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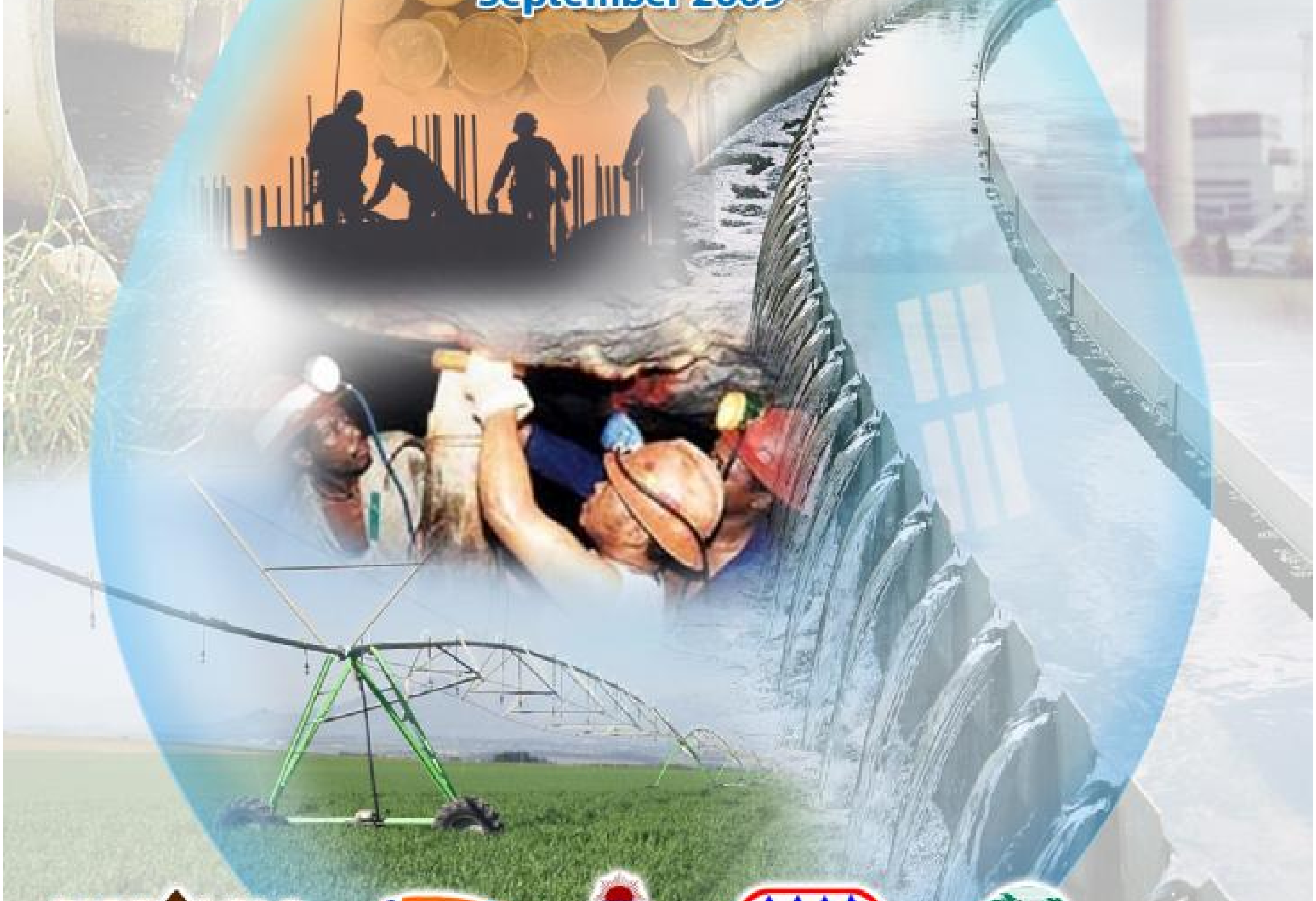
Development of an Integrated Water Quality Management Plan for the Vaal River System

Task 5

Water Quality Economic Impact Modelling

September 2009



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Development of an Integrated Water Quality Management Plan for the Vaal River System

TASK 5:

WATER QUALITY ECONOMIC IMPACT MODELLING

FINAL REPORT

Directorate National Water Resource Planning
Department of Water Affairs and Forestry

September 2009

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EXECUTIVE SUMMARY

Introduction

One of the outcomes of the study is the setting of Resource Water Quality Objectives (RWQO) for the main stem of the Vaal River and the major tributaries. The setting of the RWQO is an economic balance between water user and ecological water quality requirements on the one hand and the costs of the mitigation measures to achieve the RWQO on the other. The approach to the assessment of the water quality management strategies is a comparison of the economic dis-benefit due to the water quality received by the users and the cost of a particular management strategy. The purpose of this report is to describe the approaches and algorithms used to calculate the economic dis-benefits used in the assessment of the water quality management strategies.

The categories of users considered in the economic analysis include:

- the domestic sector;
- the agricultural sector;
- the power generating sector; and
- the industrial sector (Sasol)

Domestic Sector

The calculation for the water quality dis-benefits for the domestic sector was based on the Water Research Commission studies undertaken by Urban Econ and the Human Sciences Research Council (HSRC) for salinity impacts. These studies provided the changes in cost of households moving from the Upper Vaal where water with low TDS concentrations are supplied to the users to the Middle Vaal where high TDS water is supplied. The costs included in the analysis were the impacts on:-

- Plumbing, geysers and domestic appliances.
- The use of soaps, detergents and softeners.
- Fabrics

The costs were given for different household types. The Stats SA population figures were related to the different household types and the costs per household were determined for the Sedibeng Water, Rand Water, Midvaal Water and the Frances Baard water service providers (WSP). The costs for each WSP are given in **Table E1.** The total annual costs calculated for each WSP were expressed as the cost per unit volume of water used for each mg/ℓ that the TDS concentration changes from the base line concentration. The change in concentration used was 390 mg/ℓ that occurred in the HSRC study.

Table E1: 2001 Total Cost, annual water use and the unit cost per mg/l per m^3 of water used per WSP

WSP	Total annual cost (2001 R)	Annual volume (2001) (million m^3/annum)	Cost Cents per m^3 per mg/ℓ (2001)	Cost Cents per m^3 per mg/ℓ (2006)
Rand Water	1 986 617 736	1 134	0.449	0.572
Sedibeng	109 702 253	63	0.446	0.568
Midvaal	63 149 265	42	0.385	0.490
Frances Baard	58 624 968	35	0.429	0.546

Agriculture Sector

The objective of the economic model is to simulate, in financial terms, the agricultural production of the main irrigation areas that are supplied with water from the Vaal River, and then to examine different scenarios for various enterprise mixes at different levels of water quality. In order to do this the amount of land under irrigation needs to be estimated, along with the main enterprises grown. The building blocks of the economic model will be the gross margins for the main enterprises. The main crop types grown are grapes, citrus, maize, cotton, wheat, pasture/lucerne and ground nuts. The net income per hectare for the different crop types for different TDS concentrations are given in **Table E2.** The areas of the different crops and the TDS concentrations of the irrigation water as modelled for the different water quality management scenarios were then applied to the enterprises drawing water from Vaal River main stem to determine the loss in income due to salinity changes. A spreadsheet model was developed to read in the model results to calculate the water quality dis-benefits.

Table E2: Net income per hectare for different crops for different values of TDS concentration (mg/ℓ)

TDS (mg/ℓ)	Lucerne	Maize	Wheat	Cotton	Groundnut	Grapes	Citrus
200	3 839	5 757	3 666	238	1 367	58 619	10 045
400	3 839	5 757	3 666	238	1 367	58 619	10 045
600	3 839	5 757	3 666	238	1 367	58 619	10 045
800	3 839	5 390	3 666	238	1 367	53 943	8 507
1000	3 347	4 626	3 666	238	1 367	48 098	5 304
1200	2 762	3 863	3 666	238	1 367	42 253	2 101
1400	2 177	3 099	3 666	238	1 122	36 408	-1 102
1600	1 592	2 335	3 666	238	247	30 563	-4 305

Power Stations

The impact of the changes on the power station costs was determined in conjunction with Eskom. The costs of different salinity intake water for each of the power stations receiving water from the Vaal River System were assessed. The results are given in Appendix A for each of the power stations.

Industries (Sasol)

Sasol was approached to determine the impact of different water quality input water on their Secunda and Sasolburg plants. After consultation with Sasol, the approach agreed upon was that Sasol would accept the current water quality as acceptable and any increase in TDS concentration would be treated before use in the process. A side stream would be treated to achieve a blend that was the same as the current intake water quality.

The treatment process was desalination using reverse osmosis. The brine was treated in a crystalliser with the waste disposed at a hazardous waste site. The costs determined for the different plants are given in **Table E3** and **Table E4** for Sasolburg and Secunda respectively.

Table E3: Estimated total capital investment, O&M cost associated with the different scenarios (Sasolburg)

Parameters	Scenario (TDS conc)		
	1 (208 mg/l)	**2 (294 mg/l)**	**3 (450 mg/l)**
Capital investment cost (R million)			
- UF/RO plant	R47.4	R85.4	R113.2
- E/C plant	R117.5	R188.2	R235.7
- Total	R164.9	R273.6	R348.9
Operations and maintenance cost (R million/year)			
- UF/RO plant	R18.3	R40.0	R58.3
- E/C plant	R3.6	R8.0	R11.7
- Waste disposal	R13.7	R30.0	R43.7
- Total	R35.6	R78.0	R113.7
Unit cost :			
- Capital investment for side stream treatment (R million per Mℓ/day capacity)	R14.9	R11.2	R9.8
- Unit operating cost of side stream treatment (R/m^3 treated)	R8.79	R8.79	R8.79
- Current raw water cost (R/m^3 intake)	R2.36	R2.36	R2.36
- Incremental operating cost associated with desalination (R/m^3)	R1.74	R3.82	R5.56

Table E4: Estimated total capital investment, O&M cost associated with the different scenarios (Secunda)

Parameters	Scenario (TDS conc) 1 (208 mg/l)	2 (249 mg/l)	3 (285 mg/l)
Capital investment cost (R million)			
- UF/RO plant	R129.7	R194.3	R238.2
- E/C plant	R262.7	R363.0	R427.4
- Total	R392.4	R557.3	R665.6
Operations and maintenance cost (R million/year)			
- UF/RO plant	R69.8	R119.7	R157.0
- E/C plant	R14.0	R23.9	R31.4
- Waste disposal	R52.3	R89.8	R117.8
- Total	R136.1	R233.4	R306.2
Unit cost :			
- Capital investment for side stream treatment (R million per Mℓ/day capacity)	R9.2	R7.6	R7.0
- Unit operating cost of side stream treatment (R/m^3 treated)	R8.77	R8.77	R8.77
- Current raw water cost (R/m^3 intake)	R2.36	R2.36	R2.36
- Incremental operating cost associated with desalination (R/m^3)	R1.46	R2.51	R3.29

Conclusions

The following conclusions can be made as a result of this investigation :-

- The unit domestic sector costs exclude the economic impact on the industries that are directly supplied by a WSP. These are generally small water users. If there are large water users sensitive to water quality then the approach used in assessing Sasol should be applied to these industries. A possible application of this approach is Sappi Enstra supplied by Rand Water.

- Herold (pers. comms) was a member of the study team which undertook an economic assessment of the dis-benefit of salinity on the water users in 1987. The analysis included some of the larger industrial water users. The unit cost in 1987 Rands was 0.06 c/m^3/(mg/ℓ). Applying the CPI to convert to 2006 Rands gives a unit cost of 0.54 c/m^3/(mg/ℓ) which is comparable to the unit costs calculated in this study.

- The reduction in gross margins for the agricultural sector only starts when the soil salinity reaches 600 mg/ℓ for the more sensitive crops. Thereafter there is a sharp reduction in the gross margins with increasing soil salinity. A factor has been included in the model which converts the TDS concentration of the irrigation water to soil salinity. The factor depends on the soil types and the leaching fraction. For a typical leaching fraction of 15% to 20% applied at Vaalharts, a factor of 1.5 is considered reasonable.

- The assessment of the power stations showed that for the current water qualities, Eskom will not have to invest any capital to be able to operate. Only Tutuka Power Station may require an evaporator/crystalliser if the ashing facility cannot cope with the additional effluents.

- The additional operating costs for the power stations from the base EC of 20 mS/m are relatively low for the current 95 percentile intake water quality (EC of 25 mS/m).

- The approach used to assess the impact on the two Sasol plants is not optimal. The accuracy of the costs is adequate to provide an initial assessment of the efficacy of the water quality management options. If the use of poorer quality water by Sasol is found to be economically attractive then the costs should be revisited.

DOCUMENT INDEX

Reports as part of this project:

Bold type indicates this report.

Report Index	Report number	Report title
1		Inception Report
2	P RSA C000/00/2305/1	Water Quality Status Assessment
3	P RSA C000/00/2305/2	Salinity Balance
4	P RSA C000/00/2305/3	Integration of Resource Water Quality Objectives
5	**P RSA C000/00/2305/4**	**Water Quality Economic Impact Modelling**
6	P RSA C000/00/2305/5	Evaluation of Water Quality Management Scenarios
7	P RSA C000/00/2305/6	Monitoring Programme
8	P RSA C000/00/2305/7	Water Quality Management Strategy

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1 INTRODUCTION

The water resources of the Vaal River System are an important asset to the country and its people, supporting major economic activities and a population of about 12 million people. The Vaal River System comprises the C primary drainage region within the water management basins of South Africa and spans four water management areas (WMAs), *viz.* the Upper, Middle, part of Lower Vaal and part of the Upper Orange (Modder Riet catchment) WMAs. Due to the cascading orientation and associated inter-dependency of these WMAs, it is vital that the water resources of this river system are managed in an integrated manner to achieve a balance between meeting specific water user and use requirements in each WMA as well as in fulfilling the transfer obligations between these WMAs, and the donating and receiving WMAs that form part of the larger integrated system. The Vaal River serves as a conduit to transfer water among the three Vaal WMAs and significant transfers out of the Upper Vaal WMA occur through the distribution system of Rand Water to the Crocodile West and Marico WMA. The Vaal River System has extensive water resource infrastructure and is linked to other water resource systems (Thukela, Usutu, Lesotho) through substantial transfers between them.

The Upper Vaal is highly altered by catchment development, with the Middle Vaal having a few major development centres and agriculture and mining being the main activities. The Lower Vaal WMA is less developed with agriculture being the predominant land use. The Modder Riet catchment is dominated by agricultural activities with a few urban centres. The significant development within the system includes both formal and informal urbanisation, industrial growth, agricultural activities, power generation and widespread mining activities. This development has led to deterioration in the water quality of the water resources in the system, requiring that management interventions are needed to ensure that water of acceptable quality is available to all users in the system, especially as land use activities continue to grow and intensify. Salinisation and eutrophication of the water resources in the Vaal River System appear to be the two major water quality problems being experienced. If the system is going to sustain the envisaged growth and development, sound strategies and actions are needed to ensure that the water resources of the Vaal River System are managed to meet the needs of all water users while at the same time affording an adequate level of protection of instream resource quality.

The challenge is to develop a detailed understanding of the current water quality situation of the water resources within the system and the processes that drive the impact and associated pollution such that the resulting water quality management plan identifies optimum, sustainable solutions that not only serve to alleviate the water quality issues but also accommodate the interdependency of the linked resource systems.

One of the basic principles of management is that "*you can only manage what you measure*". This principle applies to any human endeavour and to the world that surrounds us, with the domain of water resource management being no different.

Thus, in order that the water resources in the Vaal River System are effectively managed into the future and sound strategies for water quality management are developed, relevant information about water related conditions, issues and developments in the WMAs is needed to appropriately address the threats and problems that currently prevail. This "measurement" process of collating, processing and interpreting such information generally takes the form of situation analyses and basin studies.

One of the outcomes of the study is the setting of Resource Water Quality Objectives (RWQO) for the main stem of the Vaal River and the major tributaries. The setting of the RWQO is an economic balance between water user and ecological water quality requirements on the one hand and the costs of the mitigation measures to achieve the RWQO on the other. The approach to the assessment of the water quality management strategies is a comparison of the economic disbenefit due to the water quality received by the users and the cost of a particular management strategy. The purpose of this report is to describe the approaches and algorithms used to calculate the economic disbenefits used in the assessment of the management strategies.

The categories of users considered in the economic analysis include:

- the domestic sector;
- the agricultural sector;
- the power generating sector; and
- the industrial sector (Sasol)

2 DOMESTIC SECTOR

2.1 Introduction

The water quality impact on the economics of the domestic sector is based extensively on the work conducted by Urban-Econ as given in WRC (2000a) and the associated sectoral study WRC (2000b) by the Human Sciences Research Council ("HSRC").

This report essentially involves the adaptation of this work to the area under study.

This report discusses a conceptual framework for costs in the domestic sector and presents the following :-

- The costs derived in the work conducted by Urban-Econ and the Human Sciences Research Council;
- Describes the domestic user base of the Vaal River System;
- Applies the costs to that user base.

The resulting spreadsheet model can be applied to assess the economic dis-benefit associated with the various water quality management options.

2.2 Cost framework for the domestic sector

The total cost impact of increased salinisation in the domestic sector includes both private costs (incurred directly by households) and social costs (which include total household costs and other costs carried by the state or society as a whole).

Private costs comprise financial and non-financial costs. Financial costs include corrosion and scaling of plumbing and appliances, and increased consumption of items like soap and detergents. Non-financial costs are those that affect the quality of life of the household, such as the impact of increased salinity on health, and aesthetic impacts like the taste, smell and appearance of water.

Social costs include the impact on the state health system, the welfare system, productivity, social unrest and crime. The impact of salinisation in other sectors may also affect the household sector, in that the closure, relocation or reduced profitability of entities in other sectors impact wage and employment levels in households.

2.2.1 Financial costs

Plumbing, geysers and domestic appliances

Metal piping, geysers and other appliances may be subject to corrosion depending on the materials used for their construction. The composition of the water affects the rate of corrosion, which leads to increased maintenance and replacement costs. A further effect requiring consideration in saline water conditions is scaling. Calcification leads to reduced efficiency and ultimately total blockage or breakdown. Once again, this leads to increased maintenance and replacement costs.

Soaps, detergents and softeners

Although manufacturers claim that salinity has little effect on the efficacy of soaps, detergents and softeners, salinity can have a considerable effect, particularly with soap. The increased costs of consumption would need to be accounted for in an economic disbenefit model.

Fabrics

Washing with hard water is generally agreed to reduce the life of washable fabrics, but this is very difficult to quantify. Estimates range between a 2.5% - 4.5% reduction in the life of material. However, some effects are aesthetic such as abrasiveness and discolouration, and households may for example increase expenditure on softeners or move to other fabrics.

2.2.2 Non-financial costs

Health costs

The World Health Organisation (WHO) maintains that reliable data on the possible health effects associated with TDS is not available, and it would be extremely difficult (and for other reasons, inaccurate) to try and quantify the health effects. DWAF et al (1998) gives insignificant health effects on sensitive groups for TDS concentrations less than 1000 mg/L. Health costs need therefore only be considered for TDS concentrations in excess of 1000 mg/L. The TDS concentrations in the Vaal main stem and the major tributaries are less than 1000 mg/L at the 95 percentile level ie 95 percent of the concentrations are less than 1000 mg/L. The RWQO are not likely to be set at concentrations higher than the current 95 percentile concentration so health costs for TDS need not be considered in the analysis.

Costs of aesthetic acceptability

The aesthetic acceptability of water affects quality of life and financial and health costs associated with compensatory behaviour. Alternatives to aesthetically acceptable water incur financial costs such as the purchase of bottled water, carbonated drinks, collection from more distant points or water treatment devices, and/or health costs due to the use of unsafe alternative water sources.

2.3 Cost estimation

2.3.1 Methodology

The HSRC gave much consideration to the methodology to be used for the estimation of the cost effects of salinity. Difficulties in estimating the cost effects include:

- **The magnitude of the cost impact:** Changes in household expenditure due to changes in salinity are small adjustments to items such as electricity and detergents already used in some quantity. Increased salinity may shorten the life of appliances rather than reduce their utility.
- **The marginal nature of the increase in salinity:** Salinity increases take place over prolonged periods resulting in gradual changes in household behaviour. Households may be oblivious or only partially aware of these adjustments in behaviour.
- **The oblique impact of factors affecting expenditure on items affected by salinity:** There are many factors impacting household expenditure, and items that are affected by increased salinity are affected by many other factors as well, making it difficult to isolate the effects of salinity.

Ideally the costs of increased salinity would be derived by comparing the expenditure and behaviour of similar households in areas of differing salinity, but the marginal effect of increased salinity would be drowned out by the "noise" from the factors above. The fundamental problem is that established residents of an area would regard their behaviour as "normative", and would not be in a position to identify their response to changing water salinity.

One group that would be aware of the impact of water salinity would be newcomers to an area. In the HSRC study, respondents which had moved from the Gauteng region into the Middle Vaal area were identified, and interviewed to establish the cost effects of salinity, moderated by the extent to which the behaviour of newcomer households was representative of established households in the area.

Sampling categories were selected on the basis of access to services, broadly conforming to housing type and economic status. The categories selected were:

- **Suburban households:** these households have access to full services, including in-house plumbing, and housed in formal structures.
- **Township households:** have less privileged access to services, not necessarily with access to indoor water or continuous electricity supply. The dwellings are of formal construction.
- **Informal households:** are typified by informal structures and a lack of indoor plumbing.

2.3.2 Results of the survey

The estimated monthly expenditure by household in 1995 Rands is shown in **Table** 1 below. These costs need to be converted to today's money values. According to statistics on the Statistics South Africa website, the Consumer Price Index ("CPI") for 1995 was 72.4, while the CPI for December 2006 was 136.5 (where CPI for 2000 = 100). This gives a conversion factor of 1.89. The resulting estimated monthly expenditure by household in December 2006 Rands is shown in **Table 2**.

This represents the monthly cost per household for respondents moving from the Gauteng region to the Middle Vaal region. At the time of the survey, the TDS concentration of the Vaal Dam water (from which the water supplying Gauteng is abstracted) was approximately 103 mg/ℓ (DWAF, 1998). The average TDS concentration in the Midvaal region was 493 mg/ℓ. Applying the 390 mg/ℓ difference in base TDS concentration to the costs above allows us to derive a change in economic costs per household per 10 mg/ℓ change in TDS concentration. This ratio will allow decision-makers to understand the effect of salinity targets on the Vaal River system.

Table 1: The results of the HSRC domestic salinity study - summarised monthly cost per household in 1995 Rands

Cost Category (1995 Rands)	Suburban	Township	Informal
Laundry	4.57	16.08	8.70
Personal Care	10.46	12.17	2.37
Dishwashing	3.03	5.05	1.99
Electric Kettles	0.83	0.22	0.00
Steam Irons	1.10	0.64	0.00
Water Filters	0.06	0.00	0.00
Geysers	6.32	0.00	0.00
Taps and Piping	7.95	0.00	0.00
Pools	3.76	0.00	0.00
Vehicles	11.30	2.23	1.04
Total	**49.38**	**36.39**	**14.10**

Table 2: The results of the HSRC domestic salinity study - summarised monthly cost per household, converted to December 2006 Rands

Cost Category (2006 Rands)	Suburban	Township	Informal
Laundry	8.62	30.32	16.40
Personal Care	19.72	22.94	4.47
Dishwashing	5.71	9.52	3.75
Electric Kettles	1.56	0.41	0.00
Steam Irons	2.07	1.21	0.00
Water Filters	0.11	0.00	0.00
Geysers	11.92	0.00	0.00
Taps and Piping	14.99	0.00	0.00
Pools	7.09	0.00	0.00
Vehicles	21.30	4.20	1.96
Total	**93.10**	**68.61**	**26.58**

The resulting estimated monthly expenditure per 10 mg/ℓ change in TDS concentration by household in December 2006 Rands is shown in **Table 3** below.

Table 3: Monthly cost per household per 10mg/ℓ change in TDS concentration, in December 2006 Rands

Cost Category (2006 Rands)	Suburban	Township	Informal
Laundry	0.22	0.78	0.42
Personal Care	0.51	0.59	0.11
Dishwashing	0.15	0.24	0.10
Electric Kettles	0.04	0.01	0.00
Steam Irons	0.05	0.03	0.00
Water Filters	0.00	0.00	0.00
Geysers	0.31	0.00	0.00
Taps and Piping	0.38	0.00	0.00
Pools	0.18	0.00	0.00
Vehicles	0.55	0.11	0.05
Total	**2.39**	**1.76**	**0.68**

This monthly expenditure can be applied to the population statistics in the Vaal River System to estimate the total economic effect.

2.4 Population statistics for the Vaal River System

The majority of domestic consumers of water in the Vaal River System are supplied by four Water Service Providers (WSPs) namely Rand Water, Sedibeng Water, Midvaal Water and Frances Baard (Kimberley). The number of households supplied by each of these WSPs was extracted from the 2001 Census statistics downloaded from the Statistics South Africa website.

The Census statistics provide information on the source of water for households. Only those households drawing water from reticulated water systems were considered in this study, so those drawing water from sources such as boreholes, springs, streams and rainwater were excluded. The categories available in the Census used in this study are:

- Piped water inside dwelling
- Piped water inside yard
- Piped water from a community standpipe: distance less than 200m from dwelling
- Piped water from a community standpipe: distance greater than 200m from dwelling

These categories do not correspond directly with those in the HSRC study. For the purposes of this study, the following equivalences were assumed:

- **Suburban** = Piped water inside dwelling
- **Township** = Piped water inside yard
- **Informal** = Piped water from a community standpipe (both categories)

The resulting household statistics are shown in **Table 4**. Rand Water dominates the number of households, with a total of 2.9 million or 88.5% of the households obtaining water from the Vaal River System.

2.5 The cost effects of salinity

The purpose of this study is to provide input into the evaluation of strategies to manage water quality in the Vaal River System. The Water Resources Planning Model (WRPM) set up for the Vaal River System simulates the water volumes and the TDS concentrations supplied by the WSPs to their users for the different water quality management scenarios assessed. The calculation of the disbenefit described in Sections 2.3 and 2.4 is based on housing types and the number of houses. The economic model must also account for the growth in the population and the different housing types in the future as the water requirements grow. In terms of the WRPM output, it would be easier to calculate the economic disbenefit based on the volume of water used rather than the numbers of the different types of houses. The volume of water supplied is directly dependent on the growth in population. By assuming that the number of dwelling types (hence population) grows in the same proportion as the 2001 ratios, the volume of water can be used instead of the number of dwellings to determine the disbenefit in the future.

2.5.1 Derivation of cost effects

The purpose of the derivation of cost effects is to produce factors which will allow the calculation of the total disbenefit to a region of a particular volume of water supplied at a particular TDS concentration relative to a base TDS concentration. The approach used in deriving these factors from the disbenefit costs described in Section 2.3 is summarised as follows:

- The summarised monthly costs per household shown in **Table 1** were adjusted to 2001 Rands (the year in which the census was conducted). The revised costs are shown in

Table 5: The summarised monthly cost per household adjusted to 2001 Rands

- .

- The numbers of the household types in 2001 were obtained from Statistics SA in the four WSP regions (See **Table 4**).

- The total annual costs per region for 2001 were obtained by multiplying the monthly costs per household (

Table 5: The summarised monthly cost per household adjusted to 2001 Rands

-) by the by the number of households (**Table 4**) in each WSP. and multiplying by the number of months in a year.

- The volume of water supplied by the WSPs in 2001 was obtained. The total annual costs per region for 2001 were divided by these volumes and the 390 mg/ℓ TDS concentration change in the original HSRC study to give the unit cost per WSP per m^3 per mg/ℓ. The 2001 unit costs were scaled by a factor of 1.273 to give 2006 costs. These values are summarised in **Table 6.**

- The disbenefit of salinity will be incurred across the entire spectrum of TDS concentrations. However to apply the model a realistic base TDS concentration is required from which to calculate the change in TDS concentration to determine the economic disbenefit. The historical water quality data for the last 10 years and the modelled future TDS concentrations in Vaal Dam show that the TDS concentration in Vaal Dam did not go below 70 mg/ℓ. A TDS concentration of 70 mg/ℓ was therefore used as the base concentration for the calculation of the disbenefits.

Table 4: Number of households supplied by WSPs and the associated municipalities for the Vaal River System

Municipal areas	Inside Dwelling	Inside Yard	Community Standpipe	Total	%
Rand Water					
City of Johannesburg Metropolitan Municipality	528 122	371 371	133 571	1 033 064	*32.0%*
Ekurhuleni Metropolitan Municipality	333 815	311 271	129 644	774 729	*24.0%*
Tshwane Metropolitan Municipality	288 455	186 092	92 421	566 968	*17.6%*
Emfuleni Local Municipality	99 429	80 227	15 976	195 632	*6.1%*
Mogale City Municipality	34 734	40 258	11 354	86 347	*2.7%*
Rustenburg Local Municipality	25 544	50 683	26 235	102 462	*3.2%*
Govan Mbeki Municpality	22 284	24 601	16 234	63 118	*2.0%*
Metsimaholo l.ocal Municipality	14 222	13 415	6 058	33 694	*1.0%*
Subtotal	1 346 605	1 077 917	431 492	2 856 014	*88.5%*
Sedibeng Water					
Matjhabeng Local Municipality	31 661	56 963	32 291	120 915	*3.7%*
Nala Local Municipality	5 208	15 131	5 973	26 311	*0.8%*
Tswaing Local Municipality	3 359	8 567	12 055	23 981	*0.7%*
Maquassi Hills Local Municipality	3 556	8 084	5 182	16 822	*0.5%*
Subtotal	43 783	88 745	55 501	188 029	*5.8%*
Mid Vaal Water					
City Council of Klerksdorp	27 192	54 840	15 296	97 328	*3.0%*
Subtotal	27 192	54 840	15 296	97 328	*3.0%*
Frances Baard District Municipality					
Sol Plaatje Local Municipality	27 758	19 268	6 664	53 690	*1.7%*
Dikgatlong Local Municipality	2 502	4 983	1 976	9 461	*0.3%*
Magareng Local Municipality	1 421	3 545	822	5 788	*0.2%*
Phokwane Local Municipality	4 639	8 329	4 107	17 074	*0.5%*
Subtotal	36 319	36 126	13 568	86 014	*2.7%*
TOTAL	**1 453 900**	**1 257 628**	**515 857**	**3 227 385**	***100%***

Table 5: The summarised monthly cost per household adjusted to 2001 Rands

Cost Category (Dec 2001 Rands)	Suburban	Township	Informal
Laundry	R 6.77	R 23.81	R 12.88
Personal Care	R 15.49	R 18.02	R 3.51
Dishwashing	R 4.49	R 7.48	R 2.95
Electric Kettles	R 1.23	R 0.33	R 0.00
Steam Irons	R 1.63	R 0.95	R 0.00
Water Filters	R 0.09	R 0.00	R 0.00
Geysers	R 9.36	R 0.00	R 0.00
Taps and Piping	R 11.77	R 0.00	R 0.00
Pools	R 5.57	R 0.00	R 0.00
Vehicles	R 16.73	R 3.30	R 1.54
Total	**R 73.12**	**R 53.88**	**R 20.88**

Table 6: 2001 Total Cost, annual water use and the unit cost per mg/l per m^3 of water used per WSP

WSP	Total annual cost (2001 R)	Annual volume (2001) (million m^3/annum)	Cost Cents per m^3 per mg/ℓ (2001)	Cost Cents per m^3 per mg/ℓ (2006)
Rand Water	1 986 617 736	1 134	0.449	0.572
Sedibeng	109 702 253	63	0.446	0.568
Midvaal	63 149 265	42	0.385	0.490
Frances Baard	58 624 968	35	0.429	0.546

The cost per m^3 per mg/ℓ above can be now used in models which simulate the supply flows and TDS concentrations in the different regions to calculate the cost effects of salinity.

2.5.2 Cost effect simulations

For different water quality management scenarios, the WRPM for the Vaal River System produces simulations of monthly water volumes and TDS concentrations supplied by the WSPs to their users. These simulations typically result from stochastic runs where between 100 and 1000 sequences are run. Each sequence was 19 years in length covering the period 2006 to 2025.

A simulation spreadsheet model was built to simulate the cost effects in the WSP regions based on this data. This model works in conjunction with the output from the WRPM described in the previous section. The model description is as follows:

1. **Model inputs:** the desired WSP region for analysis is selected, and the model accordingly accesses the base TDS concentration and cost per m^3 per mg/ℓ for that WSP region from the disbenefit calculation model. The root folder, TDS concentration and volume base file names, and the number

of stochastic sequences are entered. Economic data comprising the desired discount and inflation rates are also entered.

2. **Model functioning:** analysis is initiated by pressing a button marked “Analyse”. This calls up a VBA module which, for each sequence of the simulation reads in the TDS concentration and volume data from the data files. The resulting disbenefit cost of salinity is calculated for each month, and the present value of the disbenefits for the entire period of the simulation calculated. Various statistical data for each sequence are recorded (see next point).

3. **Results:** the following data are recorded for each sequence:-
   - Sequence number
   - TDS concentration: average and standard deviation
   - Excess TDS concentration above base concentration: average and standard deviation, and the number of months in which the TDS concentration exceeds the base concentration
   - Volume: average and standard deviation
   - Disbenefit cost: total; monthly average and standard deviation; and present value
   - Count: number of months in the simulation

4. **Overall results:** All sequences are then analysed to give the overall results. The overall results include the average, standard deviation and box plot data for present value (PV) of disbenefits, average monthly disbenefit, average TDS concentration, excess TDS concentration, and monthly volume.

2.5.3 Simulation result example

The results of a sample simulation are shown in **Figure 1** below. This simulation was conducted for 100 sequences in the Kimberley (Frances Baard) region. The target TDS concentration is set at 200 mg/ℓ, the discount rate at 10% and the inflation rate at 5%.

REGIONAL DATA		Regions table
		RWB
Region	Frances Baard	Sedibeng
TDS target	200	Midvaal
		Frances Baard
Unit cost - R per m³ per mg/ℓ		
0.005469		

Analyse

Note: before analysing, all blue cells must contain the correct information

ECONOMIC DATA	
Discount rate	10.00%
Monthly	0.80%
Inflation rate	5.00%
Monthly	0.41%
Monthly PV factor	0.9961

TDS DATA FILES	
Root	D:\7274 - Vaal IWQMP\TSRTC115\
TDS File base name	TSRTC115
Volume File base name	TSRTQ115
Number of iterations	100

ANALYSIS OUTPUT

Iterations: 100

OVERALL	Average	SD	Max	95%-ile	75%-ile	Median	25%-ile	5%-ile	Min	Units
Present Value	786 952 320	50 063 496	897 816 750	754 915 548	825 811 615	792 084 820	754 915 548	698 536 207	670 305 434	**R**
Monthly Average	5 235 722	314 209	5 927 119	5 048 091	5 460 893	5 273 810	5 048 091	4 684 492	4 318 007	**R**
TDS	494.7	18.8	534.7	483.7	509.0	496.5	483.7	461.8	439.6	**mg/ℓ**
Excess TDS	295.8	18.2	334.8	284.8	309.5	297.6	284.8	264.2	243.4	**mg/ℓ**
Volume	3.233	0.016	3.238	3.238	3.238	3.238	3.238	3.219	3.110	**million m³/month**

	TDS		Excess TDS			Volume		Cost					
Iteration	**Average**	**SD**	**Average**	**SD**	**Months exceeding**	**Average**	**SD**	**Total**	**Monthly Average**	**SD**	**PV**	**Count**	**TDS Data source Filename**
Overall	494.69	122.63	295.80	119.81	219	3.233	0.098	1 193 744 593	5 235 722	2 129 564	786 952 320	22800	
1	497.85	117.24	298.97	114.15	220	3.238	0.087	1 209 095 741	5 303 051	2 042 147	794 031 539	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.001
2	488.94	121.86	290.10	118.82	221	3.238	0.087	1 172 812 237	5 143 913	2 117 533	773 761 219	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.002
3	504.41	113.65	304.83	112.44	223	3.238	0.087	1 231 425 226	5 400 988	1 995 549	808 666 501	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.003
4	507.92	105.84	308.10	105.29	226	3.235	0.087	1 243 909 360	5 455 743	1 875 683	827 723 155	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.004
5	516.04	100.58	317.06	97.05	223	3.224	0.102	1 275 056 228	5 592 352	1 717 639	843 183 417	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.005
6	500.70	117.44	300.97	116.75	223	3.238	0.087	1 216 724 225	5 336 510	2 076 463	785 193 697	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.006
7	495.69	128.10	296.95	124.96	217	3.238	0.087	1 200 569 632	5 265 656	2 218 021	779 086 673	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.007
8	461.41	147.21	264.25	141.64	206	3.238	0.087	1 068 158 571	4 684 906	2 517 385	722 657 270	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.008
9	502.38	119.04	302.76	118.01	223	3.238	0.087	1 224 103 055	5 368 873	2 102 736	810 293 695	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.009
10	519.06	104.92	319.40	103.84	223	3.238	0.087	1 290 758 085	5 661 220	1 845 717	863 852 550	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.010
11	472.07	142.24	274.42	137.24	214	3.238	0.087	1 109 886 869	4 867 925	2 435 981	749 321 682	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.011
12	508.16	120.59	309.07	118.09	220	3.238	0.087	1 248 606 086	5 476 342	2 103 956	831 524 712	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.012
13	475.29	140.29	277.14	136.27	216	3.238	0.087	1 121 111 230	4 917 155	2 421 902	756 614 283	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.013
14	481.09	129.91	282.42	126.82	215	3.238	0.087	1 142 388 030	5 010 474	2 259 722	741 311 194	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.014
15	494.22	125.68	295.43	122.58	219	3.238	0.087	1 193 325 379	5 233 883	2 173 047	783 211 851	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.015
16	515.68	105.34	315.80	104.98	227	3.238	0.087	1 276 653 054	5 599 355	1 873 099	839 890 822	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.016
17	499.59	126.31	300.46	124.11	219	3.238	0.087	1 213 377 173	5 321 830	2 200 472	807 796 080	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.017
18	501.46	123.44	303.07	119.10	219	3.226	0.100	1 219 887 734	5 350 385	2 109 237	815 688 052	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.018
19	478.08	147.56	281.24	140.90	210	3.238	0.087	1 136 344 086	4 983 965	2 502 957	765 102 978	228	D:\7274 - Vaal IWQMP\TSRTC115\TSRTQ115.019

Figure 1: Sample screen capture of a domestic salinity simulation

The average monthly excess TDS concentration for the entire simulation is 295.80 mg/ℓ, giving an average monthly disbenefit to the domestic users in the region of R 5 235 722.

This may be compared with sequence 1, in which the average monthly excess TDS concentration is 298.97 mg/ℓ, giving an average monthly disbenefit to the domestic users in the region of R 5 303 051.

3 AGRICULTURE SECTOR

3.1 Introduction

The objective of the economic model is to estimate the economic cost to agriculture of using irrigation water with various TDS concentrations. In order to do this, a spreadsheet model was compiled in order to simulate current agricultural production in financial terms along the Vaal main stem. Once this has been achieved, a scenario analysis can be undertaken using different levels of water quality and enterprise mix.

This section begins with an explanation of the technical framework regarding water salinity and the associated reduction in agricultural production. The main elements of the economic model are then explained, along with the main assumptions of the model. The results of the simulation model and the scenario analyses are then discussed.

3.2 The effect of salinity on crop yield

Water quality can have a significant effect on crop production. All irrigation water contains dissolved mineral salts, but the concentration and composition of the dissolved salts vary according to the source of the water. Very high salt levels can reduce and even stop crop growth, and it is therefore important to have a firm assessment of water quality.

Crop yield is not decreased significantly until a threshold irrigation water salinity level is exceeded, and then the yields decrease approximately linearly as water salinity increases beyond the threshold value. This linear equation is:

$$Y = \frac{100(TDSdw - TDSw)}{TDSdw - TDSw100}$$

Where

- Y is the yield expressed as a percentage of maximum yield
- TDSw is the TDS concentration of the soil water (mg/ℓ)
- TDSw100 is the soil salinity threshold value (maximum TDSw where Y is still 100%)
- TDSdw is the salinity at zero yield (TDSw where Y = 0)

A generic diagrammatic illustration of the effect of soil salinity on crop yield is presented in **Figure 2**.

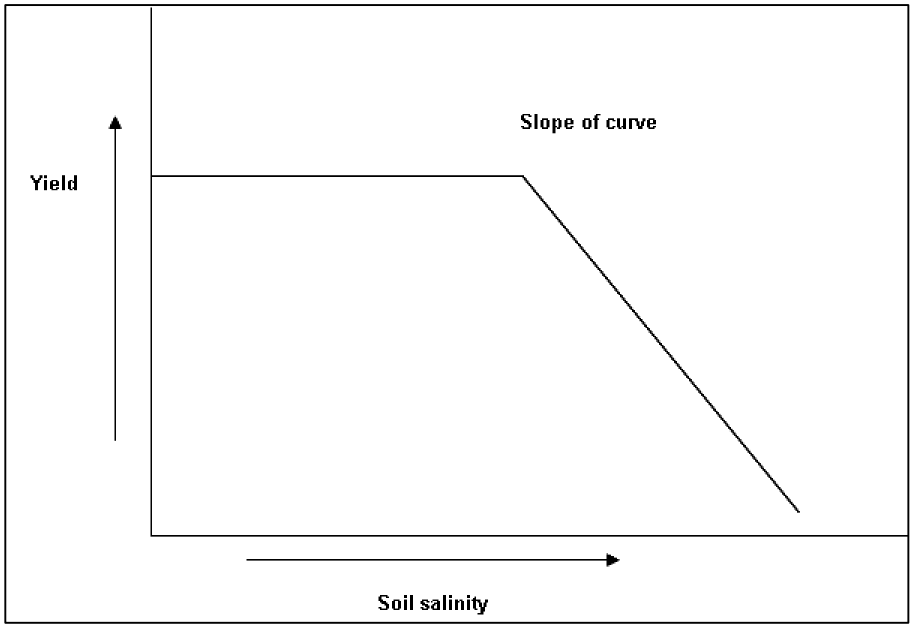

Figure 2: Diagrammatic representation of the effect of soil salinity on crop yield

Salts exert both general and specific effects on plants which directly influence crop yield. Additionally, salts affect certain soil physio-chemical properties which, in turn, may affect the suitability of the soil as a medium for plant growth. Growth suppression is typically initiated at some threshold value of salinity, which varies with crop tolerance and external environmental factors which influence the need of the plant for water. These factors include:

- Actual response to salinity – this varies with growing conditions, including climatic and soil conditions, agronomic and irrigation management, crop variety, stage of growth etc;
- Climate - this is a major factor affecting salt tolerance. Most crops can tolerate greater salt stress if the weather is cool and humid than if it is hot and dry. The effect of salinity on crop yield is greater when atmospheric humidity is low;
- Crop growth stage - plants are generally relatively tolerant to salinity during germination, but become more sensitive during emergence and early seedling stages of growth;
- Cultivar – there are significant differences in salt tolerance among varieties of some species;
- Irrigation method - sprinkler-irrigated crops are potentially subject to additional damage caused by foliar salt uptake and desiccation (burn) from spray contact with the foliage. The degree of spray injury varies with weather conditions, especially with regard to the water deficit of the atmosphere.

Salinity of water is measured by two common water assessment criteria. The first, total dissolved solids (TDS), expressed in milligrams per litre (mg/ℓ), is the total amount of salt that remains after a litre of water is evaporated. The higher the TDS, the higher the salinity.

The second measurement of salinity is electrical conductivity (EC). The dissolved salts conduct electricity and therefore salt concentration is directly related to the EC reading. EC is a more useful measurement than TDS, since it is easier to take EC readings using a portable EC meter than it is to determine the TDS concentration of a particular sample. There are two types of EC determinations:

(a) ECw = Irrigation water source
(b) ECe = Saturation soil extract

In South Africa, EC is generally reported in millisiemens per metre (mS/m), but is often reported in decisiemens per metre (dS/m) in other parts of the world.

There is a conversion factor between TDS and EC, but caution is advised in the use thereof, as it is related to the salinity level and the salt composition of the water.

The tolerance levels for certain crop species are presented in **Table 7**.

Table 7: Tolerance levels and percentage decrease of certain crops

Crop	Crop irrigation water threshold TDS concentration (mg/ℓ)	Percentage decrease in yield for each 100 mg/ℓ rise in salinity
Lucerne	832	1.7%
Maize	704	2.6%
Wheat	2560	1.7%
Cotton	3264	1.2%
Groundnut	1344	5.2%
Grape	640	2.2%
Orange	704	3.1%

This relationship is graphically illustrated in **Figure 3**.

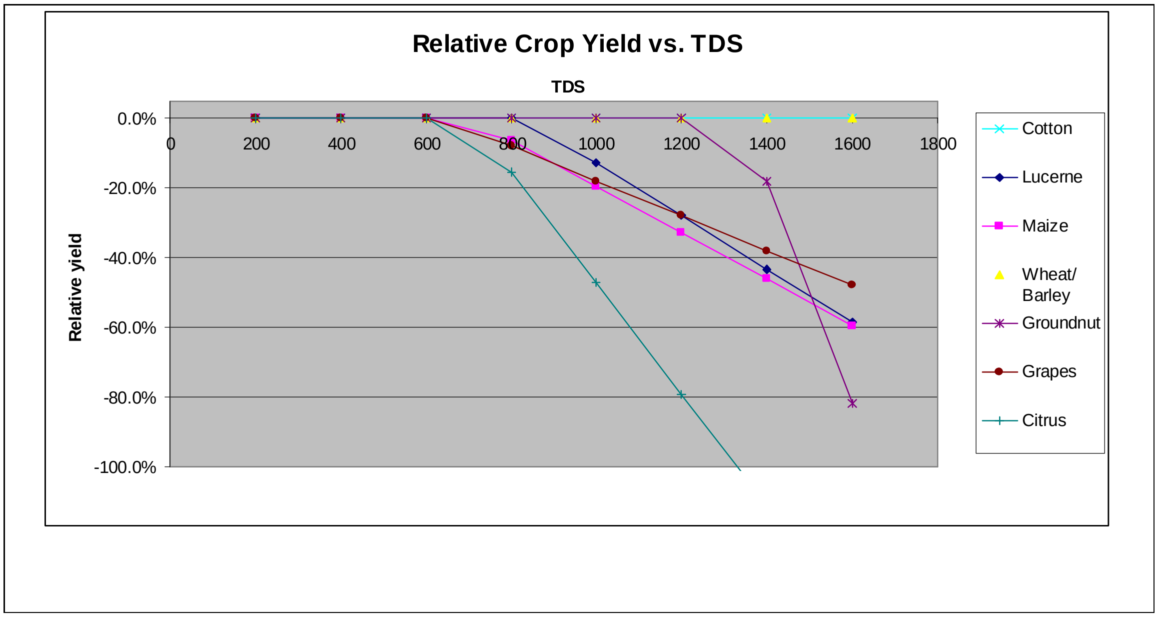

Figure 3: Graph showing the tolerance level and yield decrease with increase in TDS concentration

As can be seen from **Table 7** and **Figure 3**, cotton and wheat are the most tolerant crops in terms of salinity, with some vegetables, citrus and table grape being relatively sensitive to an increase in salinity.

3.3 Economic model

The objective of the economic model is to simulate, in financial terms, the agricultural production of the main irrigation areas that are supplied with water from the Vaal River, and then to examine different scenarios for various enterprise mixes at different levels of water quality. In order to do this the amount of land under irrigation needs to be estimated, along with the main enterprises grown. The building blocks of the economic model will be the gross margins for the main enterprises. These components are discussed separately below.

3.3.1 Land under Irrigation

A survey of the area under irrigation that is supplied from the Vaal River is documented in report DWAF (2007). The largest irrigation scheme is Vaalharts with 25194 ha. For the purposes of this report, the Vaalharts area will be used as an example.

3.3.2 Main Enterprises

The estimated area for each enterprise in the Vaalharts scheme is given in **Table 8** and **Table 9** below. The enterprises are divided into orchard crops and field crops.

Table 8: Present cropping patterns (Permanent/orchard crops (ha))

Grapes	Citrus	Nuts	Berries	Total
315	394	787	94	**1 590**

Table 9: Present cropping patterns (Field crops (ha))

Lucerne	Maize	Wheat/ Barley	Cotton	Ground nut	Potato	Vegs Summer	Vegs Winter	Total
5 905	5 118	9 841	2 756	5 905	39	20	20	**29 604**

From the above, a consolidated list of the main crops grown was derived, and areas of similar crops are combined. This is presented in **Table 10**.

From **Table 10**, it is assumed that the total area cropped is 30234 ha, which gives a land use percentage of 124 %. For the purposes of this analysis, vegetable crops were ignored as they form a fraction of 1% of the crops under consideration. Nuts and berries were also ignored, as data on their sensitivity to TDS concentration and financial margins could not be obtained at the time of writing. They also represent a small portion of the overall area.

Table 10: Enterprise breakdown

Enterprise	Area (ha)
Lucerne	5 905
Maize	5 118
Wheat/Barley	9 841
Cotton	2 756
Groundnut	5 905
Grapes	315
Citrus	394
Total	**30 234**

3.3.3 Gross Margins

Gross margins represent income from the sale of the produce, less all direct costs that can be allocated to the production of the specific crop.

Generalised production programmes have been compiled for each of the proposed enterprises, and indicative gross margins from the suitable crops for the region were calculated. The gross margins for each enterprise have been estimated from production budgets, and are based on the following assumptions:

- The gross margins are based on an average farmer in the area in an attempt to be representative of a typical farming operation in the region. However, in reality, there is a wide range of expertise and experience among farmers, which results in a wide variation in actual income and costs of enterprises;
- Gross income is based on representative yields and current prices for the enterprise. Where the gross margin applies over a number of years (e.g. citrus) the values are given in constant 2006 rand terms;
- The average water cost is 10 cents/m^3 of irrigation water;
- All deductions from gross income such as market agents' commission are included. The market agents' commission on fresh produce is estimated at 12.5% of gross income;
- The gross margin costs include:
  - **input costs** such as seed, chemicals and fertilizer;
  - **mechanical operations** such as ploughing and spraying;
  - **water charges and pumping costs** (an average pumping head of 15 metres is assumed in estimating the energy costs for irrigation);
  - all directly allocated **labour costs** (overhead labour costs such as the farm manager's salary are not included in the gross margin);
  - **packaging and transport** costs to the market;
- A **contingency amount of 5%** of total costs to allow for miscellaneous expenses.

A summary of the gross margins for the selected enterprises is given in **Table 11**. The gross margins show the returns for the specific enterprise at full development (e.g. the gross margin shown for citrus is for the seventh year of production).

Table 11: Summary of indicative gross margins for selected crops

Item (Units)	Citrus	Table grape	Maize	Cotton	Wheat	Pasture Lucerne	Ground-nut
Gross income (R/ha)	46,215	129,658	14,000	8,100	8,370	17,100	7,200
Production costs (R/ha)	16,424	66,800	8,243	7,862	4,704	11,051	5,833
Gross margins (R/ha)	29,791	62,858	5,757	238	3,666	6,049	1,367
Establishment costs (R/ha)	18,806	84,785	0	0	0	11,052	0

Table 11 above shows that, while the orchard enterprises have the highest gross margins, they are capital intensive enterprises and have high establishment costs.

3.3.4 Main Assumptions of Model

From the information given in the previous sections, an overall model can be compiled that simulates, in financial terms, the agricultural production of the irrigators along the Vaal River. The main assumptions for the financial analysis are listed below:

- The financial analysis is done in constant 2006 Rand values;
- No residual value or salvage value of the project is included at the end of the project;
- The cost of land is not included;
- The total capital cost of the proposed development is included in the analysis;
- No financing costs are included in the analysis;
- Income and production costs are derived from the gross margin estimates;
- With regard to perennial orchard crops it is assumed that 5% of the total area is established every year, therefore the aging of the enterprise is estimated accordingly;
- Overhead costs have been estimated for each farmer model or enterprise, and is included in the analysis. These include management salaries, general repairs, bank charges, auditing fees etc.

3.3.5 Results of Model

Using the TDS sensitivity in **Table 7**, the change in yield per hectare can be calculated as a change in gross revenue (i.e. revenue) for each crop. It is assumed that the cost base remains the same for any value of TDS concentration. This then allows the change in net income per hectare to be calculated, which can be applied to the enterprise areas as given in **Table 10** to estimate the total effect of changes in TDS concentration on the study area. The Rand results are given in **Table 12**, with the relative results in **Table 13**.

Table 12: Net income per hectare for different crops for different values of TDS concentration (mg/ℓ)

TDS (mg/ℓ)	Lucerne	Maize	Wheat	Cotton	Groundnut	Grapes	Citrus
200	3 839	5 757	3 666	238	1 367	58 619	10 045
400	3 839	5 757	3 666	238	1 367	58 619	10 045
600	3 839	5 757	3 666	238	1 367	58 619	10 045
800	3 839	5 390	3 666	238	1 367	53 943	8 507
1000	3 347	4 626	3 666	238	1 367	48 098	5 304
1200	2 762	3 863	3 666	238	1 367	42 253	2 101
1400	2 177	3 099	3 666	238	1 122	36 408	-1 102
1600	1 592	2 335	3 666	238	247	30 563	-4 305

Table 13: Relative income effect per hectare for different crops for different values of TDS concentration (mg/ℓ)

TDS (mg/ℓ)	Lucerne	Maize	Wheat	Cotton	Groundnut	Grapes	Citrus
200	0%	0%	0%	0%	0%	0%	0%
400	0%	0%	0%	0%	0%	0%	0%
600	0%	0%	0%	0%	0%	0%	0%
800	0%	-6%	0%	0%	0%	-8%	-15%
1000	-13%	-20%	0%	0%	0%	-18%	-47%
1200	-28%	-33%	0%	0%	0%	-28%	-79%
1400	-43%	-46%	0%	0%	-18%	-38%	-111%
1600	-59%	-59%	0%	0%	-82%	-48%	-143%

The results in Table 13 show that significant decreases in net return only occur when the TDS concentration exceeds 600 mg/ ℓ. From the above it can be seen that the value of agricultural production significantly increases with an increased area under citrus and table grape. However, the loss in agricultural production is greater as water quality decreases as these crops are relatively more sensitive to salinity.

3.4 Simulation Model

The Water Resources Planning Model (WRPM) set up for the Vaal River System simulates the water volumes and the TDS concentrations at various nodes in the river system for the different water quality management scenarios assessed. As with the domestic analysis, for different water quality management scenarios, the WRPM produces simulations for water abstracted from the river system at various nodes for irrigation purposes. These simulations typically produce 100 to 1000 files of 19 years of monthly data.

The economic model for agriculture includes a simulation model which reads in the simulation data and calculates the economic effect of the simulated TDS concentration on the irrigation area. The model description is as follows:

1. **Model inputs:** The root folder, TDS and base file names, and the number of stochastic sequences of the simulation are entered. Economic data comprising the desired discount and inflation rates are also entered.

2. **Model functioning:** analysis is initiated by pressing a button marked “Analyse”. This calls up a VBA module which for each sequence of the simulation reads in the TDS concentration data from the data files. The resulting disbenefit cost of salinity for each crop is calculated for each year by extracting the peak water TDS concentration during that crop’s growing season, converting it to a soil TDS concentration by means of the input conversion factor, and calculating the effect of the peak TDS concentration on the crop’s gross income. The total and present values of the disbenefits for the entire period of the simulation are calculated. Various statistical data for each sequence are recorded (see next point).

3. **Sequence results:** The following data are recorded for each sequence:-
    - Sequence number
    - The number of years in the sequence
    - TDS concentration: average and standard deviation for the node
    - For the region: the total cost, the average cost per year, the standard deviation and present value over all years
    - For each crop: the maximum TDS concentration recorded, the number of years in which the peak TDS concentration exceeds the crop threshold, the total cost over the years of the simulation and the average annual cost

4. **Overall results:** The above are averaged to give the overall results. Additional summary information includes the average, standard deviation and box plot data for PV of disbenefits, total disbenefit, average annual disbenefit and average TDS concentration.

3.5 Simulation Result Example

The results of a sample simulation are shown in **Figure 4** below. This simulation was conducted for 3 sequences of the Vaalharts scheme. The discount rate is set at 10% and the inflation rate at 5%.

The average TDS concentration for the entire simulation is 497.1 mg/ℓ, with a total disbenefit to the agricultural users in the region of R 9 365 628.

In sequence 1, the average TDS concentration is 497.85 mg/ℓ, with a total disbenefit to the agricultural users in the region of R 9 588 589. For lucerne, the threshold TDS concentration is never exceeded, and there is no disbenefit. However for maize, with its lower threshold TDS concentration, the threshold is exceeded in 5 of the years of the simulation, with a resulting disbenefit of R 1 973 137.

REGIONAL DATA	
Region	VaalHarts
TDS target	200

Analyse

ECONOMIC DATA	
Discount rate	10.00%
Inflation rate	5.00%
PV factor	0.9545

Note: before analysing, all blue cells must contain the correct information

TDS DATA FILES	
Root	D:\7274 - Vaal IWQMP\TSRTC115\
File base name	TSRTC115
Number of files	3

NB: put backslash "\" at end of path!

CROP SUMMARY INFORMATION												
Crop	**Lucerne**	**Maize**	**Wheat/ Barley**	**Cotton**	**Groundnut**	**Potato**	**Vegetables Summer**	**Vegetables Winter**	**Grapes**	**Citrus**	**Nuts**	**Berries**
Area (ha)	**6 168**	**5 231**	**12 288**	**2 756**	**6 846**	**39**	**20**	**20**	**315**	**394**	**787**	**94**
Vaalharts	5 905	5 118	9 841	2 756	5 905	39	20	20	315	394	787	94
Taung	263	113	2 447	0	941	0	0	0	0	0	0	0
TDS_{max} (mg/ℓ)	832	704	2560	3264	1344	0	0	0	640	704	0	0
ΔYield/100mg/ℓ	-1.71%	-2.73%	-1.68%	-1.17%	-6.08%	0.00%	0.00%	0.00%	-2.25%	-3.47%	0.00%	0.00%
Gross income (R/ha)	17 100	14 000	8 370	8 100	7 200	0	0	0	129 658	46 215	0	0

ANALYSIS OUTPUT

OVERALL	**Average**	**SD**	**Max**	**95%-ile**	**75%-ile**	**Median**	**25%-ile**	**5%-ile**	**Min**	**Units**
Present Value	6 317 325	1 115 435	7 352 467	7 263 570	6 907 982	6 463 498	5 799 754	5 268 759	5 136 011	**R**
Total Cost	9 365 628	1 895 314	11 139 600	10 984 499	10 364 094	9 588 589	8 478 642	7 590 685	7 368 696	**R**
Average Cost	492 928	81 448	586 295	578 132	545 479	504 663	446 244	399 510	387 826	**R**
TDS	497.1	7.8	504.4	503.8	501.1	497.9	493.4	489.8	488.9	**mg/ℓ**

Iteration (Shows last iteration results)	**Years of data**	**TDS**		**Total: All crops**				**Lucerne**				**Maize**			
		Average	SD	Total Cost	Average Cost	Std Dev	PV	Max TDS	Yrs exceed	Total Cost	Average Cost	Max TDS	Yrs exceed	Total Cost	Average Cost
Vaalharts				11 103 533	584 396	543 745	7 325 900			0	0			1 633 561	85 977
Taung				36 067	1 898	4 121	26 567			0	0			36 067	1 898
Total	**19.00**	**504.41**	**113.65**	**11 139 600**	**586 295**	**546 875**	**7 352 467**	**687.52**	**0**	**0**	**0**	**669.33**	**6**	**1 669 628**	**87 875**

Iteration	**Years of data**	**TDS**		**Total: All crops**				**Lucerne**				**Maize**			
		Average	SD	Total Cost	Average Cost	Std Dev	PV	Max TDS	Yrs exceed	Total Cost	Average Cost	Max TDS	Yrs exceed	Total Cost	Average Cost
Overall		**497.07**	**117.63**	**9 365 628**	**492 928**	**482 173**	**6 317 325**	**680.84**	**0**	**0**	**0**	**659.12**	**4**	**1 356 962**	**71 419**
1	19	497.85	117.24	9 588 589	504 663	553 714	6 463 498	677.44	0	0	0	657.87	5	1 973 137	103 849
2	19	488.94	121.86	7 368 696	387 826	302 987	5 136 011	677.55	0	0	0	650.15	2	428 121	22 533
3	19	504.41	113.65	11 139 600	586 295	546 875	7 352 467	687.52	0	0	0	669.33	6	1 669 628	87 875

Figure 4: Sample screen capture of an agricultural salinity simulation

4 COAL FIRED POWER STATIONS

Coal-fired power stations derive thermal energy from the burning of coal. The thermal energy is converted to electrical power and distributed via the national grid. The overall energy efficiency of coal-fired power stations is low, with approximately 35 % of the potential coal energy converted into electrical power for distribution. As much as 55 % of the coal energy leaves the power stations cooling towers as evaporated water and the residual 10 % coal energy leaves via the gas stacks.

Water supply to the power stations is mainly used for:

- Demineralised water production as make-up water for steam generation process.
- Cooling of the turbine condensors.
- Potable water
- Ash disposal

The generic and simplified coal-fired power station water circuit is shown in **Figure 5**.

4.1 Description of water circuits

4.1.1 Steam system

The steam driven turbine generator water circuit requires a very high quality water. The steam circuit make-up water is demineralised to a conductivity of $\leq$ 0.06 $\mu Scm^{-1.}$ Small amounts of chemically pure ammonia are used to buffer the demineralised water to an electrical conductivity of between 3 and 5 μScm^{-1}

The steam loop water is successively converted to steam that drives the turbine generators, condensed and polished before being recycled again.

The demineralisation (demin) treatment plant typically uses ion exchange technology, although membrane-based technology is being retrofitted to Grootvlei Power Station. Komati Power Station will be equipped with a state-of-the-art demineralised water plant, comprising ultrafiltration followed by double reverse osmosis and Electro Deionisation. The use and thus the disposal of soluble chemical waste is largely eliminated through this approach. The conventional demin plant ion exchange resins require generation, typically using:

- Sodium hydroxide NaOH.
- Sulphuric acid, H_2SO_4.

The demin plant regenerant therefore mainly contains sodium sulphate salinity. The spent regenerants from the demineralisation plant are typically discharged to the ashing system.

The steam loop system loses some flash water vapour and the consumptive use is typically only 30 to 50m^3/GW-hr power generated by stations with condensate polishing and approximately 90m^3/GW hr generated by for stations without condensate polishing.

4.1.2 Cooling water system

The cooling water systems of a 6 × 600 MW wet cooled power station comprise of two dedicated cooling systems. These systems each contain approximately 60Mℓ of concentrated cooling water. Cold lime softening instead of acid is used for the de-carbonation of the cooling water in order to minimise pollution of the cooling water, thus allowing higher cycles of concentration. Typical cooling water circulation rates through the turbine condensers are in the order of 23 m^3/minute per condenser. Typical evaporation rates from a wet cooling system are in the order of 1600m^3 per GW hr generated by a station operating close to a 35% overall efficiency. The evaporation rate from the more modern cooling towers increases by approximately 4m^3 for each 0.1% reduction in overall thermal efficiency. Evaporation from older power stations is dictated by the state of the technology at the point of design and construction of these stations. Evaporation from open evaporative cooling systems at a fossil fuel power station amounts to between 85% and 90% of the total raw water intake. Both direct dry and indirect dry cooling techniques are used on most of the newer power stations. Dry cooled power stations use approximately 15 times less water, but consume approximately 8% more coal. Grootvlei Power Station was the test station for dry cooling in South Africa and two units at this power station are dry cooled. Both direct and indirect dry cooling were incorporated as tests as far back as the late sixties.

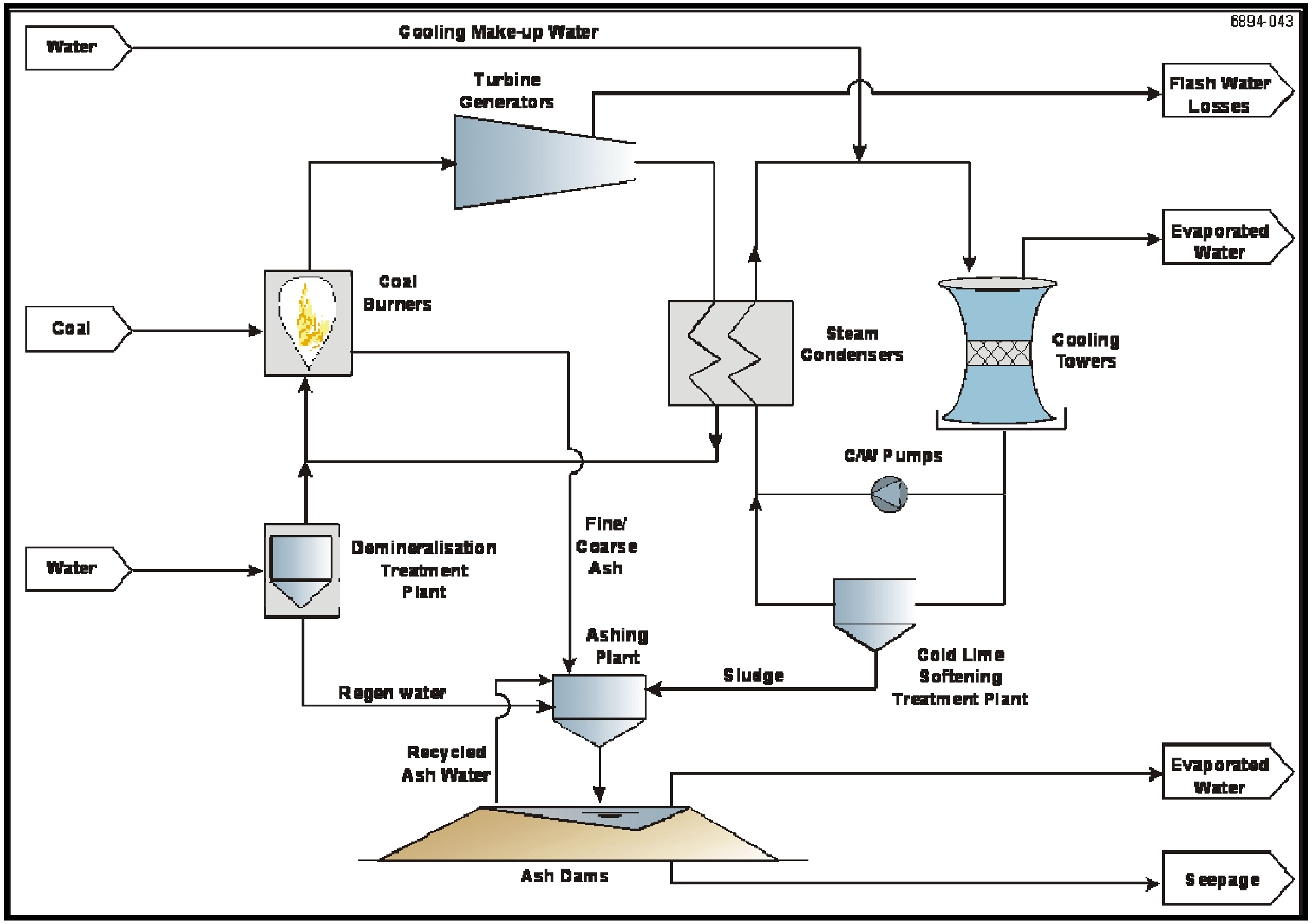

Figure 5: Coal-Fired Power Station Water Circuit

The water quality in the cooling loop must also be maintained at a level which does not pose corrosion or scaling risk to the cooling tower and associated infrastructure. Eskom typically uses the following guidelines for cooling loop water quality:

- Ca ≤ 500 mg/ℓ as $CaCO_3$
- Mg ≤ 180 mg/ℓ as $CaCO_3$
- Na ≤ 500 mg/ℓ as Na
- Cℓ ≤ 400 mg/ℓ as Cℓ
- SO4 ≤ 1 000 mg/ℓ as SO_4
- M-Alkalinity ≤ 120 mg/ℓ as $CaCO_3$
- CaSO4 ≤ 380 mg/ℓ as $CaCO_3$
- Mg x Si ≤ 25 000

The cooling loop water quality is controlled by a side-stream cold lime softening treatment process based on the following chemical reactions:

$$Ca\,(HCO_3)_2 + Ca\,(OH)_2 \rightarrow 2\,CaCO_3\downarrow + 2H_20$$

$$Mg\,(HCO_3)_2 + 2Ca\,(OH)_2 \rightarrow CaCO_3\downarrow + \; + Mg\,(OH)_2\downarrow + 2H_20$$

$$Mg\,SO_4 + Ca\,(OH)_2 \rightarrow CaSO_4 + Mg\,(OH)_2\downarrow$$

Cold lime softening can only remove the temporary hardness associated with Ca and Mg bicarbonates. No permanent hardness, Ca and Mg sulphate or NaCℓ is removed by the process. The waste sludge generated in the cold lime process is discharged to the ashing system Silica adsorbs onto the magnesium hydroxide precipitate and is thus also removed during the process. The Lime-Soda Process is only used when temporary hardness concentrations are problematic.

Cold lime softening is a very effective decarbonation technique for high alkalinity make-up water. The contamination of make-up water with sulphates of calcium and magnesium, however, could render this technique ineffective as large amounts of soda ash must be used to negate the concentration of non carbonate hardness.

$$MgSO_4 + Ca(OH)_2 \rightarrow CaSO_4 + Mg(OH)_2\downarrow$$

$$CaSO_4 + Na_2CO_3 \rightarrow Na_2SO_4 + CaCO_3\downarrow$$

The pollution of the cooling water and thus also the waste water (blow-down) with sodium from the soda ash application is clearly demonstrated by the above equation. The typical limit to the cooling loop conductivity is ≤ 3 000 μS/cm. The cooling loop is operated at a set cycle of concentration, based on the following water mass balances (see shown in **Figure 6**).

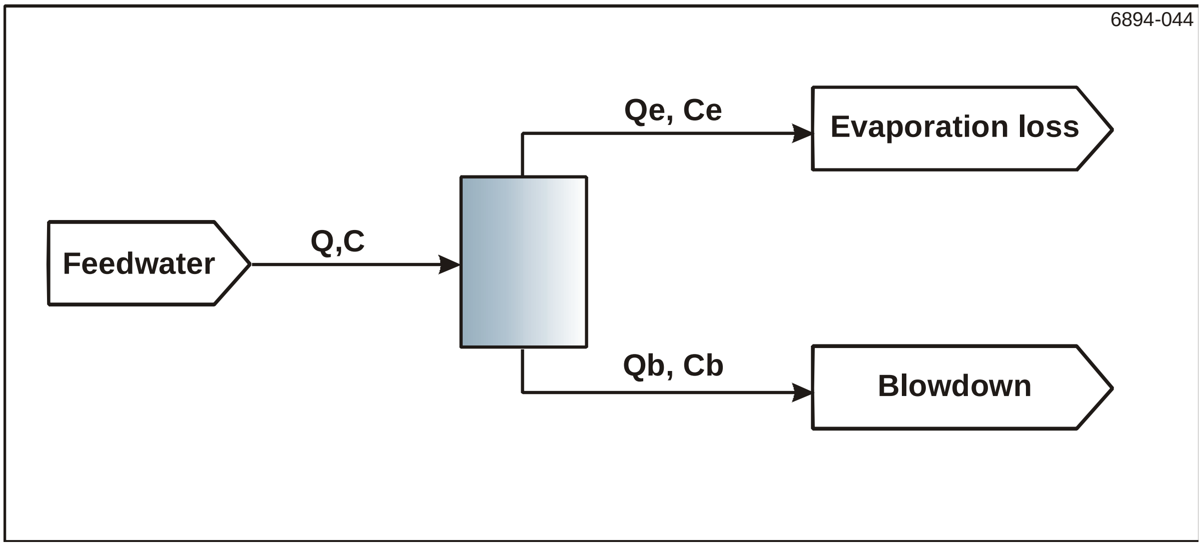

Figure 6: Cooling Water System Flow and Mass Balance where Q = flow rate and C = concentration

Cycles of concentration (COC) refers to the degree of concentration of a conservative salt species, such as Potassium (Na not a conservative salt in power station context), in the cooling loop. The controlling flow and mass balance equations are:

$$Q = Qe + Qb \quad (1)$$

$$Q.C = Qe.Ce + Qb.Cb \quad (2)$$

If we assume that the evaporated water contains low salt levels, then:

$$Q.C = Qb.Cb \quad (3)$$

$$\text{The COC} = Cb/C \quad (4)$$

Therefore $Q = Qb/[COC]$

Substituting into (1) gives

$$Qb\,[COC] = Qe + Qb \quad (5)$$

The amount of blowdown water required to operate the cooling loop is then $Qb = Qe / [COC-1]$.

The COC is sensitive to the feedwater quality, for example if the feed water contains Na = 20 mg/ℓ and the acceptable cooling loop Na ≤ 500 mg/ℓ, then the maximum acceptable COC = 500/20 = 25

The chemical attack on the cooling loop concrete infrastructure depends on the type of salt in the following order of aggressiveness:

$Mg\,SO_4 > Na_2\,SO_4 > Ca\,SO_4$

4.1.3 Ash water system

The coal waste ash is generated as:

- Coarse ash
- Fine ash

Dry ash disposal practices are incorporated in all Eskom power stations built beyond the early eighties. Dry ashing entails the conditioning of the fly ash with approximately 10% moisture (effluents). The coarse ash which collects in the bottom of the boiler is quenched with effluents and de-watered. A conveyer system complete with stackers is used for the transport and ultimate disposal of the ash. The relative dry ash dump consumes water through dust suppression. At wet ashing stations the ash is hydraulically transported and disposed on ash dams. The ash particles separate under gravity, leaving a clear decant water for recycle and re-use. The ash water system consumptively uses water in the following manner:

- Evaporation during the quenching of the coarse / bottom ash
- Evaporation from the return water pool and system.
- Interstitially retained water.
- Seepage to the environment.

The ash water system is maintained at high pH ≥ 12 as in this pH range, calcium sulphate precipitates as ettringite and magnesium precipitates as hydroxide.

The ash water loop water balance must be carefully controlled to prevent any direct or indirect water releases to the receiving surface and groundwater environment. This places a limitation on the amount of cooling loop blowdown water, which can be accommodated and indirectly places a constraint on the acceptable intake water quality to the power station.

The ash dams are also regarded as an effective salt sink and the guideline is not to exceed 300 gram of soluble salts ($NaC\ell$ and $Na_2\ SO_4$) per dry ton of ash.

4.1.4 Station drains

The power station drains generally receive leaks, drainage and purging water from a variety of systems. Approximately 50% of the demineralised water reports to the station drains together with the bulk of the wash water used in the power station. Leaks from the cooling water systems together with the storm water from the power station footprint also report to the station drains. Station Drains Management represents a critical element of compliance with zero liquid effluent discharge. The station drains on most power stations are recovered to the cooling water system to restrict the volume of water disposed with the ash. All dry cooled, dry ashing power stations were designed to reduce the station drains flow as the station drains can only report to the ashing system on these stations. Duvha Power Station is the only wet cooled wet ashing power station where the station drains cascade to the ashing system on a continuous basis.

The more modern power stations incorporate an elaborate valve and conductivity monitoring system to facilitate the recovery of process waste water with a salinity of < $500\mu Scm^{-1}$ to the cooling water system and process waste water with a salinity < $150\mu Scm^{-1}$ to the demineralised water plant feed sump. Only Duvha Power Station can maintain zero liquid effluent discharge with the station drains cascading to the ash system. This is mainly achieved through the incorporation of cold lime softening, the relatively good quality of the Komati System raw water and the large evaporative footprint of the Duvha Power Station Ash Dam and Dump System. The station drain water quality is monitored and if the drain water quality is good (EC < 500 µS/cm), it is recycled to the cooling water loop. Only Kendal and Matimba (Dry cooling, dry ashing) Power Stations are deliberately designed to dispose of the station drains on the ash. Duvha Power Station has a system to route their station drains to the emergency pan from where the water can be gradually recovered to the concentrated cooling water systems (CCW) or ash system in the event of rain or temporary poor raw water quality (Witbank Dam water usage).

4.2 Impact of deteriorating intake water quality

A deterioration of the power station supply water quality will have a direct impact on the different water circuits:

- The cooling towers will have to be operated at a lower COC to still maintain the cooling loop water quality within the system guidelines.
- The steam loop demin plant will require more regenerant cycles and a higher demin regenerant effluent generation.
- More effluents may be produced than can be accommodated in the ash disposal system.

Deterioration of the supply water quality typically requires modification to the station water circuits and introduction of a supplementary effluent concentration. This water circuit modification typically incorporates the following main components as reflected in **Figure 7**:

- Desalination treatment on a sidestream of the cooling water loop. The appropriate position for the cooling water desalination plant is downstream of the cold lime softening plant. The cold lime softening process then also serves as pre-treatment to the desalination treatment, which is typically a membrane-based process.
- The desalinated cooling water is then blended back into the main cooling water loop, effectively sweetening the cooling water loop water quality.
- Desalination treatment of the demineralisation plant feed water may be required. This treatment is required to operate the existing demineralisation plant within the acceptable salt design loads, for which the demin plant was originally constructed. Permeate from the first stage of the reverse osmosis plants are increasingly being used as feed water for the demineralisation plants. Tutuka and Lethabo Power Stations have modified their demineralised water production process to accommodate

this feature. Grootvlei Power Station will return to service producing demineralised water from permeate produced by the cooling water desalination plant. This desalination plant is specifically incorporated in the Grootvlei Power Station water treatment chain to circumvent the negative impact of the poor quality raw water abstracted at Vaal Marina. Grootvlei Power Station abstracts its raw water upstream from Vaal Marina and is subjected to major raw water quality fluctuations once the level of the Vaal Dam drops. The Grootvlei Power Station desalination plant will allow Grootvlei Power Station to reduce the disposal of soluble salts by approximately 90%.

- The reject from the desalination treatment plants is further concentrated, typically using evaporation / crystallisation technology. The condensate from the evaporation / crystallisation is of high quality and can serve as a feed water to the demin treatment plant. The final waste residue is moist salt crystals, which require disposal to a licensed waste disposal site.

The financial implications to poorer power station feed water quality include:

- Capital expenditure for desalination treatment plants and evaporator crystallizer plants.
- Higher operating costs for cold lime softening process.
- The incorporation of the Soda Lime process
- Operating cost for desalination treatment plant
- Operating cost for evaporation / crystallization plant.
- Disposal cost for salt waste.

Eskom conducted an independent assessment associated with deteriorating intake water for the different power stations located in or drawing water from the Vaal River catchment. The detailed outcome of the assessment is attached to this report as Appendix A. The summarized results are contained in the next report sections.

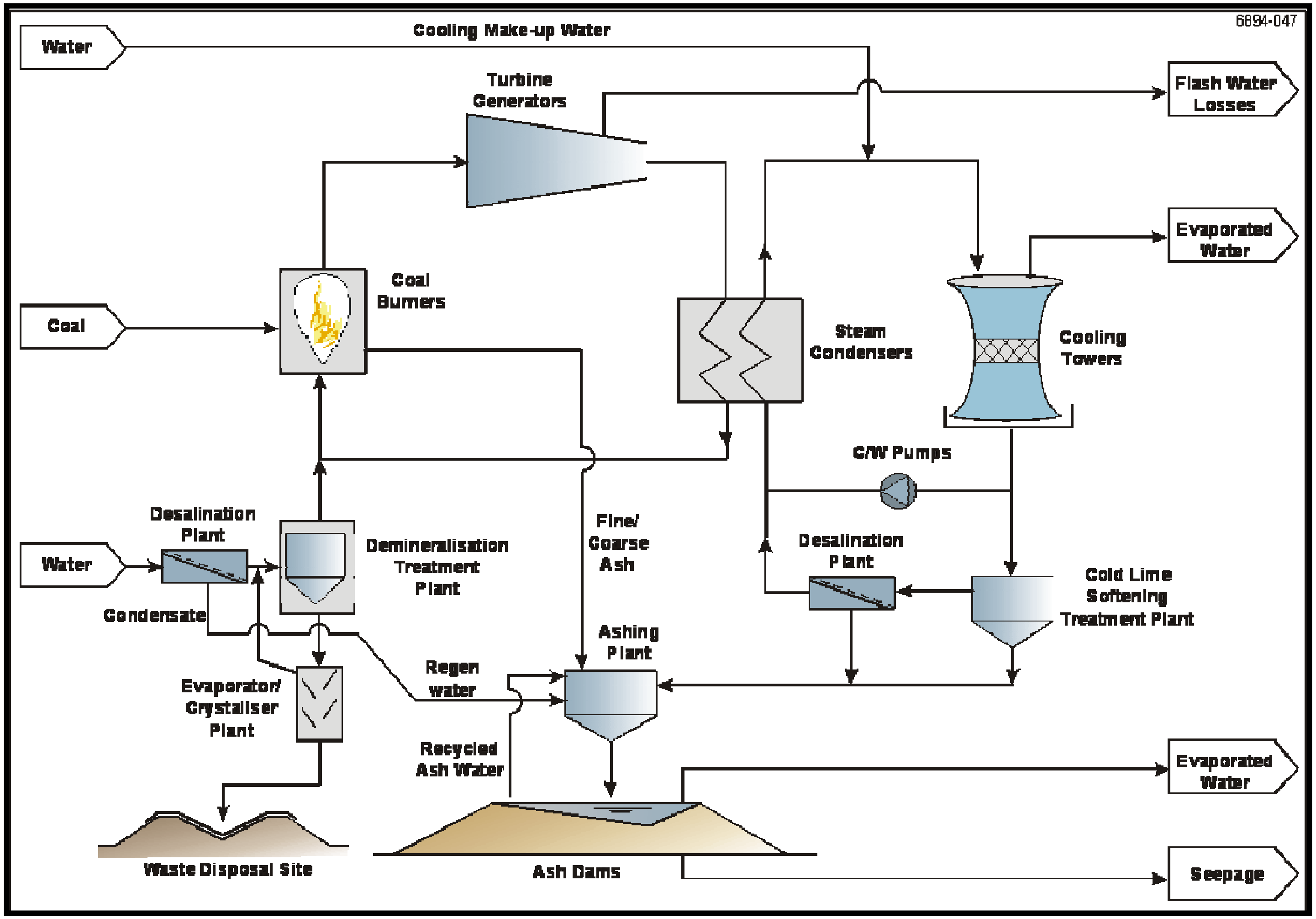

Figure 7: Modifications to power stations water circuits to deal with poor feed water quality

4.3 Grootvlei Power Station

The summarised approach to managing deteriorating feed water quality is as follows: (See **Table 14**).

Table 14: Impact at Deteriorating Intake Water Quality on Grootvlei Power Station

Feed water quality conductivity (mS/cm)	Water system modifications
150	The existing water circuits will be operated with sulphuric acid dosing to decarbonate the cooling water circuit.
200	The existing water circuits will be operated with additional sulphuric acid dosing to decarbonate the cooling water circuit.
250	A membrane – based desalination plant on the demin plant feed water is required. The desalination plant will require operation and maintenance. Increasing sulphuric acid dosing to decarbonate the cooling water circuit is also required.
300	A membrane – based desalination plant on the demin plant feed water is required. The desalination plant will require operation and maintenance. Increasing sulphuric acid dosing to decarbonate the cooling water circuit is also required.
500	A substantial upgrade of the existing cold lime softening treatment plant on the side-stream cooling water circuit is required. A membrane-based desalination plant to pretreat the demineralisation plant feed water is required. The salt load to the ash dams will exceed an acceptable threshold, and an evaporator/crystaliser plant is proposed to concentrate up the demin plant regen effluents. Separate, probably off-site salt crystal disposal will be required.

4.4 Matla Power Station

Matla Power Station is not receiving any mine water from a third party, and therefore has some capacity to deal with increasing salt loads associated with deteriorating feed water quality. Matla Mine however, has excess polluted water and integration of the mine and power station water management system is under consideration.

A progressive deterioration of feed water quality from 200 µS/cm to 400 µS/cm was evaluated.

No major capital investment in new desalination treatment plants is required. The operating cost of the cold lime softening plant will increase, due to higher chemical consumption levels.

4.5 Kriel Power Station

Kriel Power Station also has capacity to deal with an increasing salt load when operating on a raw water supply from the Usutu System. The return to service of Komati Power Station requires augmentation of the yield of the Komati River System. The Usutu System supplying Kriel Power Station will be used for this purpose thus leaving Kriel Power Station to use Vaal River quality. The cooling water treatment system at Kriel Power Station was designed for the low salinity raw water from the Usutu System and extensive modifications were already incorporated to accommodate Vaal System quality raw water. The Kriel Mine has excess polluted water and integration of the mine water system with the power station water management system might be required. but may reach the limits of the existing treatment infrastructure capacity. The power station is also not receiving excess mine water from any of the neighbouring mines.

A progressive deterioration of feed water quality from 200 μS/cm to 400 μS/cm was evaluated.

Up to a feed water conductivity of 300 μS/m, the poorer feed water quality impacts can be managed by modified operation of the existing cold lime treatment process. Higher operating costs will result due to the higher chemicals consumption.

At a feed water conductivity of exceeding 400 μS/cm, the design capacity of the existing demineralization plant will be exceeded. It is proposed to install a membrane-based desalination plant as pre-treatment for the demineralization plant. This will require a capital investment and operating costs associated with a desalination plant.

4.6 Tutuka Power Station

Tutuka Power Station already receives an external mine water feed from New Denmark Colliery and has **no** capacity to receive an increased feed water salinity load. The power station recently installed an upgrade to the desalination plant treatment capacity. The increased desalination plant capacity has positioned the power station to manage an increased feed water salinity load. Disposal of the increased salt load on the ash has however exposed Eskom to long-term liabilities and alternatives for the disposal of the excessive salt load are under investigation.

The impact of a deteriorating feed water quality over the conductivity range of 200 μS/cm to 400 μS/cm on the power station water circuits was evaluated. Two different probable future operating scenarios were formulated to deal with the increased feed water conductivity:

- The current operating regime has the benefit of the recently upgraded desalination plant capacity. The cost impacts on the power station water circuits include the following:

    - Desalination plant increasing operating costs
    - Cold lime softening plant increasing operating costs
    - Evaporator / crystallizer operating Capex and Opex

  These operating costs increase as the feed water quality deteriorates, but these costs are not very sensitive to the feed water conductivity when assuming that all the salts could be disposed on the ash.

- A possible future requirement may include the construction of an evaporator / crystalliser plant at a substantial capital investment. The cost impacts of the deteriorating feed water quality also include a number of inflated operating costs, including:

    - desalination plant increasing operating costs
    - Cold lime softening plant increasing operating costs
    - Evaporator / crystallizer operating cost.
    - Off-site disposal of salt crystals

The off-site disposal of salt crystals generated by the evaporator/crystallizer plant is a substantial additional cost.

4.7 Lethabo Power Station

The impact of increasing feed water conductivity over the range of 150 µS/m to 500 µS/m on the power station water circuits was evaluated. The power station has an existing desalination plant to provide an acceptable feed water quality to the demineralisation plant. The impacts on the power station water circuits with increasing feed water conductivity are summarized as follows:
(See Table 15:)

Table 15: Impact of Deteriorating Feed Water Quality on Lethabo Power Station

Feed water quality conductivity (µS/cm)	Water circuits system modifications.
150	The existing water system infrastructure can deal with the feed water quality.
200	The existing water system infrastructure can deal with the feed water quality. Increased operating costs are associated with the cold lime softening and the desalination plant.
250	The existing water system infrastructure can deal with the feed water quality. Increased operating costs are associated with the cold lime softening and the desalination plant. Additional costs are also incurred with the off-site disposal of salt crystals.
300	The existing water system infrastructure can deal with the feed water quality. Increased operating costs are associated with the cold lime softening and the desalination plant. Additional costs are also incurred with the off-site disposal of salt crystals
500	The power station water infrastructure will be substantially upgraded by the construction of a desalination plant expansion as well as a new evaporator / crystalliser plant. Increased operating costs are associated with cold lime softening (also now requiring soda ash), desalination plant, evaporator / crystalliser plant and off-site salt crystals disposal.

4.8 Water quality impact on power station costs

The operating costs as determined by Eskom for the different water qualities from the different sources are summarised in the tables below. The source for Lethabo and Grootvlei Power Stations was Vaal Dam with Grootdraai Dam being the source for Tutuka, Matla and Kriel. The costs are divided into operating and capital costs. The operating costs are given in **Table 16** and the capital costs in **Table 17**.

Table 16 : Summary of operating costs (R/month) for power stations with different intake water quality

Power Station	TDS concentration (mg/ℓ) of intake water				
	140 (20 mS/m)	175 (25 mS/m)	210 (30 mS/m)	280 (40 mS/m)	350 (50 mS/m)
Lethabo	513 022	1 042 820	1 202 033		9 956 265
Grootvlei	47 116	391 606	404 798		1 471 329
Tutuka (option 1)	1 387 783	1 487 792	1 596 249	1 848 205	-
Tutuka (option 2)	3 265 600	3 362 404	3 469 749	3 707 120	-
Kriel	315 829	455 622	538 640	809 934	-
Matla	354 702	513 893	605 834	686 262	-

Note that apart from Tutuka Option two and Lethabo (50mS/m) it is assumed that all the additional salts could be disposed on the ash and no costs were included manage the long-term liability.

Table 17 : Summary of capital costs (million Rand) for power stations with different intake water qualities

Power Station	TDS concentration (mg/ℓ) of intake water				
	140 (20 mS/m)	175 (25 mS/m)	210 (30 mS/m)	280 (40 mS/m)	350 (50 mS/m)
Lethabo	0	0	0	0	153
Grootvlei	0	11	11	-	93
Tutuka (option 1)	0	0	0	0	-
Tutuka (option 2)	133	135	140	158	-
Kriel	0	0	0	0	-
Matla	0	0	0	0	-

For the modelling, 20 mS/m is taken as the current intake water quality for which the power stations have been designed. Any increase in the conductivity of the intake water above 20 mS/m will mean that Eskom will incur additional operating costs. The additional costs above the 20 mS/m basis are listed in **Table 18**.

Table 18 : Power Station operating costs (R/month) above the 20 mS/m base

Power Station	TDS concentration (mg/ℓ) of intake water				
	140 (20 mS/m)	175 (25 mS/m)	210 (30 mS/m)	280 (40 mS/m)	350 (50 mS/m)
Lethabo	0	529 798	699 011		9 443 243
Grootvlei	0	344 490	357 682		1 424 213
Tutuka (option 1)	0	100 009	208 467	460 423	-
Tutuka (option 2)	0	96 804	204 149	441 520	-
Kriel	0	139 793	222 811	494 105	-
Matla	0	159 191	251 132	331 560	-

5 INDUSTRY (SASOL)

Sasol is a large petrochemical company that converts oil, coal and natural gas to transportation fuels and chemicals, including gases, solvents, polymers and wax products. Sasol has two large facilities in South Africa:

- Sasol operations in Sasolburg, drawing intake water from the Vaal River at Lethaba weir, downstream of the Vaal Dam. Water can also be drawn from the Vaal Barrage but this offtake is not often used due to the water quality of the Vaal Barrage water being unsuitable.
- Sasol Synfuels in Secunda, drawing intake water from the Vaal River at Grootdraai Dam. This water supply will soon be augmented by water from the Vaal Dam via the new (VRESAP) Vaal Dam Pipeline.

Sasol utilises water for a number of processes, including steam generation, cooling, and ash handling.. The Sasol facilities have large integrated water systems.

Sasol was approached to develop an understanding of the potential impacts associated with increasing salinity of intake water on the mainly process use of water. A detailed assessment of the impacts would require a comprehensive process water and salinity mass balance model. Such a model must be able to simulate the changes in water flow and TDS in the Sasol complexes water circuits, as a result of increasing intake water TDS concentrations.

The simulated process water flows and TDS concentrations would then provide an understanding of the impacts of different processes and would be the basis for evaluating process water circuits modifications to deal with the higher intake water salinity. The impacts could then be quantified in terms of:

- Capital investment required to upgrade water treatment facilities
- Capital investment required for the increased waste (sludge/brine) production and the associated disposal costs
- O&M cost increases associated with the higher feed water salinity treatment and waste disposal.

However, this approach was considered to be overly complicated, time consuming and costly. An alternative approach had to be developed to assess the impact of a high salinity feed water. The alternative approach to assess these impacts is based on the following:

- The current water supply and associated median salinity were established as the base line or reference situation
- A fraction of the more saline intake water would be treated on a sidestream to effectively desalinate this water

- The sidestream desalinated water would be blended back into the mainstream flow feeding the Sasol factory complex
- The concentrated brine from the side stream desalination process would be further treated in an evaporation/crystallisation (E/C) plant to reduce the waste stream volume
- The low TDS condensate from the evaporation/crystallisation plant would also be blended back into the mainstream flow to the factory
- The concentrated salt crystals from the evaporator/crystallisation plant would be disposed to a licensed hazardous land fill.

The approach to the pre-treatment of the more saline intake water is reflected in **Figure 8**.

The objectives of the side-stream desalination treatment of a fraction of the intake water are twofold:

- Maintain the salinity of the blended intake water to the factory at the same level as the current reference situation
- Maintain the total intake water volume to the factory at the current reference level.

The technical and financial evaluation of the side-stream desalination treatment of the intake water was based on the following assumptions:

- Sufficient intake water would be diverted to the side-stream desalination treatment to maintain the main feed stream to the factory of the base line salinity levels
- Ultrafiltration/reverse osmosis (UF/RO) was selected as the most appropriate desalination treatment technology. The main unit treatment processes were assumed to operate at the following water recoveries:
    - ultrafiltration @ 90 %
    - reverse osmosis @ 95 %.
- The evaporator/crystalliser would recover 95 % of the water contained in the saline brine reject stream
- The UF/RO desalinated water is treated to the baseline intake water TDS concentration of 178 mg/ℓ and the E/C condensate water was assumed to be in essence salt free (TDS = 0 mg/ℓ).

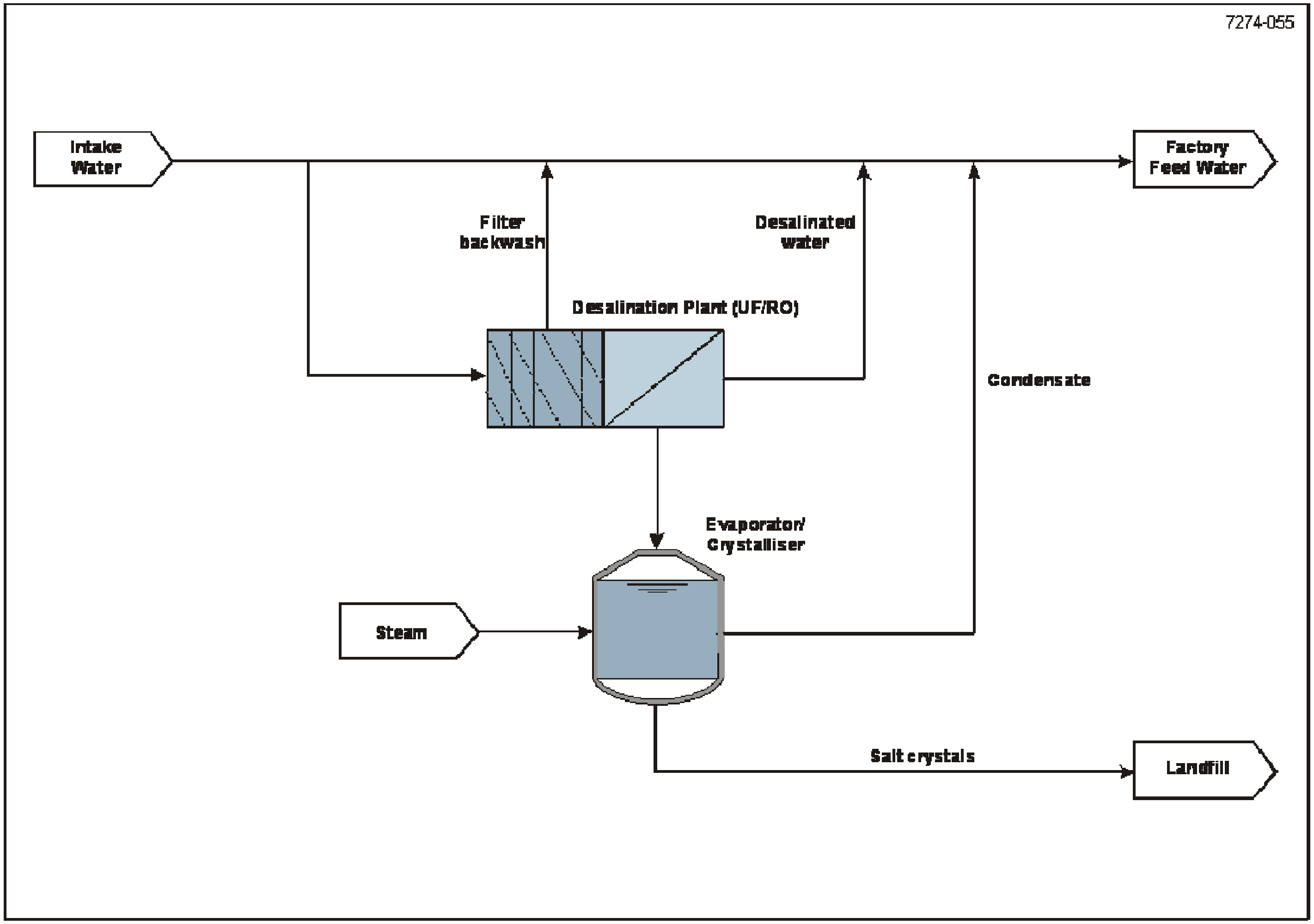

Figure 8: Conceptual Layout of Sasol Intake Water Treatment

The capital and operating cost estimates were prepared at an indicative level of accuracy (± 35 %) based on the following assumptions:

- The UF/RO capital cost was estimated, based on a reference plant, which was recently costed in a proposal as R63.6 million to treat 44 Mℓ/day. Sasol also applies a multiplier of 2.5 to calculate the total project capital investment cost
- The evaporation/crystalliser (E/C) capital cost was estimated based on a reference plant, which was recently constructed for R30.3 million and treating 246 m^3/day.

The capital investment cost for different sizes of desalination plants is calculated using the equation:

- C_2 = $Co (Q_2/Q_o)^N$
- Where Co = reference plant capital investment (R million)
- C_2 = new project capital investment cost (R million)
- Q_o = reference plant treatment capacity (Mℓ/day)
- Q_2 = new plant treatment capacity (Mℓ/day)
- N = 0.75 for the RO and UF and 0.6 for the E/C.

The estimated operating and maintenance costs were as follows:

- UF/RO treatment = R5.00/m^3
- E/C treatment = R20/m^3
- Salt waste disposal = R1500/ton.

Sasol Sasolburg Complex

The technical and financial evaluation of different intake water salinity profiles was performed to reflect the impacts of potential future increased Vaal River salinity. The main water-related features of the current base case and the possible salinity scenarios are summarised in **Table 19**.

Table 19: Summary of the main water-related features of the current base case and the salinity scenarios (Sasolburg)

Parameters	Base Case	Scenario		
		1	2	2
Intake water volume (Mℓ/day)	56	56	56	56
Salinity of intake water: - mS/m - mg/ℓ TDS	 25 167	 30 208	 40 294	 73 450
Side-stream treatment plant capacity (Mℓ/day)	-	11.1	24.4	35.5
Side-stream treatment as a fraction of intake water (%)	-	20	43	63
Evaporation/crystalliser capacity (ton/hour)	-	21	46	67

The estimated total capital investment, O&M cost associated with the different scenarios are summarised in **Table 20**.

Table 20: Estimated total capital investment, O&M cost associated with the different scenarios (Sasolburg)

Parameters	Scenario		
	1	2	3
Capital investment cost (R million) - UF/RO plant - E/C plant - Total	 R47.4 R117.5 R164.9	 R85.4 R188.2 R273.6	 R113.2 R235.7 R348.9
Operations and maintenance cost (R million/year) - UF/RO plant - E/C plant - Waste disposal - Total	 R18.3 R3.6 R13.7 R35.6	 R40.0 R8.0 R30.0 R78.0	 R58.3 R11.7 R43.7 R113.7
Unit cost : - Capital investment for side stream treatment (R million per Mℓ/day capacity) - Unit operating cost of side stream treatment (R/m^3 treated) - Current raw water cost (R/m^3 intake) - Incremental operating cost associated with desalination (R/m^3)	 R14.9 R8.79 R2.36 R1.74	 R11.2 R8.79 R2.36 R3.82	 R9.8 R8.79 R2.36 R5.56

Sasol Secunda Complex

The technical and financial evaluation of different intake water salinity profiles was performed to reflect the impacts of potential future increased Vaal River salinity. The main water-related features of the current base case and the possible salinity scenarios are summarised in **Table 21.**

Table 21: Summary of the main water-related features of the current base case and the salinity scenarios (Secunda)

Parameters	Base Case	Scenario		
		1	2	2
Intake water volume (Mℓ/day)	255	255	255	255
Salinity of intake water: - mS/m - mg/ℓ TDS	 25 178	 30 214	 35 249	 40 285
Side-stream treatment plant capacity (Mℓ/day)	-	42.5	72.9	95.6
Side-stream treatment as a fraction of intake water (%)	-	17	29	37
Evaporation/crystalliser capacity (ton/hour)	-	77	137	179

The estimated total capital investment, O&M cost associated with the different scenarios are summarised in **Table 22**:

Table 22: Estimated total capital investment, O&M cost associated with the different scenarios (Secunda)

Parameters	Scenario		
	1	2	3
Capital investment cost (R million) - UF/RO plant - E/C plant - Total	 R129.7 R262.7 R392.4	 R194.3 R363.0 R557.3	 R238.2 R427.4 R665.6
Operations and maintenance cost (R million/year) - UF/RO plant - E/C plant - Waste disposal - Total	 R69.8 R14.0 R52.3 R136.1	 R119.7 R23.9 R89.8 R233.4	 R157.0 R31.4 R117.8 R306.2
Unit cost : - Capital investment for side stream treatment (R million per Mℓ/day capacity) - Unit operating cost of side stream treatment (R/m^3 treated) - Current raw water cost (R/m^3 intake) - Incremental operating cost associated with desalination (R/m^3)	 R9.2 R8.77 R2.36 R1.46	 R7.6 R8.77 R2.36 R2.51	 R7.0 R8.77 R2.36 R3.29

6 CONCLUSIONS

The following conclusions can be made as a result of this investigation:-

- The unit domestic sector costs exclude the economic impact on the industries that are directly supplied by a WSP. These are generally small water users. If there are large water users sensitive to water quality then the approach used in assessing Sasol should be applied to these industries. A possible application of this approach is Sappi Enstra supplied by Rand Water.

- Herold (pers. comms) was a member of the study team which undertook an economic assessment of the disbenefit of salinity on the water users in 1987. The analysis included some of the larger industrial water users. The unit cost in 1987 Rands was 0.06 c/m^3/(mg/ℓ). Applying the CPI to convert to 2006 Rands gives a unit cost of 0.54 c/m^3/(mg/ℓ) which is comparable to the unit costs given in **Table 6**.

- The reduction in gross margins for the agricultural sector only starts when the soil salinity reaches 600 mg/ℓ for the more sensitive crops. Thereafter there is a sharp reduction in the gross margins with increasing soil salinity. A factor has been included in the model which converts the TDS concentration of the irrigation water to soil salinity. The factor depends on the soil types and the leaching fraction. For a typical leaching fraction of 15% to 20% applied at Vaalharts, a factor of 1.5 is considered reasonable.

- The assessment of the power stations showed that for the current water qualities, Eskom will not have to invest any capital to be able to operate. Only Tutuka Power Station may require an evaporator/crystalliser if the ashing facility cannot cope with the additional effluents.

- The additional operating costs for the power stations from the base EC of 20 mS/m are relatively low for the current 95 percentile intake water quality (EC of 25 mS/m).

- The approach used to assess the impact on the two Sasol plants is not optimal. The accuracy of the costs is adequate to provide an initial assessment of the efficacy of the water quality management options. If the use of poorer quality water by Sasol is found to be economically attractive then the costs should be revisited.

7 REFERENCES

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APPENDIX A

DETAILED POWER STATION COST BREAKDOWNS

LETHABO POWER STATION

Calculated Water Balance

	Vaal Barage EC	450
Window Period	Days	**1**

Effluent Sink		
Fly ash conditioning	Ml	0.953
Retention on coarse ash	Ml	1.106
Evaporation during coarse ash quenching	Ml	0.627
Evaporation from the ash dump dirty dams	Ml	0.417
Ash dump dust suppression	Ml	1.080
Total Effluent sink capacity	**Ml**	**4.183**
Effluents		
Demin and Condensate polishing effluents	Ml	0.342
Cooling water sludge	Ml	1.236
Chemical drains sump effluents	Ml	0.100
Rain water ingress into dirty dams	Ml	0.683
Rain water ingress into mine pit area from ash dump phase	Ml	0.210
Cooling water blow downs	Ml	27.286
Total effluents	**Ml**	**29.856**
Effluent excess	**Ml**	**25.673**
Desalination requirement to match effluents with sink	Ml	**34.338**
Desalination plant brine to be disposed at current desalination plant efficiency	Ml	**6.868**
Sink available for effluent disposal through ash conditioning and ash quenching	Ml	**2.686**
Total concentrated effluents following desalination of cooling water blow-downs	Ml	**8.545**
Brine concentration	Ml	**5.859**

Cost

Lime	R for window	R 17,769.28
Soda ash	R for window	R 23,183.62
Desalination plant operating cost	R for window	R 58,374.60
Evaporation Plant operating cost	R for window	R 63,866.95
Off site salt disposal	R for window	R 41,693.29
Cost of capital	R for window	R 509,733.85
Total for operating cost	R for window	R 714,621.59

Additional Capital

Desalination plant		R 111,689,994
Evaporator Crystallizer		R 260,415,718
Total additional capital		R 372,105,713

Basis for calculation:

Station load factor		0.81
Season		An Average
Rainfall	**mm per annum**	639
Coal burn rate	Tons per GW hr so	670
Coal ash content (as received basis)	**%**	39.78
Fly to coarse ash ratio	**%**	90:10
Moisture retention on coarse ash	**%**	60
Moisture retention on fly ash	**%**	9
Ash sales	Tons per day	6000
Desalination plant water recovery rate	**%**	80
Desalination plant salt rejection rate	**%**	93
Mine water intake	Ml	8.000
Demineralised water consumption rate	m^3 GW hr so	45

LETHABO POWER STATION

Calculated Water Balance

	Vaal EC	25
Window Period	Days	**1**
Effluent Sink		
Fly ash conditioning	Ml	0.953
Retention on coarse ash	Ml	1.106
Evaporation during coarse ash quenching	Ml	0.627
Evaporation from the ash dump dirty dams	Ml	0.417
Ash dump dust suppression	Ml	1.080
Total Effluent sink capacity	**Ml**	**4.183**
Effluents		
Demin and Condensate polishing effluents	Ml	0.342
Cooling water sludge	Ml	0.774
Chemical drains sump effluents	Ml	0.100
Rain water ingress into dirty dams	Ml	0.683
Rain water ingress into mine pit area from ash dump phase	Ml	0.210
Cooling water blow downs	Ml	6.005
Total effluents	**Ml**	**8.112**
Effluent excess	**Ml**	**3.930**
Desalination requirement to match effluents with sink	Ml	**5.256**
Desalination plant brine to be disposed at current desalination plant efficiency	Ml	**1.051**
Sink available for effluent disposal through ash conditioning and ash quenching	Ml	**2.686**
Total concentrated effluents following desalination of cooling water blow-downs	Ml	**2.267**
Brine concentration	Ml	**0.000**

Cost

Lime	R for window	R 12,555.62
Soda ash	R for window	R 0.00
Desalination plant operating cost	R for window	R 8,935.40
Evaporation Plant operating cost	R for window	R 0.00
Off site salt disposal	R for window	R 12,793.47
Cost of capital	R for window	R 0.00
Total for operating cost	R for window	R 34,284.49

Additional Capital

Desalination plant		R 0
Evaporator Crystallizer		R 0
Total additional capital		R 0

Basis for calculation:

Station load factor		0.81
Season		An Average
Rainfall	**mm per annum**	639
Coal burn rate	Tons per GW hr so	670
Coal ash content (as received basis)	**%**	39.78
Fly to coarse ash ratio	**%**	90:10
Moisture retention on coarse ash	**%**	60
Moisture retention on fly ash	**%**	9
Ash sales	Tons per day	6000
Desalination plant water recovery rate	**%**	80
Desalination plant salt rejection rate	**%**	93
Mine water intake	Ml	8.000
Demineralised water consumption rate	m^3 GW hr so	45

LETHABO POWER STATION

Calculated Water Balance

	Vaal EC	50
Window Period	Days	**1**
Effluent Sink		
Fly ash conditioning	Ml	0.953
Retention on coarse ash	Ml	1.106
Evaporation during coarse ash quenching	Ml	0.627
Evaporation from the ash dump dirty dams	Ml	0.417
Ash dump dust suppression	Ml	1.080
Total Effluent sink capacity	**Ml**	**4.183**
Effluents		
Demin and Condensate polishing effluents	Ml	0.342
Cooling water sludge	Ml	1.141
Chemical drains sump effluents	Ml	0.100
Rain water ingress into dirty dams	Ml	0.683
Rain water ingress into mine pit area from ash dump phase	Ml	0.210
Cooling water blow downs	Ml	15.823
Total effluents	**Ml**	**18.298**
Effluent excess	**Ml**	**14.115**
Desalination requirement to match effluents with sink	Ml	**18.879**
Desalination plant brine to be disposed at current desalination plant efficiency	Ml	**3.776**
Sink available for effluent disposal through ash conditioning and ash quenching	Ml	**2.686**
Total concentrated effluents following desalination of cooling water blow-downs	Ml	**5.358**
Brine concentration	Ml	**2.672**

Cost

Lime	R for window	R 18,084.56
Soda ash	R for window	R 14,100.07
Desalination plant operating cost	R for window	R 32,093.72
Evaporation Plant operating cost	R for window	R 29,125.27
Off site salt disposal	R for window	R 24,130.09
Cost of capital	R for window	R 209,795.57
Total for operating cost	R for window	R 327,329.27

Additional Capital

Desalination plant		R 34,393,288
Evaporator Crystallizer		R 118,757,474
Total additional capital		R 153,150,763

Basis for calculation:

Station load factor		0.81
Season		An Average
Rainfall	**mm per annum**	639
Coal burn rate	Tons per GW hr so	670
Coal ash content (as received basis)	**%**	39.78
Fly to coarse ash ratio	**%**	90:10
Moisture retention on coarse ash	**%**	60
Moisture retention on fly ash	**%**	9
Ash sales	Tons per day	6000
Desalination plant water recovery rate	**%**	80
Desalination plant salt rejection rate	**%**	93
Mine water intake	Ml	8.000
Demineralised water consumption rate	m^3 GW hr so	45

LETHABO POWER STATION

Calculated Water Balance

	Vaal EC	30
Window Period	Days	**1**
Effluent Sink		
Fly ash conditioning	Ml	0.953
Retention on coarse ash	Ml	1.106
Evaporation during coarse ash quenching	Ml	0.627
Evaporation from the ash dump dirty dams	Ml	0.417
Ash dump dust suppression	Ml	1.080
Total Effluent sink capacity	**Ml**	**4.183**
Effluents		
Demin and Condensate polishing effluents	Ml	0.342
Cooling water sludge	Ml	0.881
Chemical drains sump effluents	Ml	0.100
Rain water ingress into dirty dams	Ml	0.683
Rain water ingress into mine pit area from ash dump phase	Ml	0.210
Cooling water blow downs	Ml	6.793
Total effluents	**Ml**	**9.008**
Effluent excess	**Ml**	**4.826**
Desalination requirement to match effluents with sink	Ml	**6.454**
Desalination plant brine to be disposed at current desalination plant efficiency	Ml	**1.291**
Sink available for effluent disposal through ash conditioning and ash quenching	Ml	**2.686**
Total concentrated effluents following desalination of cooling water blow-downs	Ml	**2.613**
Brine concentration	Ml	**0.000**

Cost

Lime	R for window	R 14,839.48
Soda ash	R for window	R 0.00
Desalination plant operating cost	R for window	R 10,972.01
Evaporation Plant operating cost	R for window	R 0.00
Off site salt disposal	R for window	R 14,036.18
Cost of capital	R for window	R 0.00
Total for operating cost	R for window	R 39,847.67

Additional Capital

Desalination plant		R 0
Evaporator Crystallizer		R 0
Total additional capital		R 0

Basis for calculation:

Station load factor		0.81
Season		An Average
Rainfall	**mm per annum**	639
Coal burn rate	Tons per GW hr so	670
Coal ash content (as received basis)	**%**	39.78
Fly to coarse ash ratio	**%**	90:10
Moisture retention on coarse ash	**%**	60
Moisture retention on fly ash	**%**	9
Ash sales	Tons per day	6000
Desalination plant water recovery rate	**%**	80
Desalination plant salt rejection rate	**%**	93
Mine water intake	Ml	8.000
Demineralised water consumption rate	m^3 GW hr so	45

LETHABO POWER STATION
Calculated Water Balance

	Vaaldam EC	20
Window Period	Days	**1**
Effluent Sink		
Fly ash conditioning	Ml	0.953
Retention on coarse ash	Ml	1.106
Evaporation during coarse ash quenching	Ml	0.627
Evaporation from the ash dump dirty dams	Ml	0.417
Ash dump dust suppression	Ml	1.080
Total Effluent sink capacity	**Ml**	**4.183**
Effluents		
Demin and Condensate polishing effluents	Ml	0.342
Cooling water sludge	Ml	0.657
Chemical drains sump effluents	Ml	0.100
Rain water ingress into dirty dams	Ml	0.683
Rain water ingress into mine pit area from ash dump phase	Ml	0.210
Cooling water blow downs	Ml	5.146
Total effluents	**Ml**	**7.137**
Effluent excess	**Ml**	**2.954**
Desalination requirement to match effluents with sink	Ml	**3.952**
Desalination plant brine to be disposed at current desalination plant efficiency	Ml	**0.790**
Sink available for effluent disposal through ash conditioning and ash quenching	Ml	**2.686**
Total concentrated effluents following desalination of cooling water blow-downs	Ml	**1.889**
Brine concentration	Ml	**0.000**

Cost

Lime	R for window	R 10,148.72
Soda ash	R for window	R 0.00
Desalination plant operating cost	R for window	R 6,717.77
Evaporation Plant operating cost	R for window	R 0.00
Total for operating cost	R for window	R 16,866.49

Basis for calculation:

Station load factor		0.81
Season		An Average
Rainfall	**mm per annum**	639
Coal burn rate	Tons per GW hr so	670
Coal ash content (as received basis)	**%**	39.78
Fly to coarse ash ratio	**%**	90:10
Moisture retention on coarse ash	**%**	60
Moisture retention on fly ash	**%**	9
Ash sales	Tons per day	6000
Desalination plant water recovery rate	**%**	80
Desalination plant salt rejection rate	**%**	93
Mine water intake	Ml	8.000
Demineralised water consumption rate	m^3 GW hr so	45

LETHABO POWER STATION

Calculated Water Balance

	Vaaldam	EC=15
Window Period	Days	**1**
Effluent Sink		
Fly ash conditioning	Ml	0.953
Retention on coarse ash	Ml	1.106
Evaporation during coarse ash quenching	Ml	0.627
Evaporation from the ash dump dirty dams	Ml	0.417
Ash dump dust suppression	Ml	1.080
Total Effluent sink capacity	**Ml**	**4.183**
Effluents		
Demin and Condensate polishing effluents	Ml	0.342
Cooling water sludge	Ml	0.582
Chemical drains sump effluents	Ml	0.100
Rain water ingress into dirty dams	Ml	0.683
Rain water ingress into mine pit area from ash dump phase	Ml	0.210
Cooling water blow downs	Ml	4.962
Total effluents	**Ml**	**6.878**
Effluent excess	**Ml**	**2.696**
Desalination requirement to match effluents with sink	Ml	**3.606**
Desalination plant brine to be disposed at current desalination plant efficiency	Ml	**0.721**
Sink available for effluent disposal through ash conditioning and ash quenching	Ml	**2.686**
Total concentrated effluents following desalination of cooling water blow-downs	Ml	**1.745**
Brine concentration	Ml	**0.000**

Cost

Lime	R for window	R 8,741.50
Soda ash	R for window	R 0.00
Desalination plant operating cost	R for window	R 6,129.41
Evaporation Plant operating cost	R for window	R 0.00
Total for operating cost	R for window	R 14,870.91

Basis for calculation:

Station load factor		0.81
Season		An Average
Rainfall	**mm per annum**	639
Coal burn rate	Tons per GW hr so	670
Coal ash content (as received basis)	**%**	39.78
Fly to coarse ash ratio	**%**	90:10
Moisture retention on coarse ash	**%**	60
Moisture retention on fly ash	**%**	9
Ash sales	Tons per day	6000
Desalination plant water recovery rate	**%**	80
Desalination plant salt rejection rate	**%**	93
Mine water intake	Ml	8.000
Demineralised water consumption rate	m^3 GW hr so	45

Basis for calculations

1. It was assumed that all power stations operate on base load and achieve a 90% availability and 90% load factor while available.
2. Water qualities used are as submitted for the different systems
3. Current and committed to recovery of 3rd Party waste water was included in the calculations.
4. The cooling water de-carbonation options are in accordance with the status quo. All stations on lime apart from Grootvlei Power Station where sulphuric acid is used for de-carbonation of the cooling water.
5. Off site salt disposal is based on R900 per ton
6. Operation cost of the desalination plants exclude the cost of capital and is in accordance with Eskom's experience R1600 / Ml feed water.
7. Evaporator Crystalliser Plants are cost in accordance with Industry experience. Capacity and thus capital expenditure allows for limitations with respect to the availability of this technology
8. Evaporator Crystalliser Plant operating cost is in accordance with industry experience (R9000 per Ml feed) and exclude the cost of capital

Grootvlei Power Station - Operating cost with varying Vaal Dam water quality

Parameter	Units	Value	Value	Value	Value	Value
Electrical conductivity	mSm^{-1}	15	20	25	30	50 Note 3
Capex[1]	Rands	Nil	Nil	R11 Million Note 1	R11 Million	R11 Million R 82 Million Note 2
De-carbonation of cooling water with sulphuric acid	Rands per annum	R443 612	R565 388	R 748 052	R 906 361	Not feasible
Opex Desalination plant excluding cost of capital	Rands per annum	Not required	Not required	R3 951 214	R3 951 214	R3 951 214
Opex Lime Soda Plant	Rands per annum	Not required	Not required	Not required	Not required	R 4 574 223
Opex Evaporator Crystalliser Plant	Rands per annum	Not required	Not required	Not required	Not required	R 4 599 000
Off site salt disposal	Rands per annum	Not required	Not required	Not required	Not required	R 4 531 500
Total Additional Capex	**Rands**	**Nil**	**Nil**	**R11 Million**	**R11 Million**	**R93 Million**
Total Opex[2]	**Rands per annum**	**R443 612**	**R565 388**	**R4 699 266**	**R4 857 575**	**R17 655 947**

[1] Nil Capex in this case refers to no additional expenditure over and above plant which is already in place.
[2] Excludes to cost of capital

Note 1: Desalination plant is required to produce suitable quality feed water for the demineralisation plant as the quality of raw water abstracted at Vaal Marina is fluctuating and often of very poor quality. The desalination plant is also required to comply with Eskom’s ZLED Policy. Also note that the R11 Million Capex for the desalination plant is a once of expenditure and will be sufficient for all the water qualities listed.

Note 2: This expenditure entails the addition of a R10 million soda lime facility and R 72 Million for an Evaporator Crystalliser Plant. Note that some existing plant will be incorporated in the Lime Soda System hence the relatively low capital expenditure.

Note 3: Based on this water quality the soluble salt load on the ash system becomes excessive and off site salt disposal is thus incorporated.

Matla Power Station - Operating cost with varying Grootdraai Dam water quality

Parameter	Units	Value	Value	Value	Value
Electrical conductivity	mSm^{-1}	20	25	30	40
Effluent shortfall	Ml per day	12.8	12.9 Note 1	11.8	4.7 Note 2
Capex	Rands	Nil	Nil	Nil	Nil
De-carbonation of cooling water with sulphuric acid	Rands per annum	Not feasible	Not feasible	Not feasible	Not feasible
Opex Desalination plant excluding cost of capital	Rands per annum	Nil	Nil	Nil	Nil
Opex Cold Lime Softening[3]	Rands per annum	R4 256 428	R6 166 720	R7 270 010	R 8 235 145
Opex Lime Soda Plant	Rands per annum	Not required	Not required	Not required	Not required
Opex Evaporator Crystalliser Plant	Rands per annum	Not required	Not required	Not required	Not required
Off site salt disposal	Rands per annum	Not required	Not required	Not required	Not required
Total Additional Capex	**Rands**	**Nil**	**Nil**	**Nil**	**Nil**
Total Opex	**Rands per annum**	**R4 256 428**	**R6 166 720**	**R7 270 010**	**R8 235 145**

[3] Excludes the cost of capital

Note 1: Chloride the limiting parameter 25 EC water has a lower chloride concentration than 20 EC sample.

Note 2: Calcium sulphate the limiting parameter.

Note 3: Matla Power Station is not recovering any 3rd Party waste water hence the shortfall of effluents on sink. Desalination is thus not required.

Kriel Power Station - Operating cost with varying Grootdraai Dam water quality

Parameter	Units	Value	Value	Value	Value
Electrical conductivity	mSm^{-1}	20	25	30	40
Effluent shortfall	Ml per day	4.2	4.3	3.2	- 0.45
Capex	Rands	Nil	Nil	Nil	R 8 Million
De-carbonation of cooling water with sulphuric acid	Rands per annum	Not feasible	Not feasible	Not feasible	Not feasible
Opex Desalination plant excluding cost of capital	Rands per annum	Nil	Nil	Nil	R2 352 425
Opex Cold Lime Softening[4]	Rands per annum	R3 789 953	R5 467 464	R6 463 683	R7 366 789
Opex Lime Soda Plant	Rands per annum	Not required	Not required	Not required	Not required
Opex Evaporator Crystalliser Plant	Rands per annum	Not required	Not required	Not required	Not required
Off site salt disposal	Rands per annum	Not required	Not required	Not required	Not required
Total Additional Capex	**Rands**	**Nil**	**Nil**	**Nil**	**R8 Million**
Total Opex	**Rands per annum**	**R3 789 953**	**R5 467 464**	**R6 463 683**	**R9 719 214**

[4] Excludes the cost of capital

Note 1: Chloride the limiting parameter 25 EC water has a lower chloride concentration than 20 EC sample.

Note 2: Calcium sulphate the limiting parameter.

Note 3: Kriel Power Station is not recovering any 3rd Party waste water hence the shortfall of effluents on sink. Desalination is required for the 40 EC water as the Kriel Power Station demineralisation plant can't cope with this quality raw water.

Tutuka Power Station (Current operating regime) - Operating cost with varying Grootdraai Dam water quality

Parameter	Units	Value	Value	Value	Value
Electrical conductivity	mSm^{-1}	20	25	30	40
Capex Note 1	Rands	Note 1	Note 1	Note 1	Note 1
De-carbonation of cooling water with sulphuric acid	Rands per annum	Not feasible	Not feasible	Not feasible	Not feasible
Opex Desalination plant excluding cost of capital	Rands per annum	R10 652 805	R10 824 526	R11 249 758	R12 657 862
Opex Cold Lime Softening[5]	Rands per annum	R5 637 921	R6 484 983	R6 998 574	R7 308 351
Opex Lime Soda Plant	Rands per annum	Note 2	Note 2	Note 2	Note 2
Opex Evaporator Plant[5]	Rands per annum	R362 664	R543 996	R906 660	R2 212 250
Off site salt disposal	Rands per annum	No	No	No	No
Total Additional Capex	**Rands**	**Note 1**	**Note 1**	**Note 1**	**Note 1**
Total Opex	**Rands per annum**	**R16 653 390**	**R17 853 505**	**R19 154 992**	**R22 178 463**

[5] Excludes the cost of capital

Note 1: Tutuka Power Station has just spent R25 Million to increase the capacity of their desalination plant to 25 Ml per day feed capacity. The 2007 R value of the existing Desalination and Evaporation plant is estimated at R82 Million

Note 2: Mine water from the New Denmark contains no permanent hardness.

Note 3: Tutuka Power Station recovers on average 15Ml per day 3rd Party waste water (New Denmark mine water).

Tutuka Power Station (Complete with Evaporator Crystalliser and off site salt disposal, <u>a possible future requirement</u>))

Operating cost with varying Grootdraai Dam water quality

Parameter	Units	Value	Value	Value	Value
Electrical conductivity	mSm^{-1}	20	25	30	40
Capex Note 1	Rands	R132 795 244	R134 935 876	R140 236 706	R157 789 781
De-carbonation of cooling water with sulphuric acid	Rands per annum	Not feasible	Not feasible	Not feasible	Not feasible
Opex Desalination plant excluding cost of capital	Rands per annum	R10 652 805	R10 824 526	R11 249 758	R12 657 862
Opex Cold Lime Softening[6]	Rands per annum	R5 637 921	R6 484 983	R6 998 574	R7 308 351
Opex Lime Soda Plant	Rands per annum	Note 2	Note 2	Note 2	Note 2
Opex Evaporator Crystalliser Plant[5]	Rands per annum	R7 789 864	R7 915 435	R8 226 385	R9 256 061
Off site salt disposal	Rands per annum	R15 106 615	R15 123 912	R15 162 276	R15 263 165
Total Additional Capex	**Rands**	**R132 795 244**	**R134 935 876**	**R140 236 706**	**R157 789 781**
Total Opex	**Rands per annum**	**R39 187 205**	**R40 348 856**	**R41 636 993**	**R44 485 439**

[6] Excludes the cost of capital

Note 1: Tutuka Power Station has just spent R25 Million to increase the capacity of their desalination plant to 25 Ml per day feed capacity. The 2007 R value of the existing Desalination and Evaporation plant is estimated at R82 Million

Note 2: Mine water from the New Denmark contains no permanent hardness.

Note 3: Tutuka Power Station recovers on average 15Ml per day 3rd Party waste water (New Denmark mine water).