252	762	954
	Ennerdale S/W	98	463	45	11	495	5
	Iscor	4 425	1 102	4 876	4 375	1 277	5 587
Vaal River	Iscor Vaal	144	291	42	265	278	74
	Iscor Klipworks	11	301	3	10	328	3
	Iscor Vereniging	220	408	90	188	412	77
	AECI	887	594	527	896	594	532
	Vereeniging S/W	2 026	413	837	2 159	409	883

Table B.2.b: Main abstractions in the Vaal Barrage catchment.

Catchment	Description	Summer Flow (Ml/season)	Winter Flow (Ml/season)	Total Flow (Ml/a)
Upper Blesbokspruit	ERGO Brakpan	741	805	1 546
	Irrigation	450	450	900
Lower Blesbokspruit	ERGO Daggafontein	198	359	557
	Irrigation	1 800	1 800	3 600
Upper Suikerbosrand River	Irrigation	280	280	560
Lower Suikerbosrand River	Irrigation	2 785	2 785	5 570
	Karan Estates	382	383	765
Natalspruit	Irrigation	115	115	230
Rietspruit	Irrigation	5 915	5 915	11 830
Upper Klipspruit	Irrigation	675	675	1 350
Middle and Lower Klipsruit	Irrigation	6 975	6 975	13 950
Greater Rietspruit	Irrigation	955	955	1 910
Vaal River	Escom Lethabo	18 174	17 431	35 605
	Iscor Lethabo	5 448	5 758	11 206
	Sasol Lethabo	8 881	9 052	17 933
	RWB Lethabo	127 970	116 685	244 655
	Escom	545	609	1 154
	Iscor Vaal	6 657	6 360	13 017
	Iscor Vereeniging	203	209	412
	Sasol Barrage	6 057	6 832	12 889
	Vereeiging Refractories	157	158	315
	RWB Vereniging 1 & 2	13 545	12 764	26 309
	Irrigation	2 320	2 320	4 640

Table B.3: Flow monitoring points and their associated problems. (DWAF, 1997)

Catchment	Monitoring Point	Comment
Blesbokspruit	B10	Underestimating low flows. Data since 1981 very unreliable.
	B9	Very inaccurate.
Suikerbosrand	C2H070	Reliable data for flows between 5 and 766 m^3/s.
	S1	No record.
	C2H004 / S2	Reasonably reliable for low and medium flows.
Natalspruit	N8	Not very reliable and closed since 1988.
Rietspruit	R6	Accurate for low flows, but data only available since 1990.
Klip River	C2H071 / K19	Under-estimation of medium and high flows.
Greater Rietspruit	C2H005 / RV2	Data between 1977 – 1984 is not very reliable, while data since 1985 is reasonably reliable.
Taaibosspruit	C2H014 / T1	Reasonable data for low and medium flows.
Vaal River	C2R008	Reliable data.
	C2H003	Reliable data. Superseded by C2H122.
	C2H122	Reliable data. In operation since 1981.

B.4.2 Meteorological data

Precipitation data is based on data collected at 46 rainfall stations distributed over the whole Vaal Barrage catchment. As part of the calibration of the model, the precipitation data for the last twenty-five years has been grouped in 5 year periods and the average for the summer and winter seasons have been calculated. The seasonal average potential evaporation (including evapotranspiration) for each region was determined from the *South African Atlas of Agrohydrology and –Climatology* (Schulze, 1997).

B.4.3 Physical characteristics of the catchment area

The main literature used to determine the physical characteristics of the area include: *Hydrology of the Vaal Barrage catchment: Vaal River System Analysis Update* (DWAF, 1997) and *A Preliminary Situation analysis to Characterise the Impact of Witwatersrand Gold Mines on Catchment Water Quality* (Pulles, 1994). The physical characteristics were mainly relevant for the calculation of runoff, abstractions for irrigation, bed losses and diffuse salt loads from mines (seepage).

The mean annual runoff (MAR) has been calculated for each catchment and has been divided into summer and winter runoff according to the percentage of precipitation during each seasonal period. The runoff was calculated for the base case (period 1990 – 1994), as well as for five-year periods from 1970 – 1994, which was used to calibrate the model. The total annual calculated runoff was compared with values determined by other studies. The physical characteristics of the areas, namely the sizes of dams and permeability of the various regions in a catchment, have been determined from literature (Bailey, 1997). The MAR for the base case (1990 – 1994) is presented in Table B.4.

Table B.4: Sub-catchments' MAR (Ml/season) for the base case

Catchment	MAR Base Case	
	Summer	Winter
Suikerbosrand (C2H004 / S2)	83 742	15 237
Klip River (C2H071 / K19)	81 023	15 370
Greater Rietspruit (C2H005 / RV2)	21 529	4 677
Taaibos (C2H014 / T1)	9 819	2 091
Vaal River (incremental) (C2R008)	19 188	4 400
Total (C2R008)	**215 301**	**41 775**

The estimated flows abstracted in catchment for irrigation is presented in Table B.2.b. These values were determined from a literature survey.

It is known that there are significant bed losses in the Blesbokspruit, due to dolomitic areas along the spruit. These bed losses have not been quantified and it was assumed that up to 50% of the flow that Grootvlei discharged, i.e. 65 Ml/day, is due to water lost in the Blesbokspruit.

Major seepage from mines were identified and quantified, in terms of TDS load, during a situation analysis of the catchment (Pulles, 1994). The range of these estimated loads varies significantly and the values that were used in this study are indicated in Table B.5.

Table B.5: TDS loads added by diffuse sources (seepage from mines).

Catchment	TDS Load (t/a)
Blesbokspruit	28 600
Klip River	95 600
Greater Rietspruit	14 700
Vaal River (incremental)	20 400
Total	**159 300**

B.5 WATER AND SALT BALANCES FOR SUB- AND MAIN CATCHMENTS

With the AQUABAT software a water and salt balance was developed where all the sub-catchments were integrated. With this model the balances for each sub-catchment could be solved, as well as the balances for the larger integrated catchments.

The water and salt balance model was developed for the base case (1990 – 1994) with the data and information collected in the previous steps. The water and salt balances were calculated and compared to measured values at the various monitoring stations for validation, taking into consideration the deficiencies at the various monitoring stations as indicated in Table 3.

Data over a twenty-five year period, namely 1970 – 1994, was used to calibrate the model. The data was grouped into five-year periods. The monitoring station at the Vaal-Barrage was seen as one of the most accurate and reliable monitoring stations for this period and was, therefore, used as a key point in the system for the water and salt balance to comply with. The main portion of abstraction flows (between 60% and 85% - depending on the strategy), which will be influenced by the water management strategies, are drawn from the Vaal River downstream of the confluence with the Klip River and upstream of the Barrage. The accuracy of the costs for water users in the Vaal Barrage, due to the implementation of various water management strategies, will thus mainly depend on how accurate this river reach is modeled. Figure 4.a – 4.c illustrate the simulated water quality and flow at the Vaal-Barrage compared to the measured quality and flow.

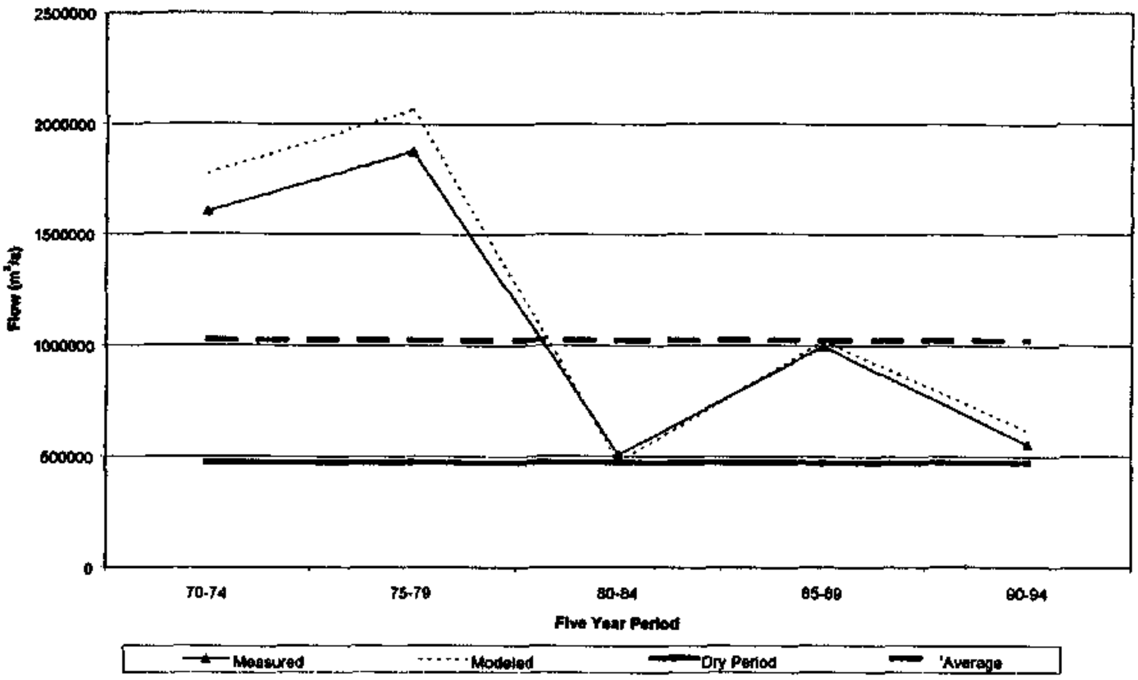


Figure B.4.a: Comparison of simulated and measured water flow at Vaal-Barrage.

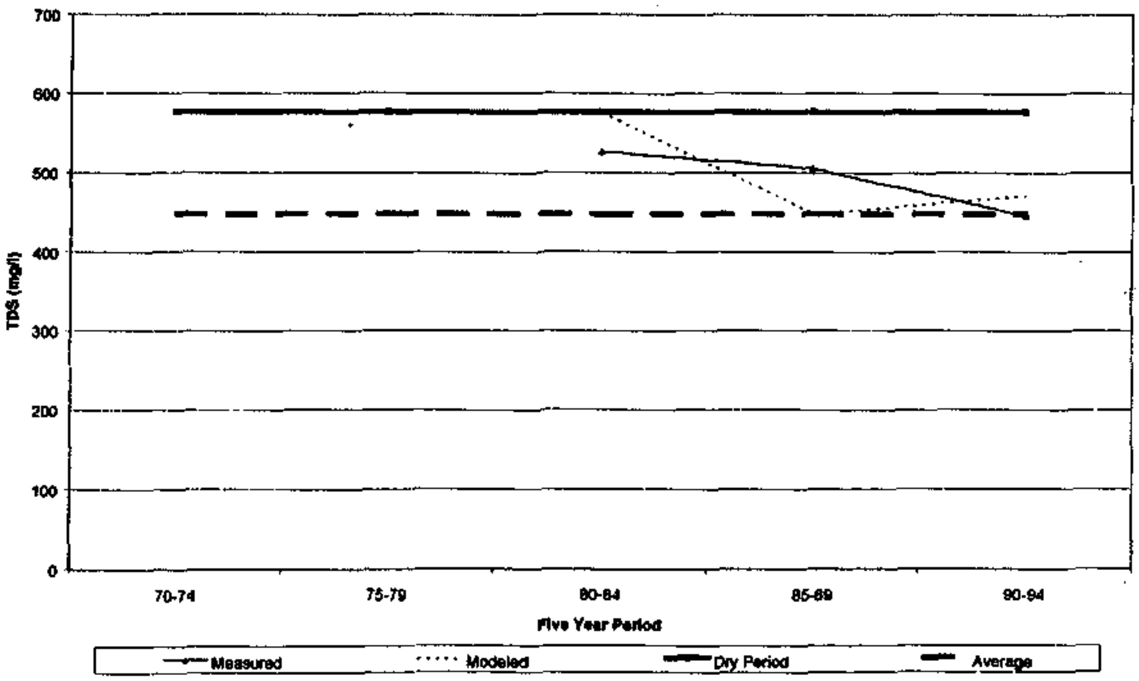


Figure B.4.b: Comparison of simulated and measured water quality (TDS) at Vaal-Barrage.

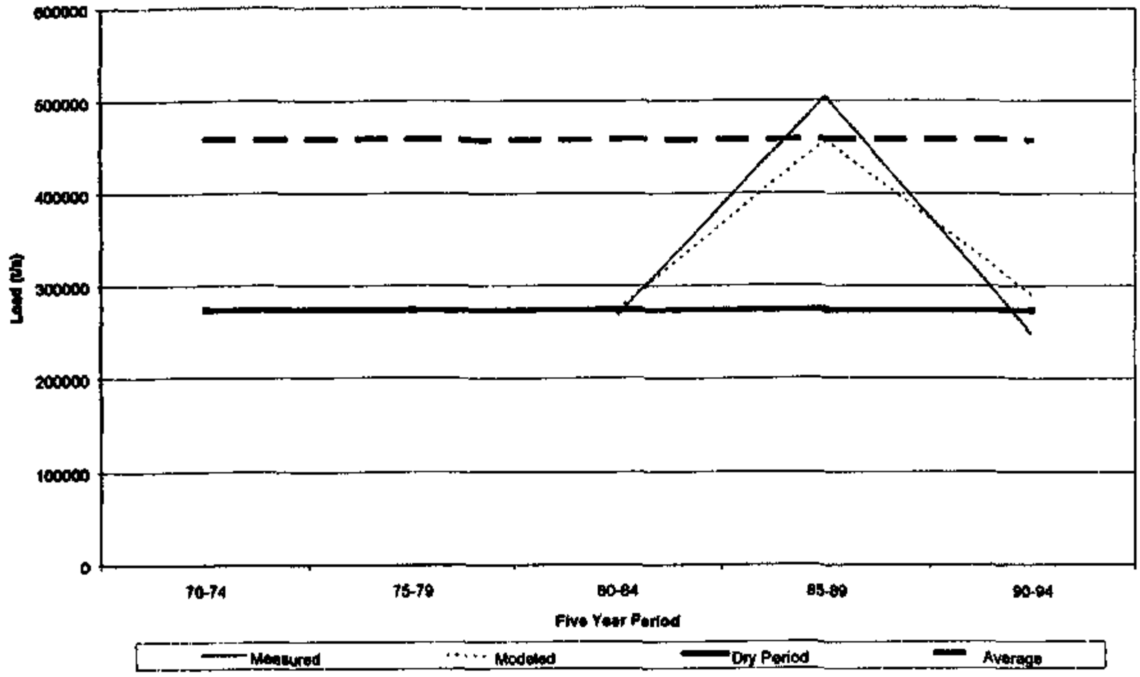


Figure B.4.c: Comparison of simulated and measured salt load at Vaal-Barrage.

Figure 4.a indicates that the model overestimates the flows for extremely high precipitation periods, e.g. 1975 – 1979, by 9.1% and underestimates flows for very dry periods, namely 1980 – 1984, by 7.1%. The accuracy of the model to simulate the hydrology of the catchment is thus within the required 70% - 80% accuracy range.

The simulation of the hydrology has an effect on the simulated TDS concentration and TDS load as indicated in Figures 4.b and 4.c. The model overestimates the TDS concentration and TDS load for the dry period (1980 – 1984) respectively by 9.5% and 2.1%. On the other hand the model underestimates the TDS concentration and load during an average precipitation period (1985 – 1989) respectively by 13.0% and 10.1%. Taking both the water quality and quantity aspects of the water and salt balance in consideration the model can be used with confidence for average to dry 5 year precipitation cycles, and will have an accuracy of at least 80%. It should, however, be noted that this evaluation is based on the limited period of water quality data, namely 15 years.

The aim with the model is to use it to simulate the effects of water management strategies for two periods, an average precipitation period and a dry period, based on the base case. Precipitation data for a seventy-five year period (1920 – 1994) was analysed in all the rainfall regions, as indicated in Table B.4, to determine the 5 year cycle with the lowest mean annual precipitation, for the largest portion of the Vaal-Barrage catchment. From the analysis it was determined that this period was 1980 – 1984. This 5 year cycle falls within the twenty-five year period for which the model has been calibrated. The accuracy of the model for this period is indicated above in Figures 4.a – 4.c. The 5 year cycle 1975 – 1979 is one of the 5 year cycles with the highest MAP for the seventy five year period. These two 5 year cycles, namely 1980 – 1984 and 1975 – 1979, can be used as the boundaries for the lowest and highest MAP and an average MAP can be calculated between these boundaries. The MAP for the 5 year cycle 1985 –1989 is approximately 7% less than this calculated average MAP. As the model is calibrated for the period 1985 – 1989 and the MAP is close to the average MAP it is seen as feasible to use the meteorological data from this period to simulate the water management strategies for the "average cycle". The simulated water qualities for the average and dry 5 year cycles are indicated in Figure 5.a – 6.b.

B.6 WATER AND SALT BALANCE MODEL - WATER MANAGEMENT TOOL

The eight strategies that were modeled are discussed in Chapter 4. For each of the strategies, where treatment is applicable, the effluent quality was modeled for three TDS concentrations, namely 300 mg/l, 750 mg/l and 1 500 mg/l, and scenarios with blending and no blending were also modeled. The modeling was done for both the average 5 year cycle and the dry 5 year cycle. These modeled water qualities, specifically at the abstraction points, were then used in the economic model to determine the change in cost for the users, as discussed in Appendix C.

Table B.6 gives an example of the effect that the different water management strategies has on the water quality in the Vaal River at the Barrage. The table shows the Barrage water qualities as ranges, namely 13% for the average 5 year cycle and 10% for the dry 5 year cycle, to compensate for overestimation during the dry cycle and underestimation for the average cycle. It should also be noted that the table presents scenarios where effluent is treated to 750 mg/l (where applicable).

Table B.6: Water quality at Barrage (mg/l TDS) for water management strategies.

Strategy	Average 5 year cycle		Dry 5 year cycle	
	Summer	Winter	Summer	Winter
No water management strategies	408 - 461	505 - 570	459 - 510	612 - 680
1: Treat Grootvlei effluent*	277 - 313	314 - 355	288 - 320	329 - 365
2: Treat Grootvlei & ERPM effluent*	260 - 294	296 - 334	268 - 298	310 - 345
3: Treat DRD & WAGM effluent*	400 - 452	493 - 557	446 - 495	587 - 652
4: Treat effluent form all four mines*	256 - 289	290 - 328	263 - 292	305 - 339
5: Treat and reuse Grootvlei effluent, and bleed brine during summer into Blesbokspruit	410 - 463	289 - 327	461 - 512	302 - 335
6: Treat smaller Grootvlei effluent flow*	267 - 302	302 - 341	279 - 310	323 - 359
7: Discharge smaller Grootvlei effluent flow (no treatment)	279 - 335	400 - 452	317 - 352	405 - 450
8: No discharge from Grootvlei into Vaal Barrage catchment.	255 - 288	289 - 327	261 - 290	302 - 335

*Effluent treated to 750 mg/l.

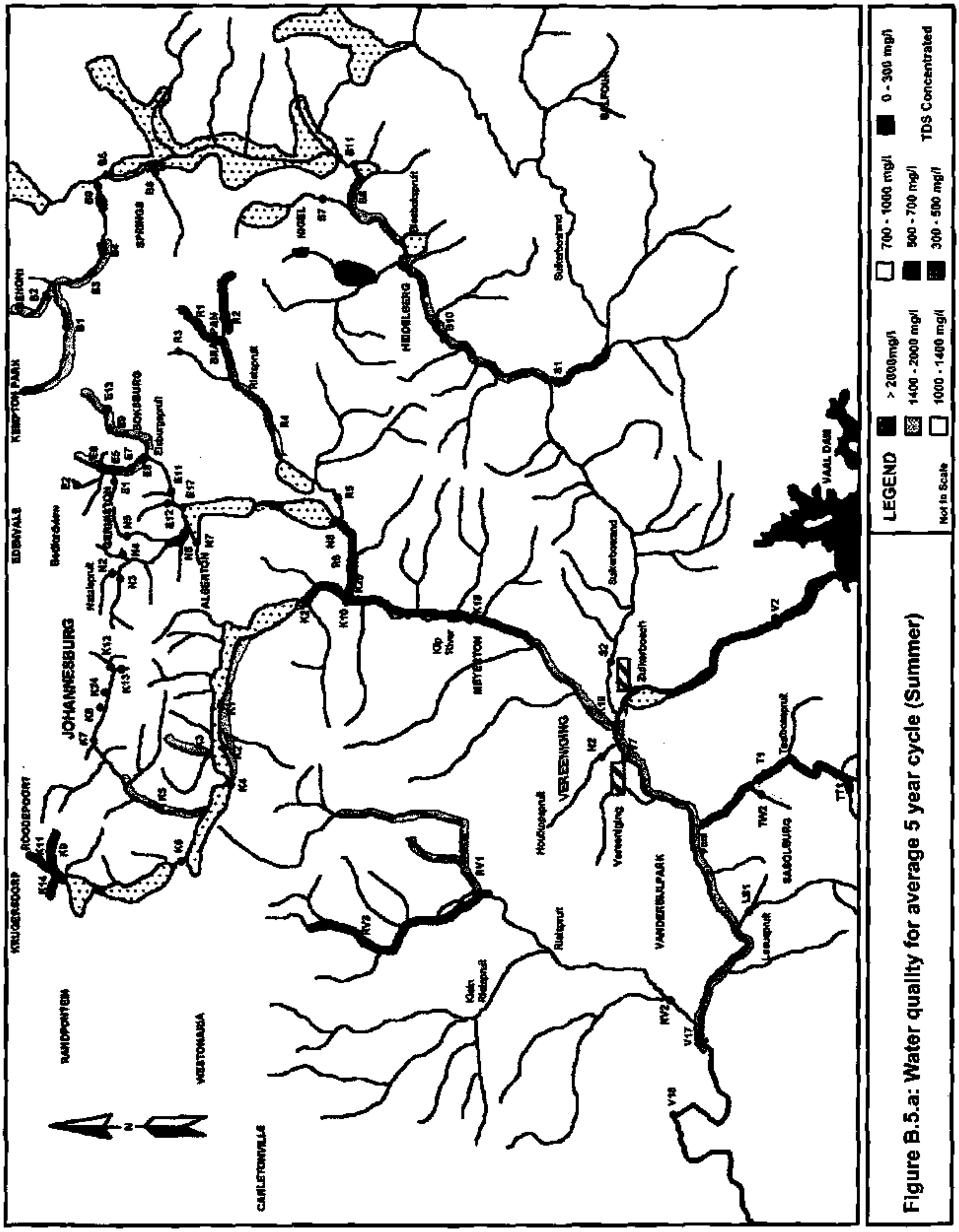


Figure B.5.a: Water quality for average 5 year cycle (Summer)

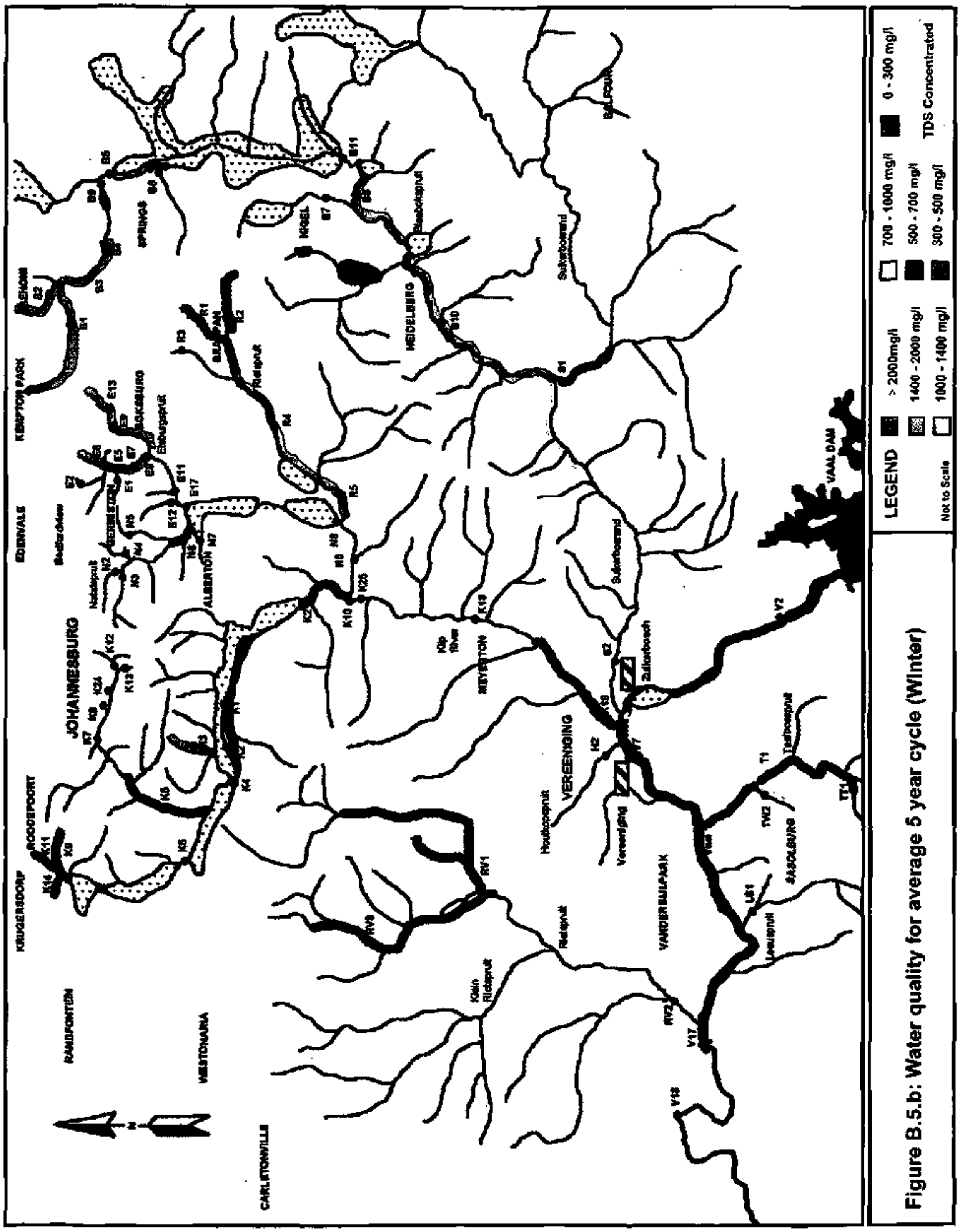


Figure B.5.b: Water quality for average 5 year cycle (Winter)

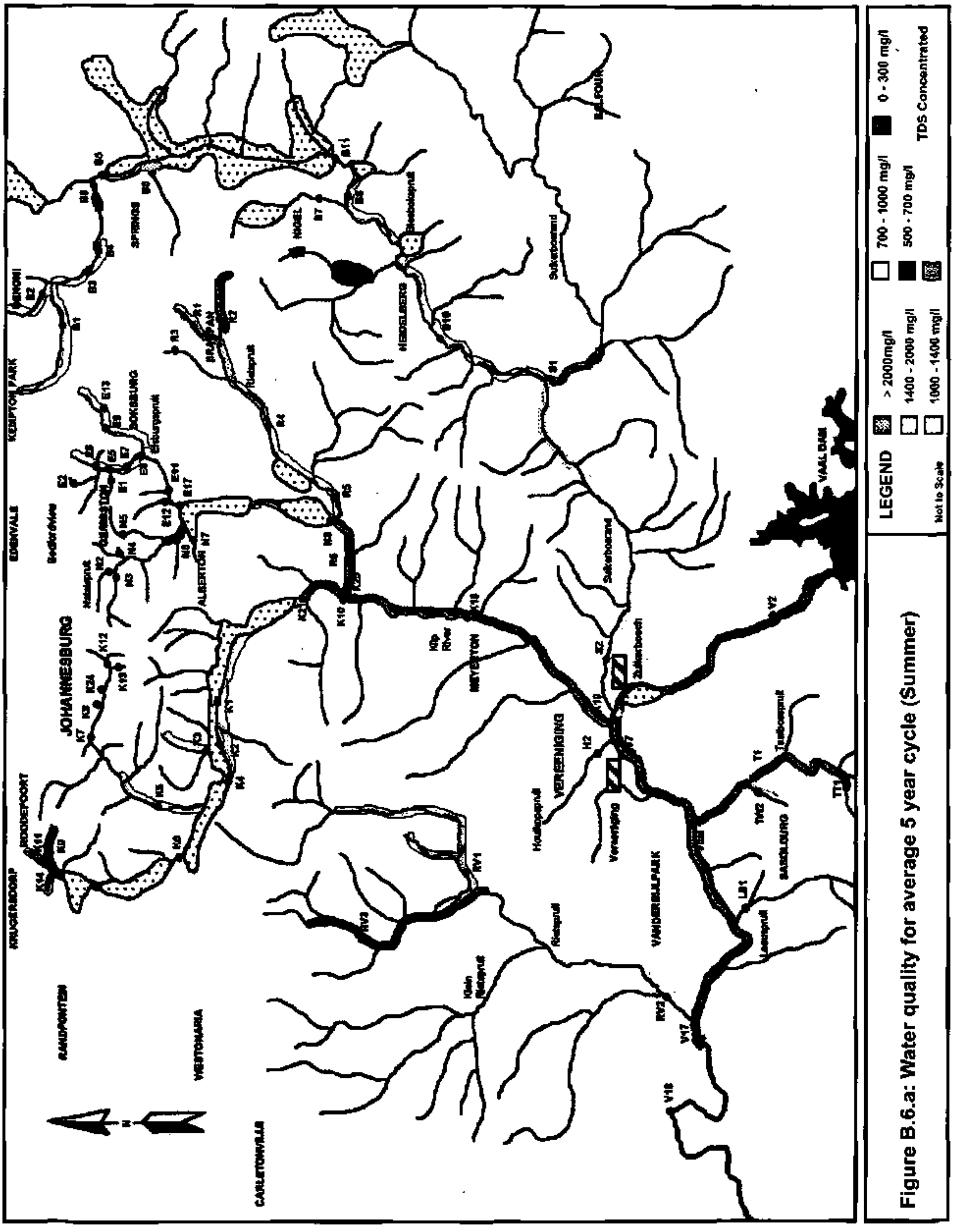


Figure B.6.a: Water quality for average 5 year cycle (Summer)

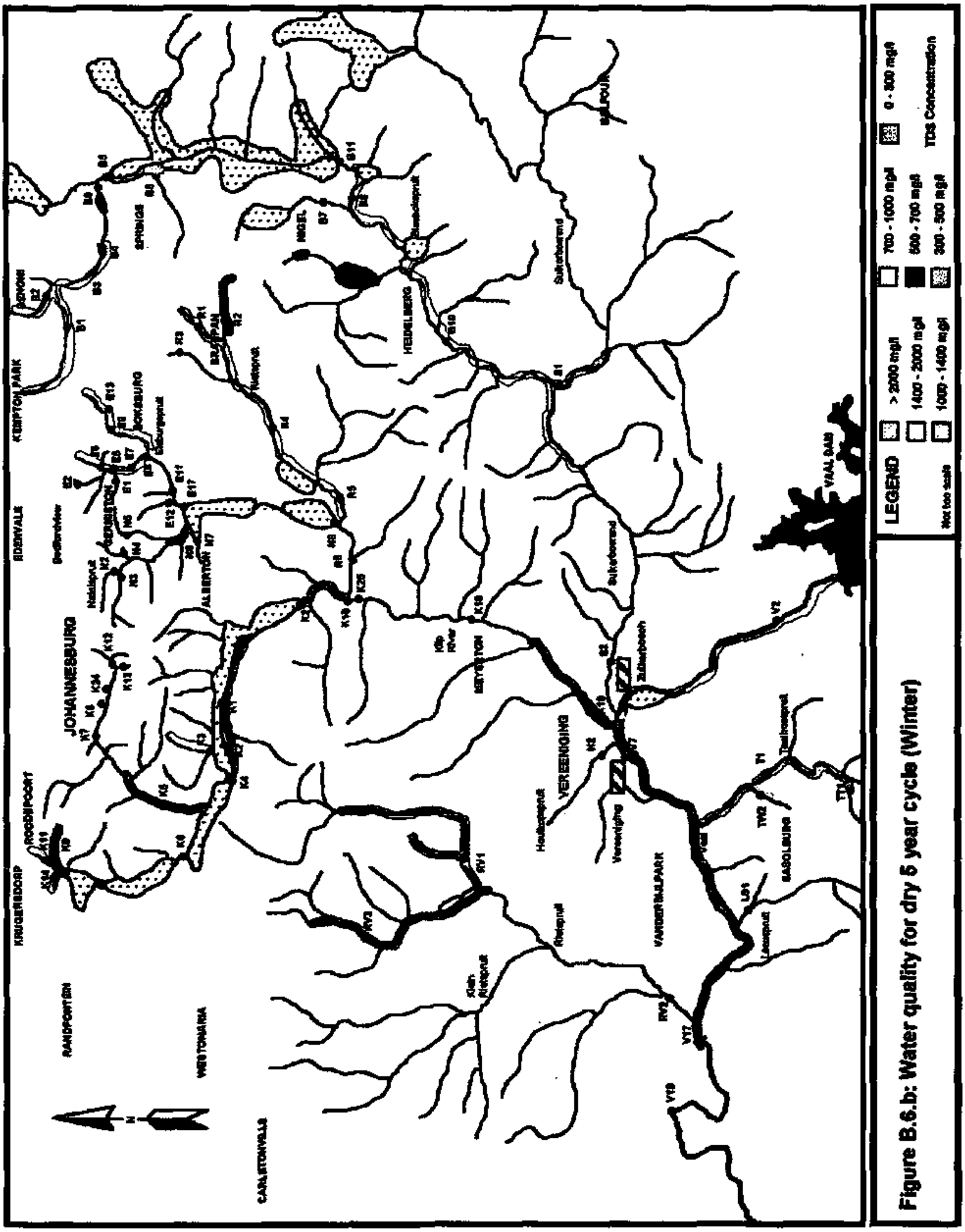


Figure B.6.b: Water quality for dry 5 year cycle (Winter)

B.7 CONCLUSIONS AND RECOMMENDATIONS

The water and salt balance model that was developed for the project with the AQUABAT software simulates the hydro-salinity for the Vaal Barrage catchment with at least an 80% accuracy. The model is specifically calibrated for summer and winter seasons, based on 5 year cycles, and is most suitable for average and dry precipitation cycles. The salinity model is based on data for a limited period, namely 15 years. It is important that water quality data continue to be collected, as this will enhance the reliability of the model. There are also deficiencies at several of the water quantity monitoring points, which renders a large amount of data to be unreliable. It is important that the monitoring system and data collection programmes functions properly, as the water management of the catchment is based on the results from these systems and programmes.

The overall water and salt balance for the Vaal Barrage catchment, based on abstractions and return flow data for the period 1991 – 1997, is summarised below in Tables B.7a - b.

Table B.7.a: Flows into the Vaal Barrage catchment.

Description	Flow (Ml/a)	TDS Load (t/a)
Vaal Dam releases	548 800	96 200
Grootvlei, DRD, ERPM and WAGM	69 500	239 100
Other Mines and Industries	256 600	297 600
Runoff	257 100	47 500
Sub-Total	**1 132 000**	**680 400**

Table B.7.b: Abstractions and releases from the Vaal Barrage catchment.

Description	Flow (Ml/a)	TDS Load (t/a)
To Middle Vaal	615 400	290 400
Rand Water	271 000	55 700
Industry	84 200	24 900
Irrigation and other losses	55 400	433 700
Sub-Total	**1 026 000**	**804 700**

The overall accuracy of the balances is 90% for the water balance and 82% for the salt balance, when the total inflows and outflows of the catchment are compared. This accuracy is within the 70% accuracy that was defined as the minimum for this project.

The water and salt balance illustrate that the four mines contribute approximately 35% of the total salt load and only 6% of the total flow. Approximately 80% of the salt load generated by the four mines, namely WAGM, DRD, ERPM and Grootvlei, emanates from Grootvlei. This implies that if the salt load at Grootvlei could be dramatically reduced then up to 540 t/d out of a total of approximately 664 t/d could be prevented from entering the Vaal Barrage. A 75% reduction in salt load from Grootvlei would translate to a reduction of approximately 20% of the total load entering the Vaal Barrage.

The water and salt balance was used to model the effect if water management strategies, discussed in Chapter 4, are implemented in the Vaal Barrage catchment. The modelling was done for both an average and a dry 5 year cycle, to determine the impact when these conditions prevail. The results from the simulations were used in the economic model to determine the cost for water users, due to the changes in water quality.

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APPENDIX C

THE CALCULATION OF USER COSTS INCURRED BY USING WATER OF VARYING SALINITY LEVELS

C.1 OBJECTIVE

One objective of this project is "to estimate the costs to users of the Vaal River between the Vaal Dam and Balkfontein (Goudveld Water abstraction point) which can be ascribed to point source discharges, for the purpose of comparison with costs of management or treatment". This appendix deals with the approach which was used to calculate these user costs.

C.2 SCHEMA

This appendix comprises:
1. a description of the methodology used to determine users costs under varying salinity levels at the abstraction points of various water users in the Vaal Barrage catchment;
2. a tabulation and discussion of the user costs obtained using this methodology under various scenarios, using salinity levels generated by the Aquabat model (see Appendix B); and
3. a comparison of these user costs against the relevant management or treatment costs (see Appendix A).

C.3 BACKGROUND

Pollution of the water in the study area by the mines is of concern, and it is desired to investigate the costs and benefits of desalinising at source as against passing the problem on to the other users. Scenarios of salinity distribution were generated assuming greater or lesser degrees of abatement by the mines, and the subsequent salinity distribution analysed by the Aquabat model (see appendix B). These distributions give rise to different levels of salinity at various abstraction points in the study area. For each scenario, the costs of desalination and the costs to users of accepting water of the given salinity levels were determined and compared. This section deals with the determination and analysis of the various costs to water users as a result of various salinity levels in their abstracted water generated in these scenarios.

C.4 METHODOLOGY AND OUTPUT

The following major water user groups were identified in the catchment area for the purpose of generating user costs:
1. Residential;
2. Water Boards;
3. Irrigated agriculture;
4. Industry;
5. Mining;
6. Eskom;
7. Sasol; and
8. Iscor.

It should be noted that Item 2 does not represent water used by Water Boards per se, but is a mix of users supplied with water by water boards. In other words it is a representative mix of Residential and Industrial users. The validity of this mix will be visited again below. Curves of cost of abatement (user costs) vs. level of salinity in abstracted water were constructed for each of these user groups as described below. Data was readily available for many user groups between 200mg/l TDS and 1200 mg/l TDS, so these limits were used for all calculations.

C.4.1 User cost curves

Information relating to user costs for user groups 1 to 5 above are available in an unpublished report entitled "Determining the Impact of the Salinisation of South Africa's Water Resources with respect to Economic effects" submitted to the Water Research Commission and the Department of Water Affairs and Forestry by Urban Econ in 1999.

The above report (the Urban Econ report) studied the costs to users of various levels of salinity in their received water. Various sectors of the economy, including households, mining, agriculture, manufacturing and services were addressed. The information contained in the report has therefore been used as the basis for user costs in this study.

Briefly, the Urban Econ approach was to interview a sample of respondents in each sector to determine how their actual costs would vary in the face of increasing water salinity levels. In the case of households, use was made of a sample of respondents who had recently moved from an area of low water salinity to one where the salinity was substantially higher. They were then interviewed to determine how their everyday costs had changed as a direct result of the increase in water salinity. As a result it was possible to obtain actual user costs for the various sectors interviewed.

In using data from the Urban Econ report in this study, a major assumption is that the mix of users in each sector in the Vaal catchment is similar to that in the study area used by Urban Econ (the Middle Vaal). It is recognised that the assumption that this mix is also representative of the entire Vaal Barrage catchment is somewhat heroic. However, it must be *borne in mind that is used as a starting point to investigate the* Vaal Barrage user costs, rather than a definitive setting down of costs. Studies such as that undertaken by Urban Econ are both costly and time-consuming, and it was not felt that such an undertaking was justified in the context of this study. As this type of data is very scarce, it is not feasible to subject this assumption to sensitivity analysis, but it is felt that the data will be accurate to within the overall levels of accuracy applicable to the report findings as a whole.

Large industries were not covered by the Urban Econ report, so a different approach was used to derive cost curves for Eskom, Iscor and Sasol (user groups 5, 6 and 7 above). The approach taken in this study was to analyse desalinisation costs appropriate to each of these users, taking their particular water quality requirements into account. Water usage was divided into three purity levels, ranging from de-ionised water (for boiler usage) through potable water to service water, and costs of desalinating to meet these requirements were calculated and a user cost for each salinity level was obtained by taking a weighted average of the water usage in each category for each industry.

The final cost curves which emerged as a result were tabular in form and are illustrated in Table C.1 below.

Table C.1: Costs of Combating Various Levels of Salinity for Various Water Users in R/Ml of Water Used

Sector	TDS							
	200 (mg/l)	400 (mg/l)	500 (mg/l)	600 (mg/l)	800 (mg/l)	1 000 (mg/l)	1 200 (mg/l)	1 300 (mg/l)
Residential	0	1 269	1 903	2 537	3 806	5 075	6 344	6 978
Water boards	0	1 196	1 823	2 456	3 620	4 784	5 949	6 531
Eskom	0	159	239	318	477	636	795	875
Sasol	0	159	239	318	477	636	795	875
Iscor	0	105	158	210	315	420	525	578
Irrigation	0	0	0	323	323	347	370	381
Industry	0	179	352	559	650	740	831	876
Mining	0	35	51	57	85	122	175	201

The same data in graphical form is presented below in Figure C1. An issue which stands out very clearly from a study of the graph, is that costs to households and water boards are higher by roughly an order than costs to other water use sectors. Therefore areas which contain many residential users are going to be more sensitive to increases in salinity levels than other areas.

Initial cost data was only available at discrete salinity levels between 200 mg/l and 1200 mg/l in 200 mg/l TDS steps. However, in this study the discrimination was improved to give steps of 10 mg/l TDS by means of linear interpolation.

C.4.2 Approach

A spreadsheet model was used as the basis for bringing all this input data together, and evaluating final user costs for each scenario studied.

A start was made by analysing the status quo situation, before any scenarios of local mine desalination were considered.

To do this, the following inputs were obtained from Pulles, Howard and de Lange and the Aquabat model:

- All major water abstractors in the catchment;
- Quantities of water abstracted in an average rainfall year and in a dry year; and
- Salinity levels facing each abstractor.

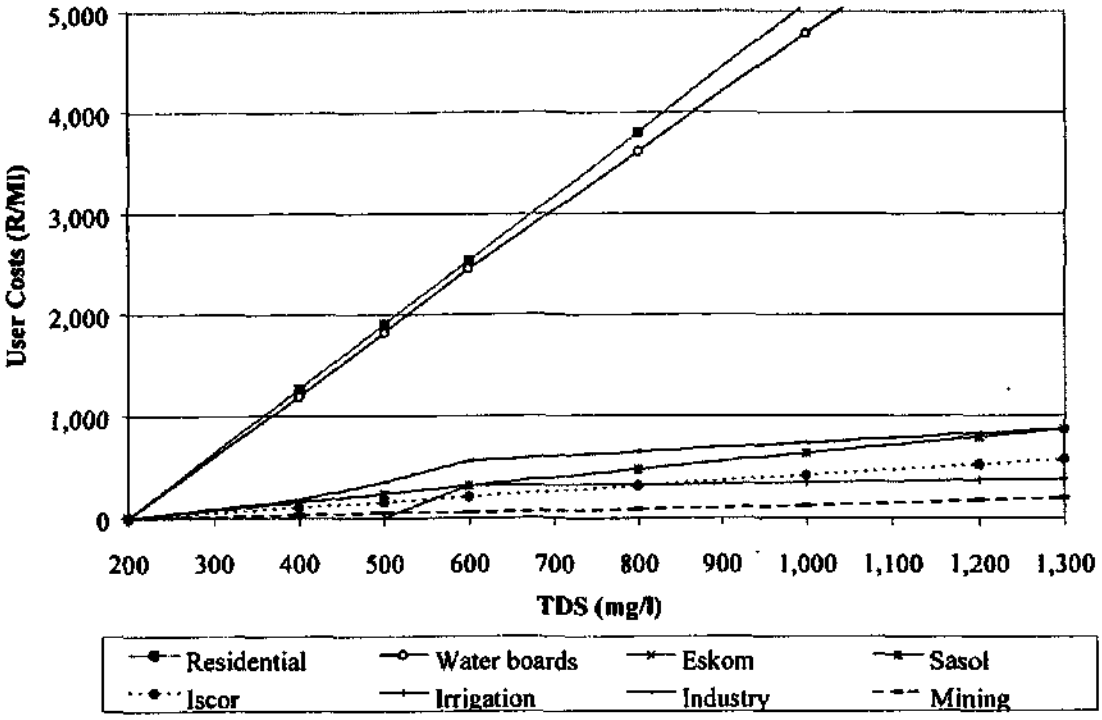

Figure C.1: User Cost Curves

Table C.2: Details of Water Users Studied

River	Abstractor	Flow	Costs	% by Volume	% by Costs
Klein Rietspruit	Irrigation	11 830	0	3	0
Middle Klip River	Irrigation	13 950	0	3	0
Vaal River	Sasol from Lethabo Pump Station	17 933	0	4	0
Vaal River	Sasol from Vaal Barrage	12 889	2 278 931	3	6
Vaal River	Rand Water Lethabo abstration (incl. Iscor/Escom)	244 655	1	61	0
Vaal River	Rand Water Vereeniging intakes No. 1&2	26 309	34 641 772	7	84
Vaal River	Iscor Vaal from Vaal Barrage	13 017	1 497 227	3	4
Vaal River	Escom Lethabo Power Station	35 605	0	9	0
	Sub-total	376 188	38 417 931	94.3	92.9
Total Catchment	**All Abstrators**	398 932	41 336 527		

In order to simplify the approach somewhat, especially as it was anticipated that many scenarios might have to be evaluated, it was decided to exclude abstractors who each took less than 2% of the total abstractions in the catchment. This approach accounted for 94.3% of the water used, and 92.9% of the user costs incurred, using an average year as the basis, as shown in Table C.2.

Making use of the user costs curves described above, user abstraction levels, and the salinities pertaining in an average year and a dry year, it was possible to calculate the costs to each group of abstractors of combating the salinity levels present in their received water. These costs, which were all calculated as annual costs in 1998 Rands, are presented in the Tables C.3 and C.4.

Table C.3: Status Quo User Costs During an Average Year

Catchment	Description	Average Year			
		TDS (mg/l)		User Costs (R/a)	
		Summer	Winter	Summer	Winter
Klein Rietspruit	Irrigation	583.5	697.5	284 210	355 262
Middle Klip River	Irrigation	283.5	697.5	284 210	· 355 262
Vaal River	Sasol from Lethabo Pump Station	282.0	258.0	564 832	359 817
Vaal River	Sasol from Vaal Barrage	583.5	697.5	1 829 820	2 661 406
Vaal River	Rand Water Lethabo abstration (incl. Iscor/Escom)	282.0	258.0	61 215 295	34 885 650
Vaal River	Rand Water Vereeniging intakes No. 1&2	583.5	697.5	31 551 095	38 036 005
Vaal River	Iscor Vaal from Vaal Barrage	583.5	697.5	1 328 072	1 636 110
Vaal River	Escom Lethabo Power Station	282.0	258.0	1 155 866	692 882
Total				98 213 399	78 982 395

Table C.4: Status Quo User Costs During a Dry Year

Catchment	Description	Dry Year			
		TDS (mg/l)		User Costs (R/a)	
		Summer	Winter	Summer	Winter
Klein Rietspruit	Irrigation	658.5	819.0	355 262	356 578
Middle Klip River	Irrigation	658.5	819.0	355 262	356 578
Vaal River	Sasol from Lethabo Pump Station	282.0	258.0	564 832	359 817
Vaal River	Sasol from Vaal Barrage	658.5	819.0	2 166 892	3 313 178
Vaal River	Rand Water Lethabo abstration (incl. Iscor/Escom)	282.0	258.0	61 215 295	34 885 650
Vaal River	Rand Water Vereeniging intakes No. 1&2	658.5	819.0	37 209 586	46 951 735
Vaal River	Iscor Vaal from Vaal Barrage	658.5	819.0	1 572 716	2 036 790
Vaal River	Escom Lethabo Power Station	282.0	258.0	1 155 866	692 882
Total				104 595 712	88 953 210

C.4.3 Scenarios

Eight strategies were developed by the team for analysis and presented to this model for user cost evaluation. For the purpose of illustrating this model, twelve scenarios were selected from these strategies. They are named and numbered for the purpose of this appendix as follows:

Scenario	Mine	Description	Strategy
1	Grootvlei	300 mg/l discharge	1 Aqua-K ave. year
2	Grootvlei	750 mg/l discharge	1 Aqua-K ave. year
3	Grootvlei	1500 mg/l discharge	1 Aqua-K ave. year
4	Grootvlei	zero discharge	1 Aqua-K ave. year
5	Grootvlei	1500 mg/l discharge	1 Savmin dry year
6	Grootvlei	300 mg/l discharge	1 Aqua-K dry year
7	Grootvlei	750 mg/l discharge	1 Aqua-K dry year
8	Grootvlei	1500 mg/l discharge	1 Aqua-K dry year
9	Grootvlei	zero discharge	1 Aqua-K dry year
10	Grootvlei/ERPM	1500mg/l discharge	2 Savmin dry year
11	Grootvlei	summer brine bleeding	5 Sparro dry year
12	Grootvlei	lower discharge	7 none dry year

These scenarios represent a mixture of the following criteria, and include some dry year and some average year situations:

- Cleanup at Grootvlei to a maximum discharge of 300 mg/l;
- Cleanup at Grootvlei to a maximum discharge of 750 mg/l;
- Cleanup at Grootvlei to a maximum discharge of 1500 mg/l;
- Cleanup at Grootvlei to a zero discharge state

The new salinity levels which would be faced by water users as a result of the clean-up represented by these scenarios were calculated by Aquabat and used to calculate new user costs for each scenario, which were calculated in the same format as the status quo costs above. The differences between the new user costs and the status quo user costs represented the total user costs (in fact, a user saving) associated with each scenario.

Note that the impact on user costs for each scenario is calculated as the difference between the cost of the scenario and the status quo cost. This amounts to a reduction in user costs as a consequence of implementing the desalinisation proposed in each scenario. This "user impact" is negative, (it in fact amounts to a saving in user costs as a result of the clean-up which has taken place on site) but is expressed positively for ease of comparison with the costs of desalination later.

Thus, if desalination costs equal user impact, then there is a break-even situation; the economic impact is neutral. If desalination costs are less than the user impact, then the economic impact is positive, and the scenario should be considered. If desalination costs are greater than the user impact, then the economic impact is negative and the scenario should not be considered.

Details of the user costs relating to these scenarios calculated as described above are presented below in Table C.5.

C.4.4 Sensitivity

It has already been mentioned that the model is sensitive to the presence of large numbers of households in the area, as these carry disproportionately large user costs. Thus over- or under-estimating residential abstractions will have a disproportionate effect on the values calculated for user impacts.

The model tested for sensitivity to variations in TDS levels presented to it. All scenarios were tested and found to react uniformly to these changes. A table of results relating to the average of all scenarios is given below as Table C.6.

It will be seen that if TDS levels are overstated by 35% then costs will be overstated by 44%. If TDS levels are understated by 35% then costs will be understated by 42%. Therefore although there is a slight sensitivity to changes in TDS levels, the model can be considered to be quite robust in the context in which it is being used.

C.5 FINAL RESULTS

The purpose behind developing the user cost savings, or user impacts detailed above was to be able to compare these with the actual costs of implementing the on-site desalination associated with each scenario. The result of this exercise is most easily demonstrated by the following histogram, Figure C2, in which these two quantities are contrasted for each scenario.

The significance of this comparison is fully developed in the main report; this histogram is only presented here for the sake of completeness.

Table C.5: Details of the User Costs for Each Scenario

Scenario number	TDS of return flow (mg/l)	Desalination costs	User cost savings
1	300	113 023 066	44 346 623
2	750	100 291 752	39 898 022
3	1 500	78 810 973	31 771 827
4	0	24 269 804	44 346 623
5	1 500	127 937 672	38 521 837
6	300	113 023 066	58 919 212
7	750	100 291 752	51 808 049
8	1 500	78 810 0973	35 726 265
9	0	24 269 804	59 812 232
10	1 500	139 678 558	39 524 831
11	0	78 755 871	40 728 469
12	0	728 732	16 353 129

Table C.6: Sensitivity of User Impacts to Changes in TDS

Sensitivity Analysis	Percentage change in output						
% Change in TDS	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
-35	-52	-47	-37	-54	-38	-48	-44
-25	-30	-26	-23	-32	-28	-30	-28
-10	-7	-8	-10	-10	-9	-8	-9
0	0	0	0	0	0	0	0
10	14	12	11	14	17	16	18
25	34	34	34	30	28	31	29
35	46	47	45	44	42	41	41
Sensitivity Analysis (Cont.)	Percentage change in output						
% Change in TDS	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12		Average
-35	-36	-48	-37	-39	-42		-44
-25	-32	-30	-30	-26	-35		-29
-10	-10	-8	-12	-9	-11		-9
0	0	0	0	0	0		0
10	18	18	17	19	19		16
25	29	31	27	33	21		30
35	40	43	38	44	35		42

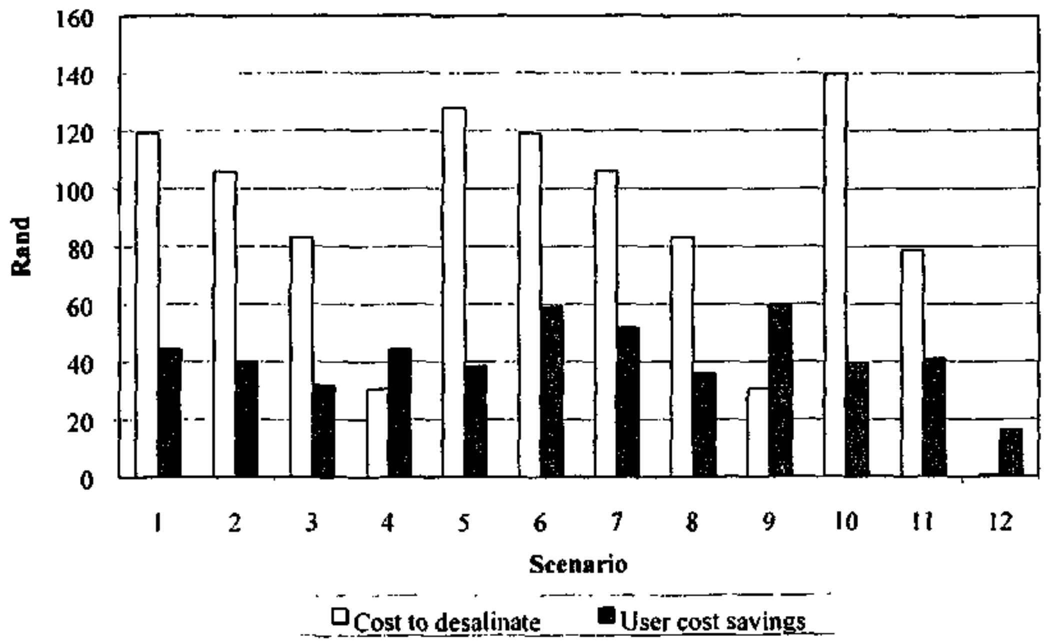

Figure C.2: Histogram of Desalination Costs vs. User Impacts

C.6 REFERENCES

Urban Econ. 1999. *Determining the impact of the Salinisation of South Africa's Water Resources with respect to Economic Effects.* Unpublished report submitted to the Water Research Commission and the Department of Water Affairs and Forestry. Pretoria.

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