INVESTIGATION INTO THE COST AND OPERATION OF SOUTHERN AFRICAN DESALINATION AND WATER REUSE PLANTS

Volume III:
Best Practices on Cost and Operation of Desalination and Water Reuse Plants

KN Turner, K Naidoo, JG Theron, J Broodryk

WATER RESEARCH COMMISSION

TT 638/15

INVESTIGATION INTO THE COST AND OPERATION OF SOUTHERN AFRICAN DESALINATION AND WATER REUSE PLANTS

Volume III: Best Practices on Cost and Operation of Desalination and Water Reuse Plants

Report to the
Water Research Commission

by

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WRC Report No. TT 638/15

September 2015

Obtainable from

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The publication of this report emanates from the Water RRC project entitled *Investigation into the cost and operation of Southern African desalination and water reuse plants* (WRC Project No. K5/2121),

The report forms part of a series of three reports. The other reports in the series are:

Volume I: Overview of Desalination and Water Reuse **(WRC Report no. TT 636/15)**
Volume II: Current Status of Desalination and Water Reuse in Southern Africa **(WRC Report no. TT 637/15)**.

ISBN 978-1-4312-0700-8
Printed in the Republic of South Africa

EXECUTIVE SUMMARY

The aim of this research project was to capture real operational and maintenance data (with associated costs) of selected desalination and water reuse plants, as well as to establish a first-order knowledge base for these types of projects in the augmentation of water supply in a Southern African context. The results, conclusions and recommendations presented in the report are based on the information gathered from site visits, investigations, interpretation of information received from the plant operator, plant designer, local municipality, historical data and/or calculations. Where accurate information was not available, or accessible, reasonable assumptions have been made based on historical data or past performance in order to obtain meaningful results. Where there are gaps in the data collected, these shall be updated in the plant database (developed by this project) as more accurate information becomes available. Available plant cost data is referenced at the date of implementation or for the period for which data was collected. The capital expenditure (CAPEX) is then projected forward to the present (2014/15) financial year and the operational expenses (OPEX) is updated by using current rates where possible.

The seven existing plants investigated in the project are:

No.	Plant	Type of Plant
1	Mossel Bay 15 Mℓ/d SWRO plant	Desalination – direct potable
2	Sedgefield 1.5 Mℓ/d SWRO plant	Desalination – direct potable
3	Albany Coast 1.8 Mℓ/d SWRO plant	Desalination – direct potable
4	Beaufort West 2.1 Mℓ/d reclamation plant	Reuse – direct potable
5	Windhoek 21 Mℓ/d Goreangab reclamation plant	Reuse – direct potable
6	George 10 Mℓ/d UF plant (full capacity tested as 8.5 Mℓ)	Reuse – indirect potable
7	Mossel Bay 5 Mℓ/d UF/RO plant	Reuse – direct industrial

The desalination and water reuse plants in this study were selected based on their location and importance with respect to augmenting water supply in the associated regions. The projects implemented in the Southern Cape, were undertaken under emergency conditions during the 2009/10 drought period with considerable time pressure, which differentiate them from the projects not completed under such strict time constraints.

Since the initiation of this study, the Mossel Bay- and Sedgefield SWRO plants, as well as the George UF plant and Mossel Bay UF/RO plant have been kept mainly in zero production mode. Typically these plants are cleaned and flushed weekly, or every two weeks, with chemicals used as required to ensure that the plant and equipment is kept in good condition.

The case studies of plants that are currently in active operation, namely the Albany Coast SWRO plant, the Beaufort West reclamation plant and New Goreangab water reclamation plant (NGWRP) were all part of the medium to long term planning of the water supply authority, municipality or water board. One can conclude that strategic (medium/long term) planning is an essential component in the success and sustainability of desalination and water reuse plants.

The capital and operational costs associated with all of these plants are greatly influenced by the actual unit processes, including pre-treatment, that are employed to achieve the desired results. In addition, the abstraction of raw water, and the conveyance of product water can have a significant impact on the plant's capital and operating costs.

In the cost data provided in the report, only the normal elements within, or close to, the plant boundary are included so that comparisons between the different plants can be made. In the case of zero or low production, the unit cost of water is extremely high, and this decreases as the water production of a particular plant increases up to the full design capacity. Depending on the water demand and cost to meet the demand, operating rules and a strategy to optimise the cost of producing water can be developed. It is recommended that the most efficient operational mode, relevant to the specific plant circumstances and water demand requirements, is selected to optimise energy use and thus cost efficiency of the selected plant. Energy consumption is one the major contributors in the process selection and operation of seawater desalination plants. Seawater desalination RO plants are relatively energy intensive, typically consuming in the region 3.5 to 4.5 kWh per m³ of treated water. In comparison, conventional physical-chemical processes associated with reuse plants are far less energy intensive as discussed below.

The Mossel Bay-, Sedgefield- and Albany Coast seawater reverse osmosis (SWRO) plants were found to be in the range of 3.0 kWh/m³ to 4.5 kWh/m³ of treated water. In the case studies of George UF plant, and New Goreangab water reclamation plant (UF), the energy consumptions figures were typically in the range of 0.25 kWh/m³ to 0.60 kWh/m³. Reuse plants using reverse osmosis (RO), typically use 1 to 2 kWh of energy per m³ of treated water.

The energy consumption of desalination and water reuse plants has a major impact on the overall operation and maintenance (O&M) cost of running/maintaining these plants. In seawater desalination particularly, the electricity costs are typically in excess of 50% of the total O&M costs, while that for reuse plants is in the range 10% to 25% of the total O&M costs.

Lessons learnt and best practices from the case studies are captured in Chapter 4 of this report. Some of these considerations include:

- Running the plant at higher capacities during off-peak times where time of use (TOU) tariffs are lower than during peak hours can lead to significant reduction in the power costs.
- Plants that are maintained in a zero production mode may benefit from doing their regular maintenance procedures such as CIPs, CEBs during cleaning and flushing of membranes and performance tests during off-peak tariff hours.
- Ensuring Ultra-Filtration/Reverse Osmosis (UF/RO) membrane integrity is maintained in optimal condition for as long as possible is a vital factor in the life cycle of reuse plants. Extending the period between membrane replacements (typically every 4 to 5 years) has significant impact on overall cost effectiveness, sustainability and lifespan of the plant.
- The implementation of an effective monitoring program is essential to ensure both the plant and UF/RO membranes are in optimal operating condition.
- Membrane replacement has major financial implications in the operation and maintenance of these plants.
- Regular monitoring, recording and interpretation of laboratory analyses and plant measurements is an essential part of day-to-day operations and troubleshooting. This is to ensure the plant operates optimally and that all physical (and chemical) barriers are maintained.

The focus of plant operation and maintenance should be to ensure that the integrity of the plant is protected and kept in excellent working condition at all times. A brief summary of the O&M costs for each of the plant case studies is presented on the following page:

Desalination Plants			
Plant	Mossel Bay SWRO plant	Sedgefield SWRO plant	Albany Coast SWRO plant
Size of Plant	15 Mℓ/d	1.5 Mℓ/d	1.8 Mℓ/d
Type of Plant	Desalination: Direct potable	Desalination: Direct potable	Desalination: Direct potable
Owner	Mossel Bay Municipality	Knysna Municipality	Amatola Water
Operator	VWS (Veolia)	Knysna Municipality	Amatola Water
Operational Status	Zero production	Zero production	1.8 Mℓ/day
Completed	2010/11	2009	1997, extension 2008
Capital Cost - at time of construction - Adjusted for 2014/15 - Per unit capacity	 R207 mill R266 mill R17.74 mill/Mℓ/day	 R16 mill R22 mill R14.66 mill/Mℓ/day	 R28 mill R36 mill R21.65 mill/Mℓ/day
O&M Cost (2014/15)	R6.81/m³	R7.16/m³	R9.00/m³
Energy Use	4.39 kWh/m³	3.97 kWh/m³	4.52 kWh/m³
Electricity Cost	R3.37/m³	R3.14/m³	R4.18/m³ (ERD rental R0.53/m³)
Chemicals	R2.16/m³	R0.70/m³	R0.39/m³
Consumables			R0.20/m³
Maintenance	R0.58/m³	R0.52/m³	R1.97/m³
Staff	R0.62/m³	R2.58/m³	R1.47/m³
Laboratory Cost	R0.04/m³	R0.11/m³	R0.15/m³
SHEQ	R0.04/m³	R0.11/m³	R0.10/m³

Water Reuse Plants				
Plant	Beaufort West reclamation plant	Windhoek Goreangab reclamation plant	George UF plant	Mossel Bay UF/RO plant
Size of Plant	2.1 Mℓ/d	21 Mℓ/d	8.5 Mℓ	5 Mℓ/d
Type of Plant	Reuse: Direct potable	Reuse: Direct potable	Reuse: Indirect potable	Reuse: Direct industrial
Owner	Beaufort West Municipality	Windhoek Municipality	George Municipality	Mossel Bay Municipality
Operator	Water & Wastewater Eng.	Wingoc	George Municipality	VWS (Veolia)
Operational Status	1.2 Mℓ/day	17.5 Mℓ/day	Zero production	Zero production
Completed	2010	2001	2010	2010
Capital Cost - at time of construction - Adjusted for 2014/15 - Per unit capacity	 R26.5 mill R34 mill R16.22 mill/Mℓ/day	 R122 mill R260 mill R12.38 mill/Mℓ/day	 R36 mill (plant) R46 mill R5.14 mill/Mℓ/day	 R40 mill R51 mill R10.19 mill/Mℓ/day
O&M Cost (2014/15)	R6.92/m³	R4.87/m³	R2.11/m³	R2.72/m³
Energy Use	2.07 kWh/m³	0.57 kWh/m³	0.23 kWh/m³	0.73 kWh/m³
Electricity Cost	R1.88/m³	R0.57/m³	R0.23/m³	R0.64/m³
Chemicals	R0.85/m³	R1.55/m³	R0.44/m³	R0.18/m³
Consumables	R0.50/m³	R1.00/m³	R0.50/m³	R0.50/m³
Maintenance	R1.01/m³	R0.78/m³	R0.23/m³	R0.49/m³
Staff	R1.96/m³	R0.88/m³	R0.49/m³	R0.79/m³
Laboratory cost	R0.47/m³	R0.06/m³	R0.15/m³	R0.07/m³
SHEQ	R0.23/m³	R0.03/m³	R0.08/m³	R0.05/m³

- Costs are given in South African Rand and exclude VAT.
- All O&M values are estimates based on variables (e.g. rates based on historical data, inflation, etc.) and represent the cost as at full production.

The following selected recommendations should be considered from the case studies evaluated in this report:

1. Time of use (TOU) tariffs can be used to optimise cost effectiveness and responsible energy use.
2. Where possible, develop projects through Public Private Partnerships (PPP) or similar partnerships between O&M contractor and water supply authority, municipality or water board.
3. Long term service level agreements between O&M contractor and water supply authority, municipality or water board encourage long term, mutually beneficial relationships between the parties concerned.
4. O&M problems can often be dealt with by good O&M practices. Periodic reviews of O&M procedures is recommended for all desalination and water reuse plants, whether in operation or while in zero production mode.
5. On-going training and development of operational staff.
6. Sufficient planning and scenario analyses to identify future water demand needs should be implemented in the medium to long term operation of existing desalination and water reuse plants, as well as in the strategic planning of new plants.
7. CAPEX and OPEX should be considered equally important when analysing the feasibility and life cycle costs of desalination and water reuse plants. Operating costs can be significantly higher than anticipated (or understood) in relation to the initial capital costs.
8. Various operating modes and scenarios should be considered when evaluating O&M costs, i.e. zero production mode, different production modes, etc. before considering mothballing of any plant.
9. While frequent starting and stopping of the desalination or water reuse plant can minimise running costs, is not optimal for the membrane lifespan.
10. It is recommended to run plants periodically during zero production periods to maintain plant operational integrity. Scenario planning, treating the cause instead of the symptoms, etc. are important considerations.
11. Social aspects in water reuse plants are vital to the successful acceptance and sustainability of these plants in the communities they service.
12. It is recommended to further develop and populate the Royal HaskoningDHV in-house developed database to capture the data from other plants not included in this study.
13. It is recommended to further develop the database and costing models referenced in this study. Further collaboration with CD Swartz Water Utilisation Engineers is recommended to further develop the REUSECOST model and include the outputs/results in this report for various operating scenarios.
14. It is recommended to further develop the database tools for base lining and predicting O&M costs for various operating scenarios and plants. This will assist authorities with improved planning for O&M aspects associated with current, new or planned desalination and water reuse plants.

ACKNOWLEDGEMENTS

The project team wishes to thank the following people for their contributions to the project.

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- The financing of the project by the Water Research Commission and the contribution of the members of the Reference Group is acknowledged gratefully. The project was only possible with the cooperation of a number of individuals and institutions. The authors therefore wish to record their sincere thanks to all those, including those mentioned above, that contributed time and effort to assist the team.

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ACRONYMS & ABBREVIATIONS

ACIP	Accelerated Community Infrastructure Programme
ACWB	Albany Coast Water Board
AOP	Advanced Oxidation Processes
BAC	Biological Activated Carbon
BEE	Black Economic Empowerment
CAPEX	Capital Expenditure
CEB	Chemical Enhanced Backwash
CEC	Contaminant of emerging concern
CIP	Cleaning in Place
CMA	Catchment Management Agencies
CoGTA	Ministry for Cooperative Governance and Traditional Affairs
CPI	Consumer Price Inflation
DAF	Dissolved Air Flotation
DOC	Dissolved Organic Carbon
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation (formerly DWA)
ED	Electrodialysis
EDC	Endocrine Disrupting Compounds
EDR	Electrodialysis Reversal
EIA	Environmental Impact Assessment
ERD	Energy Recovery Device
GAC	Granular Activated Carbon
GDP	Gross Domestic Product
GWWTP	Gammams Wastewater Treatment Plant
HACCP	Hazard Analysis and Critical Control Points
HDD	Horizontal Directional Drilling
IPS	Institute of Polymer Science (University of Stellenbosch)
IRR	Internal Rate of Return
MED	Multi-effect distillation
MFMA	Municipal Finance Management Act
MIG	Municipal Infrastructure Grant
MISA	Municipal Infrastructure Support Agent
MOD	Manipulated Osmosis Desalination
MSA	Municipal Systems Act
MSF	Multi-stage-flash
MWIG	Municipal Water Infrastructure Grant
NACQ	Nominal Annual Compounded Quarterly
NF	Nanofiltration
NGO	Non-Governmental Organization
NGWRP	New Goreangab Water Reclamation Plant
NMBM	Nelson Mandela Bay Municipality
O&M	Operation and Maintenance
OEM	Original Equipment Manufacturer
OHS	Occupational Health and Safety
OPEX	Operating Expenditure
PAC	Powdered Activated Carbon
PFMA	Public Finance Management Act
PPP	Public Private Partnerships
PSA	Pressurised Swing Adsorption

PST	Primary Settling Tank
RBIG	Regional Bulk Infrastructure Grant
REUSECOST	WRC Water Reuse Costing Model
RHIG	Rural Households Infrastructure Grant
RO	Reverse osmosis
RWU	Regional Water Utilities
SCADA	Supervisory Control and Data Acquisition
SHEQ	Safety, Health, Environmental and Quality
SLA	Service Level Agreement
SST	Secondary Settling Tank
SWRO	Seawater Reverse osmosis
TBMs	Tunnel Boring Machines
TCTA	Trans-Caledon Tunnel Authority
TDS	Total Dissolved Solids
TMP	Transmembrane pressure
TOC	Total Organic Carbon
TOU	Time of Use
TRO	Tubular Reverse Osmosis
TSS	Total Suspended Solids
UAE	United Arab Emirates
UF	Ultrafiltration
USA	United States of America
USDG	Urban Settlements Development Grant
UV	Ultra-violet
VCD	Vacuum Compression Distillation
VFD	Vacuum Freeze Distillation
WABAG	Proprietary technology from VA TECH WABAG Ltd
WHO	World Health Organisation
WINGOC	Windhoek Goreangab Operating Company Ltd
WRC	Water Research Commission of South Africa
WRP	Water Reclamation Plant
WSA	Water Services Authority
WSOS	Water Services Operating Subsidy
WSP	Water Service Provider / Water Safety Plan
WWTP	Wastewater Treatment Plant
WWTW	Wastewater Treatment Work

UNITS OF MEASURE

μm	micrometre
μS/cm	microsiemens per metre
bar(g)	bar gauge pressure
kPa(g)	kiloPascal gauge pressure
kVA	kilovolt ampere
kWh	kiloWatt hour
m^3/h	cubic meter per hour
mg/ℓ	milligram per litre
mS/m	millisiemens/meter
NTU	Nephelometric Turbidity Units
ppm	parts per million

CHEMICAL FORMULAS

$CaCl_2$	Calcium Chloride
$CaCO_3$	Calcium Carbonate (Lime)
Cl_2	Chlorine gas
CO_2	Carbon Dioxide
$FeCl_3$	Ferric Chloride
H_2O_2	Hydrogen Peroxide
H_2SO_4	Hydrogen Sulphate (Sulphuric acid)
$KMnO_4$	Potassium Permanganate
N_2	Nitrogen gas
NaClO	Sodium Hypochlorite (bleach)
Na_2CO_3	Sodium Carbonate (Soda Ash)
NaOH	Sodium Hydroxide (Caustic Soda)
$Na_2S_2O_5$	Sodium Metabisulphite (also referred to SMBS)
O_3	Ozone

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

South Africa is generally a water scarce country and water could become the limiting factor in sustaining social and economic development in the region in the future. The problem has historically been addressed by exploiting and transferring fresh surface water supplies to economic hubs and the interior of the country through schemes such as the Tugela-Vaal and the Lesotho Highlands projects. However many coastal cities, particularly in the Western and Eastern Cape, as well as KwaZulu-Natal are gradually outgrowing the natural fresh water resources available to them. The country as a whole is reaching the stage where the fresh water resources within its boundaries are nearly fully utilised and it has become necessary to investigate and exploit alternative sources of "new water" to augment existing supplies.

This state of affairs is addressed in the Department of Water and Sanitation's (formerly Department of Water Affairs) National Desalination Strategy and the Draft National Strategy for Water Reuse (DWA, 2011), which highlight the need to consider desalination and reuse in future water supply schemes.

During the last three decades tremendous development and improvements in the use of membrane technology, both internationally and locally (Lipsett, 2012), have taken place. This allowed the technology to gain popularity in desalination (Than, 2011) and advanced water reclamation schemes (Wintgen et al., 2005) as a means of providing an alternate water resource.

Desalination by reverse osmosis is now considered as playing a considerable role in the future supply of water in South Africa by the general water community (Holman, 2010) and at ministerial level (Davis, 2010). To this end, a literature review was conducted on the topic of reuse and desalination to put the treatment approach and technology into context and provide an understanding of current state-of-the-art treatment processes and configurations and how these relate to the technology used at the plants investigated under this research project.

This report concentrates on seawater desalination by reverse osmosis at coastal locations. Although the inland desalination of brackish water sources (e.g. ground or surface water) is also of importance, the desalination plants included in this investigation relate to the production of potable water from seawater.

1.2 BACKGROUND AND RATIONALE

The selection of desalination and water reuse plants for this study covers a range of plant and process configurations, various product end uses, as well as a number of contractors and equipment suppliers. Each plant location and situation has different advantages and challenges to be evaluated for making the best decisions for implementation. Around 2009/10, the Southern and Eastern Cape regions of South Africa experienced the worst drought in known history, and to prevent the risk of complete water supply failure a number of desalination and water reuse projects were undertaken.

Data for the desalination plants at Knysna and Plettenberg Bay is also readily available, and so these plants may be used as comparisons and to provide supplementary data. There has been increasing pressure in recent years on surface water supply to meet the growth in water demand. Water reuse and desalination are now being considered as options both on a local/regional level in the Integrated Development Plans of city councils and municipalities, as well as in national strategies by the Department of Water and Sanitation. The Southern Cape has almost exhausted its terrestrial water resources, particularly as a result of the drought.

Furthermore, other parts of the Western Cape, Eastern Cape and KwaZulu-Natal are fast approaching the limits of the terrestrial water resources.

Without adequate freshwater resources, municipalities will have to consider desalination and water reuse to gain access to alternative, as yet less exploited water sources. Without sufficient water, economic growth is likely to stall, resulting in a decline in socioeconomic conditions. In addition to this, health standards are likely to decline. A substantial amount of literature exists in the public domain with respect to cost and water quality aspects for desalination and reuse plants. However, none of these provide real information on cost and water quality obtained from actual plants constructed in South Africa. This research project enhances the knowledge on the subject within the South African water community and will provide information relevant to the South African situation and context. This project entails gathering of cost, operational and other data associated with local (South African) desalination and water reuse plants that have been implemented recently and are planned for implementation in the near future.

The information gathered during the project will be of beneficial use to municipal engineers and the water community as a whole to define real costs for desalination and reuse. This may be used for more effective future planning and comparison of different water supply options.

1.3 PROJECT AIMS

The following were the aims of the project:

1. To evaluate and report on the various costs (capital and operating) of the desalination and reuse plants as a function of the quantity of water produced, as well as the various technologies used with focus on the progression from non-potable to potable desalination and reuse.
2. To report on the technical, as well as operational and maintenance challenges experienced in operating the desalination and reuse plants with reference to project implementation issues.
3. To provide concise Best Operating Practices to maximise production of desalinated and reclaimed water while at the same time ensuring the sustainability of the technology in terms of cost minimisation.
4. To provide a concise report on the various institutional models which can be used to finance and operate desalination plants with a view to minimising risk to the end-user.

1.4 SCOPE AND LIMITATIONS

For reasons of practicality and availability of useable and relevant information, the battery limits for the project were the seven existing desalination plants under investigation, namely:

No.	Plant	Type of Plant
1	Mossel Bay 15 Mℓ/d SWRO plant	Desalination – direct potable
2	Sedgefield 1.5 Mℓ/d SWRO plant	Desalination – direct potable
3	Albany Coast 1.8 Mℓ/d SWRO plant	Desalination – direct potable
4	Beaufort West 2.1 Mℓ/d reclamation plant	Reuse – direct potable
5	Windhoek 21 Mℓ/d Goreangab reclamation plant	Reuse – direct potable
6	George 10 Mℓ/d UF plant (full capacity tested at 8.5 Mℓ)	Reuse – indirect potable
7	Mossel Bay 5 Mℓ/d UF/RO plant	Reuse – direct industrial

1.5 METHODOLOGY

1.5.1 Overview of Desalination and Water Reuse

The initial task was to conduct a literature search on the topic of water reuse and desalination to put the process into context and provide an understanding of current state-of-the-art treatment processes and configurations, including how these relate to the technology used at the identified plants. During this period the researcher also made contact with the various collaborating parties to establish communication and flow of information, access specialised knowledge on the subject and determine what additional aspects they would like to see being addressed in the project.

1.5.2 Initial Plant Site Visits

Site visits were conducted to each of the selected plants for familiarisation with the technology and treatment processes employed. The visits also served as an introduction to the respective operational staff at the plants and to establish lines of communication for the reporting of data. A matrix to compare and contrast the different technologies in use at the various plants was developed.

1.5.3 Data Collection

Relevant capital cost data from projects was gathered from the respective project managers, plant designers and other sources. This mainly consisted of the original capital cost data from the implementation phase where information was available. Actual operating costs (e.g. electricity consumption and unit cost, chemicals, etc.) were sourced from monthly operating reports, as well as operating company and plant owner data.

Available water analysis results were obtained from the respective project managers, operating companies and clients. The primary source of information was the routine measurements from operational reports. Additional data was sourced by collecting data on specific samples for analysis by independent laboratories. The collected data was compiled in an Access database (refer to Section 8 for additional information). The data collection phase ran for most of the duration of the project in order to maximise the period of monitoring.

Throughout the project the database was used to convert the raw data to a useful and relevant form. This entailed the data being indexed against production (volume produced) and water quality parameters (e.g. feed, product), as well as other operational aspects (e.g. power and chemical consumption).

Summary tables and graphical output were generated, and cost data (CAPEX and OPEX) was compared by means of a Unit Rate approach. This is different from the Unit Reference Value (URV) method which was developed for the evaluation of projects in the water services sector and is widely use to evaluate the development of new water resource options. The URV approach is suited to comparing proposed schemes and options and therefore, in this study, the use of unit rates is considered more appropriate for the purposes of comparing and benchmarking existing plants.

The total unit rates are indicated as the total cost per one cubic metre (m^3) of water produced for the different cost categories (capital, operational, maintenance and all other associated costs) and the total overall unit cost. The costs are then also escalated to present costs to make the rates relevant today, and to make meaningful comparisons between the different plants.

1.5.4 Operational and Maintenance Challenges

Parallel to the data acquisition and conversion task was the gathering of information related to the operation and maintenance aspects of the plants. Visits to each of the selected plants were conducted on a regular basis to discuss the plant operation with the staff on site and to investigate and document further any problems that were experienced.

1.5.5 Best Practices

A section on best operating practices and lessons learnt for water reuse and desalination plants as a whole, based on the current situation at the identified plants and suggested changes for improvement with respect to performance and cost reductions, is presented in Chapter 4 of the report.

1.5.6 Funding and Institutional Considerations

Different models available for funding and operating desalination and water reuse plants were investigated and are presented in Chapter 2 of the Volume II report, as well as summarised in Chapter 4 of this volume.

CHAPTER 2: COST AND OPERATIONAL ASPECTS OF DESALINATION PLANTS IN SOUTH AFRICA

2.1 INTRODUCTION

A summary of the plant site visits in this section provide a general report on each desalination plant including planning/funding aspects, process descriptions and schematic drawings of relevant technology employed for the intake works, pre-treatment, desalination plant (UF/RO) and distribution works. Information on water quality, life cycle costs, operational and maintenance issues is also presented. Please refer to Appendix A for a detailed photo summary with equipment and layout of each plant.

The following seawater desalination plants were selected for investigation in this study, namely: Mossel Bay 15 Mℓ/d SWRO plant, Sedgefield 1.5 Mℓ/d SWRO plant and Albany Coast 1.8 Mℓ/d SWRO plant. These plants were selected based on their location and importance with respect to augmenting water supply in the associated regions. Each of the plants is further detailed under the relevant sections below.

Table 2.1: Details of the selected desalination plants

Desalination Plants			
Plant	Mossel Bay SWRO plant	Sedgefield SWRO plant	Albany Coast SWRO plant
Size of Plant	15 Mℓ/d	1.5 Mℓ/d	1.8 Mℓ/d
Type of Plant	Desalination: Direct potable	Desalination: Direct potable	Desalination: Direct potable
Owner	Mossel Bay Municipality	Knysna Municipality	Amatola Water
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Completed	2010/11	2009	1997, extension 2008
Capital Cost - at time of construction - Adjusted for 2014/15 - Per unit capacity	 R207 mill R266 mill R17.74 mill/Mℓ/day	 R16 mill R22 mill R14.66 mill/Mℓ/day	 R28 mill R36 mill R21.65 mill/Mℓ/day
O&M Cost (2014/15)	R6.81/m³	R7.16/m³	R9.00/m³
Energy Use	4.39 kWh/m³	3.97 kWh/m³	4.52 kWh/m³
Electricity Cost	R3.37/m³	R3.14/m³	R4.18/m³ (ERD rental R0.53/m³)
Chemicals	R2.16/m³	R0.70/m³	R0.39/m³
Consumables			R0.20/m³
Maintenance	R0.58/m³	R0.52/m³	R1.97/m³
Staff	R0.62/m³	R2.58/m³	R1.47/m³
Laboratory Cost	R0.04/m³	R0.11/m³	R0.15/m³
SHEQ	R0.04/m³	R0.11/m³	R0.10/m³

- Please note that all costs are quoted in South African Rand and exclude VAT.
- All O&M values are estimates based on variables (rates based on historical data, inflation, etc.) and represent the cost as at full production.

Two of these three plants were built during the 2010/11 drought period and have been included in the study to evaluate the costs associated with building and running these plants over the duration of the study period between 2012 and 2015. These projects were mostly undertaken under emergency conditions and considerable time pressure, which differentiate them from the projects not completed under such strict time constraints. Nevertheless, the information is generally available and can be useful in the design, costing, construction and operation of such plants in future.

2.2 DATABASE DEVELOPMENT

For the duration of the project, the team collected data from the plants covered in this study, however the available records for the plants in this study were represented in significantly different formats and in certain cases the information was supplied in summarised form, which complicated the analysis and assumptions required for base lining the data.

A database was developed to build a framework to collate all the available information and align the data into a compatible format. At present the database is a collection of records, which can be updated or expanded with additional plant information and provide various reports on the available information and costs.

To ensure that this database is accessible, it is a stand-alone, packaged application (available in a CD at the back of this publication), that does not require prior installation of Access to operate.

The application organised the data into four categories, with parameters restricted to those of the desalination and reuse plants used in the study. The categories are:

- **Plant Information:** General plant information (i.e. process type, design and actual capacity, etc.) and the plant owners and operators, with complete contact information.

- **Technical Specifications:** The technical specification defines the parameters of the water quality, the process flow steps and equipment that each plant observes (report example below).

- **Geographic Profile:** This section provides the breakdown of the plant location, including region, coordinates, elevation and various supporting documentation and images, which includes photos of the plant and drawings.

- **Financial Records:** The financial records include CAPEX and OPEX costs. OPEX values are represented in both a Monthly Cost (R/month) and a Unit Cost (R/m³).

Each sub-category also allows for various reports to display static data and provide standard financial reports.

For the purposes of this study, the application with the data records of the seven plants will be made available for review. Additional functionality to provide the required quantitative data in order to establish the feasibility of existing infrastructure or build scenarios to meet future water demands is currently in development.

The installation and functionality of the database is covered in detail in Appendix B.

2.3 MOSSEL BAY SEAWATER DESALINATION PLANT

The Mossel Bay Seawater Desalination plant was constructed as an emergency project in 2010 when there was a substantial risk of failure of the main source of water for the area, the Wolwedans Dam on the Groot Brak River, due to the severe drought that was being experienced in the Southern Cape region. The plant was designed to supply desalinated water to the PetroSA refinery (5 Mℓ/d) and the Mossel Bay Municipality (10 Mℓ/d), both of whom are supplied mainly from the Wolwedans Dam.

Figure 2.1: Mossel Bay SWRO plant

2.3.1 Funding and Institutional Arrangements

The Mossel Bay seawater desalination plant is the largest desalination plant in South Africa with a capacity of 15 Mℓ/d. The project was jointly funded by the National Treasury, PetroSA and Mossel Bay Municipality, who contributed R92 million, R80 million and R30 million respectively to the total cost of around R207 million. The electricity and operational costs are split between the municipality and PetroSA.

2.3.2 Capital costs

The capital cost of the plant was approximately R207 million (excluding VAT) in 2010/11, summarised below:

Table 2.2: Mossel Bay SWRO plant (15 Mℓ/d) capital costs

Mossel Bay SWRO Plant Capital Costs	Cost (Rand) (2010)	% of Project	Cost (Rand) (2014/2015	Unit Cost (Rm/Mℓ/d) (2014/15)
Direct Costs				
Intake	25 870 547	12.5	33 281 588	2.22
Outfall	17 155 635	8.3	22 070 148	1.47
Pre-treatment	30 045 885	14.5	38 653 020	2.58
RO Plant	46 047 475	22.3	59 238 527	3.95
Post-treatment	4 112 826	2.0	5 291 013	0.35
Electrical, electronic and control	10 967 537	5.3	14 109 367	0.94
Civil building and structures	17 180 000	8.3	22 101 492	1.47
Bulk electrical supply	6 154 315	3.0	7 917 319	0.53
Product pumpstation & pipelines	26 233 189	12.7	33 748 115	2.25
Subtotal Direct Costs	**183 767 410**	**88.9**	**236 410 589**	**15.76**
Indirect Costs				
Professional fees, site monitoring, disbursements	19 499 794	9.4	29 618 314	1.97
Environmental and specialist studies, etc.	3 523 205	1.7		
Subtotal Indirect Costs	**23 022 999**	**11.1**	**29 618 314**	**1.97**
Total Cost (excluding VAT)	**206 790 409**	**100.0**	**266 028 903**	**17.74**

2.3.3 Process Description

The desalination plant was designed to treat seawater over a 24-hour cycle, with time allowed for maintenance and resolving any process related problems. Seawater is abstracted from an open sea intake and pre-treated prior to reverse osmosis (RO) treatment, disinfection and remineralisation. The brine produced during the RO process is returned to the sea. The process train at the Mossel Bay seawater desalination plant is described in Figure 2.2.

2.3.3.1 *Source*

Feed-water is abstracted from an open sea intake pipeline (900 mm diameter) measuring over 900 m in length from the intake point to the beachfront. The pipeline is also equipped with a chlorine dosing line at its entrance to reduce marine organism growth in the pipe. The feed-water is pumped to the seawater storage tank using pumps housed in the pump-station 2 m above sea level. Four intake pumps are installed with three (3) duty pumps and one (1) standby pump.

2.3.3.2 *Seawater tank*

The seawater tank functions as a storage reservoir for the feedwater to the desalination plant. The initial seawater tank overflows via weirs to drum filters before entering the adjacent seawater storage tanks.

2.3.3.3 *Pre-treatment*

The pre-treatment in the plant consists of chemical dosing and multimedia sand filtration. Ferric chloride ($FeCl_3$) is dosed as a coagulant with an optimal pH range of 4.5 to 7.0 upstream of the multi-media filters. Sulphuric acid (H_2SO_4) is dosed to adjust the pH. The coagulated seawater is filtered by means of six pressure multi-media sand filters to prevent membrane fouling.

2.3.3.4 *Reverse osmosis (RO)*

The plant consists of six banks of RO units, each with a capacity of 2.5 Mℓ/d. The ancillary equipment for the RO units comprises:

- Pre-filters to prevent sand from the multi-media filters entering the RO units.
- Anti-scalant and sodium meta-sulphite (SMBS) solution storage tanks with dosing pumps.
- Each RO unit has a high pressure pump that applies 40 bar(g) pressure to the RO membrane. These pumps are fitted with turbochargers that further increase the applied pressure to 60 bar(g).
- Cleaning in Place (CIP) tanks, pumps and manifolds.

Two streams are generated by the RO process: the permeate stream and the concentrated brine stream. the permeate stream containing the desalinated product water is fed to two product water storage tanks as indicated in process flow diagram in Figure 2.2, namely one for the municipal supply and the other for PetroSA.

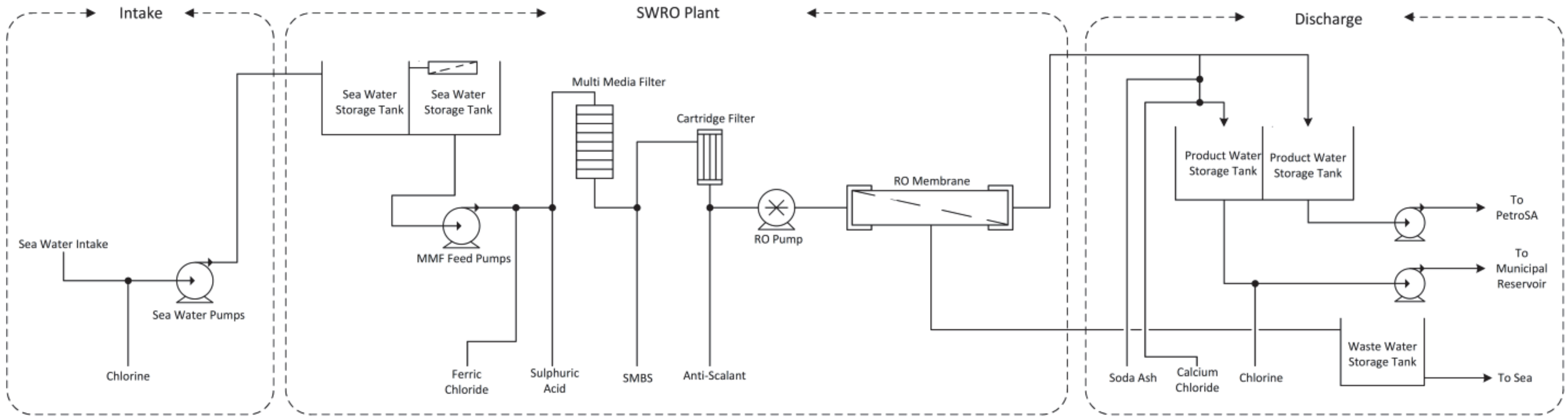

Figure 2.2: Process schematic of the Mossel Bay SWRO Plant

2.3.3.5 *Waste discharge*

The brine stream is discharged back into the sea with a vertical velocity of 9 m/s or more through 19 diffuser ports installed onto a pressurized 630 mm HDPE pipeline to ensure rapid mixing of the brine plume and to ensure that no stratification occurs with the higher density brine.

The discharge pipeline, approximately 450 m long, is laid adjacent to the intake pipeline.

2.3.3.6 *Stabilisation*

The permeate entering the product water storage tank used for municipal supply is stabilised using soda ash and calcium chloride which are dosed to stabilise and re-mineralise the desalinated product water prior to distribution to the reticulation network. This is done in order to prevent damage to concrete structures as a result of under-saturation.

2.3.3.7 *Disinfection*

Product water from the storage tank for municipal supply is disinfected using chlorine gas before being pumped to the municipal storage reservoir.

2.3.3.8 *Distribution*

The desalinated water in the product water storage tanks is distributed to the Mossel Bay Municipality (10 Mℓ/d) and PetroSA refinery (5 Mℓ/d).

2.3.4 Operation and Maintenance Aspects

The plant is currently operated and maintained on a contract basis by Veolia Water, who was also the main contractor for the RO plant portion of the project. The operation and maintenance contract was part of the main plant procurement contract, but treated as a separate contract on commissioning of the plant, and the commencement of the operation service period. As mentioned earlier, the operation and maintenance costs are split between the Mossel Bay Municipality and PetroSA.

The plant is maintained in a zero production mode most of the time, with brief periods of production as needed. Operational data collected from the plant is summarised in the following section.

2.3.4.1 *Energy*

The Mossel Bay SWRO plant is supplied with electricity by Mossel Bay Municipality using its own tariff structure, which is aligned with that of the bulk electricity supplier, Eskom. The electricity costs are split between PetroSA and Mossel Bay Municipality.

Table 2.3 shows the electrical consumption of the plant during certain times over approximately three years (October 2011 to December 2014) of operation.

Table 2.3: Mossel Bay SWRO plant energy consumption and cost data

Energy Consumption and Costs Data	Unit	Zero Production Mode	Membrane Test Production Mode	Production (28%)
Period		**Jul'12- Dec'14**	**Aug'12-Oct'13**	**Oct'11-Feb'12**
Water produced average monthly	m³	0	784	129 453
Consumption Monthly average	kWh	118 311	130 791	469 937
kVA demand	kVA	300	618	2 521
Specific energy consumption	kWh/m³	N/A	N/A	3.65
Unit kVA demand per Mℓ/d capacity (x)	kVA/x	N/A	N/A	168
Average unit consumption rate	R/kWh	0.486	0.470	0.413
Average kVA unit rate	R/kVA	159.00	153.00	135.00
Fixed monthly rate	R/month	1 781.00	1 710.00	1 505.00
Consumption charge monthly average	R/month	57 366.00	61 405.00	194 084.00
kVA charge monthly average	R/month	47 353.00	94 298.00	314 878.00
Fixed charge monthly average	R/month	1 781.00	1 710.00	1 505.00
Total cost monthly average	**R/month**	**106 500.00**	**157 4138.00**	**510 468.00**

Note: In production mode, the plant was run for limited hours, producing 28% of design capacity per day. In addition, while producing limited treated water, the product water pumps are not all operated (e.g. high lift PetroSA pump sets) and some excess water is even recycled, to give the low specific energy figure of 3.65 kWh/m³ (calculated for 28% production) in the table above.

The data has been extracted for the different modes of operation, and the costs have been averaged over the period that the plant was operated in that specific mode. The average rates show that the cost of electricity increases over time, depending on when the data was collected for each mode of operation. To compare the costs for operating in each mode, the same base rate (in this case 2011), is applied to the consumption data to calculate the average monthly costs, as shown in Table 2.4.

Table 2.4: Mossel Bay SWRO plant energy cost at base date rates

Energy Costs at base date	Unit	Zero Production Mode	Membrane Test Production Mode	Production (28%)
Period (base date 2011)		base date	base date	base date
Average unit consumption rate	R/kWh	0.413	0.413	0.413
Average kVA unit rate	R/kVA	134.56	134.56	134.56
Fixed monthly rate	R/month	1 505.10	1 505.10	1 505.10
Consumption charge monthly average	R/month	48 863.00	54 017.00	194 084.00
kVA charge monthly average	R/month	40 346.00	83 122.00	335 862.00
Fixed charge monthly average	R/month	1 505.00	1 505.00	1 505.00
Total cost monthly average	**R/month**	**90 713.00**	**138 644.00**	**531 451.00**

Applying the current 2014/15 rates, these costs increased at an average of 8.3% per annum (Table 2.5):

Table 2.5: Mossel Bay SWRO plant energy cost at current rates

Energy Costs at current date	Unit	Zero Production Mode	Membrane Test Production Mode	Production (28%)
Period (current 2014/15)		**Current date**	**Current date**	**Current date**
Average unit consumption rate	R/kWh	0.52	0.52	0.52
Average kVA unit rate	R/kVA	171.67	171.67	171.67
Fixed monthly rate	R/month	1 920.23	1 920.23	1 920.23
Consumption charge monthly average	R/month	61 522.00	68 011.00	244 367.00
kVA charge monthly average	R/month	51 472.00	106 046.00	428 488.00
Fixed charge monthly average	R/month	1 920.00	1 920.00	1 920.00
Total cost monthly average	**R/month**	**114 915.00**	**175 978.00**	**674 776.00**

When the plant is maintained in zero production mode:

- the average monthly electrical consumption is approximately 118 000 kWh
- the maximum demand is up to 300 kVA in an average month
- The average electricity cost is approximately R115 000 per month (2014/15).

The plant maintenance and CIP procedure dictates that membrane performance checks are done periodically (typically every six months). The tables above show the associated electricity costs in a month when these performance tests are done.

For membrane performance test mode:

- the average monthly electrical consumption is approximately 131 000 kWh
- the maximum demand is up to 600 kVA in an average month
- The average electricity cost is approximately R175 000 per month (2014/15).

When the plant is in production mode of 4.25 Mℓ/day (28% design capacity):

- the average monthly electrical consumption is approximately 470 000 kWh
- the maximum demand is up to 2 500 kVA in an average month
- The average electricity cost is approximately R675 000 per month (2014/15).

The plant has not been operated in full production mode for any sustained periods. However, the energy consumption of the plant can be calculated at design capacity, for different periods of production per day. Using the Mossel Bay municipality current rates, and including all product water pumping, the monthly energy consumption and costs are calculated for three scenarios.

Table 2.6: Mossel Bay SWRO plant energy cost at current date

Energy Consumption and Cost Calculation	Unit	7 hours/day	10 hours/day	24 hours/day
Daily production	m³/d	4 375	6 250	15 000
Monthly production	m³	133 164	190 234	456 563
Consumption Monthly average	kWh	596 575	852 250	2 045 400
kVA demand	kVA	2 947	2 947	2 947
Specific energy consumption	kWh/m³	4.39	4.39	4.39
Unit kVA demand per Mℓ/d capacity (x)	kVA/x	196	196	196
Average unit consumption rate	R/kWh	0.52	0.52	0.52
Average kVA unit rate	R/kVA	171.67	171.67	171.67
Fixed monthly rate	R/month	1 920.23	1 920.23	1 920.23
Consumption charge monthly average	R/month	310 219.00	443 170.00	1 063 608.00
kVA charge monthly average	R/month	505 975.00	505 975.00	505 975.00
Fixed charge monthly average	R/month	1 920.00	1 920.00	1 920.00
Total cost monthly average	**R/month**	**818 114.00**	**951 065.00**	**1 571 503.00**
Average unit energy cost	**R/m³**	**6.14**	**5.00**	**3.44**

In these scenarios, it is assumed that the plant is run at full capacity and the specific energy consumption, including full product water pumping, is taken as the relatively high calculated value of 4.39 kWh/m³.

This assumption also then attracts the maximum kVA demand charges per month which substantially increases the average unit energy cost for the low production scenario (R6.14/m³ compared to R3.44 /m³ for maximum production). Therefore, this represents a worst case in planning for the low production scenario, and indicates the importance of developing operating rules to minimise demand charges, and to take advantage of TOU tariff structures, both of which will decrease the unit energy costs.

Energy Recovery

In addition, TOU tariffs offer substantial savings for reduced pumping hours. The specific energy requirements may further broken down as indicated in Figure 2.3.

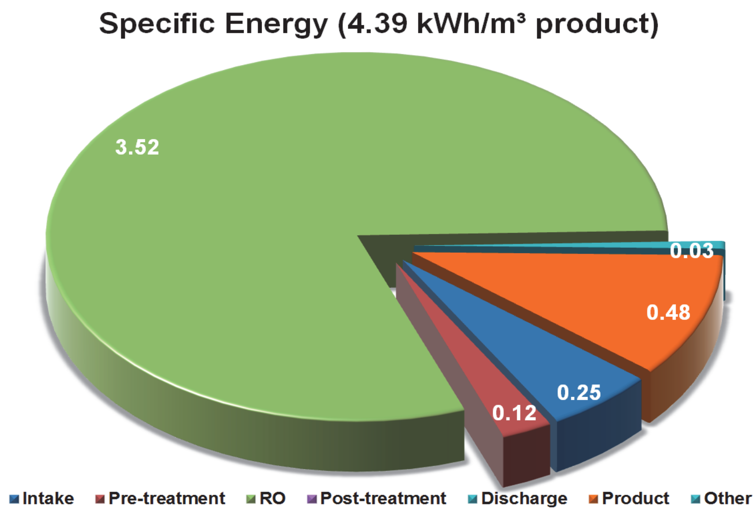

Figure 2.3: Specific energy requirements for the Mossel Bay SWRO plant (with turbocharger)

The total specific energy requirement for the Mossel Bay SWRO plant is estimated to be between 4.39 and 4.48 kWh/m³. If we exclude the intake and product pumping requirements, the figure obtained for the RO section alone is 3.66 kWh/m³. The Mossel Bay SWRO plant utilises a turbocharger type energy recovery device (ERD), for mainly emergency delivery reasons at time of implementation. The more efficient pressure exchanger ERD could reduce the total energy requirement of the RO section by 25% to below 3 kWh/m³.

2.3.4.2 *Water quality parameters*

Table 2.7 indicates the sea intake and treated potable water quality parameters for this plant.

Table 2.7: Mossel Bay SWRO plant intake and product water parameters

Parameter	Raw Seawater Intake	Treated Potable Water (SANS 241)
Temperature (°C)	14-24	-
pH	8-8.5	8.5-9 (without stabilisation)
Total Dissolved Solids (mg/ ℓ)	35 000-40 000	-
Turbidity (NTU)	< 3	<1
*Conductivity (mS/m)	5 000-5 500	300-500
Potassium (mg/ℓ)	480	-
Sodium (mg/ℓ)	11 000	-
Calcium (mg/ℓ)	400	<150
Magnesium (mg/ℓ)	1400	<70
Ammonia (mg/ℓ)	0.12	-
Sulphate (mg/ℓ)	2 600	<400
Chloride (mg/ℓ)	20 400	<200
Alkalinity (mg/ℓ)	120	-
Nitrate (mg/ℓ)	0.4	<10
Fluoride (mg/ℓ)	<0.02	0.6-1.55

*conductivity varies with seasonal changes

2.3.4.3 *Monitoring results*

The following monitoring results are based on previous measurements. Due the plant only being operated for limited periods during emergencies only, there is a lack of regular data with respect to monitoring results during live/continuous operation. The results in Table 2.8 are based on various product water samples taken during the performance testing period from 19 to 22 April 2012 (72-hour period).

Table 2.8: Mossel Bay SWRO plant final product water analysis results

Mossel Bay SWRO Plant	Final product water analysis results			
Date	**20-04-2012**	**20-04-2012**	**21-04-2012**	**21-04-2012**
pH	7.6	8.3	7.8	8.8
Turbidity (NTU)	5.0	5.0	5.0	5.0
TDS	298	258	294	268
Conductivity (at 25°C) (mS/m)	52	50	54	56
Potassium (mg/ℓ)	5	2.2	2.4	2.7
Sodium (mg/ℓ)	76	77	83	90
Calcium (mg/ℓ)	14	14	15	15
Magnesium (mg/ℓ)	0.6	0.6	0.6	0.6
Ammonia (mg/ℓ)	<0.1	<0.1	<0.1	<0.1
Sulphate (mg/ℓ)	2.0	2.0	2.0	1.8
Chloride (mg/ℓ)	133	130	136	146
Alkalinity (mg/ℓ)	34	37	46	43
Nitrate (mg/ℓ)	<0.1	<0.1	<0.1	<0.1
Fluoride (mg/ℓ)	<0.1	<0.1	<0.1	<0.1
Dissolved Organic Carbon (mg/ℓ)	<1	<3	<1	<1

2.3.4.4 *CIP and downtime*

Since commissioning, the plant has been, and currently is, in standby/zero production mode. As a result of this a sodium meta-bisulphite (SMBS) (2%) solution is used to preserve the idle membranes. This solution is replaced every six weeks and the pH is monitored and maintained above 3. The concept and principle of performing the CIP at the Mossel Bay SWRO plant is described below. The CIP is run in 3 stages:

- A high pH CIP (sodium hydroxide + chlorine) at pH 11 to remove bio-solids and a flush with freshwater.
- A low pH CIP (citric acid) in the pH range of 3 to 4 to remove scaling or chemical deposits.
- A final flush with clean water. Under normal production conditions the RO membranes would then be returned to use, but currently the membranes are preserved in a solution of SMBS.

When the plant is running continuously one reverse osmosis process train is taken offline every six months and a membrane performance check is carried out together with certain CIP checks.

2.3.4.5 *Operation and maintenance problems experienced*

Operational problems experienced by the plant operators to date are as follows:

- The membranes have an expected lifespan of five years and a maximum of seven after which they are normally replaced. The key factor in achieving an extended lifespan is the operating regime, as the plant should ideally, be run continuously. Frequent starting and stopping of the plant, to minimise running costs, is not optimal for membrane life:
  - Some membranes cartridges were leaking only months after installation.
  - Long-term preservation may also cause damage to the membranes and result in warrantee issues.

- Sand in the system causing mechanical damage, e.g. damage to the turbochargers.
- Blockage of the sea intake caused by poor sea intake conditions.
- High sand and organics in the feedwater as a result of stormy weather.
- The plant is expensive to run, and even when the surface water sources are meeting the demand, the municipality still has to pay Veolia to operate the plant, albeit at a reduced rate.
- Operational contracts for the plant operation should deal better with matters such as the operational periods per year for full production, and idling or zero production mode.
- The tourism peak season is generally in the summer months which results in a markedly increased demand for water which in turn results in high electricity consumption. However this peak season does not correspond with Eskom's peak season tariffs and as a result issues have arisen with regards to the billing of power usage in the winter and summer months. The plant is charged consumer tariffs instead of commercial tariffs.

2.3.4.6 *Operational costs*

The costs associated with plant operations and maintenance activities are listed below. This has been separated into current actual O&M costs, estimated costs during full operation, and zero production mode costs when the plant is idle. These costs have been subdivided per month, per annum and per m³. These costs are based on available information on O&M costs. In the absence of more accurate information, this has been estimated based on past performance/historical data, and using 2014/2015 electricity tariffs, and chemical and staffing costs. The estimated O&M breakdown based on a zero production mode, escalated for the year 2014/15 is indicated in Table 2.9:

Table 2.9: O&M cost breakdown for the Mossel Bay SWRO plant (zero production mode)

O&M breakdown (2014)	Zero Production Mode Cost (R/month)
Electricity	100 000.00
Consumables, chemicals and maintenance	60 000.00
Staff	96 000.00
Total Monthly Cost (excluding VAT)*	**256 000.00**

The estimated O&M cost breakdown for zero production mode is illustrated in Figure 2.4:

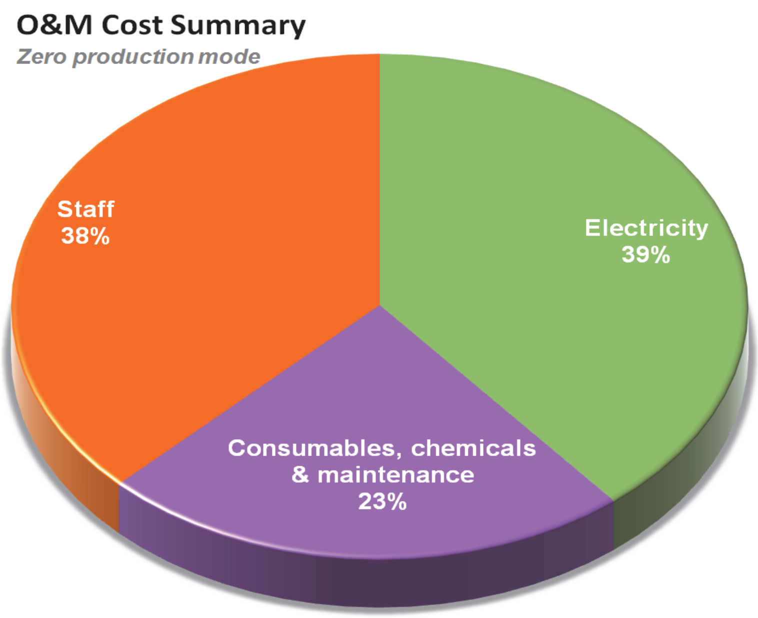

Figure 2.4: O&M Cost breakdown for the Mossel Bay SWRO plant (zero production mode)

The estimated O&M breakdown based on full production, escalated for the year 2014/15 is shown below:

Table 2.10: O&M cost breakdown for the Mossel Bay SWRO plant (full production)

O&M Parameters	Unit Cost (R/m³)	Full production Cost (R/month)
Electricity	3.37	1 539 311
Consumables & chemicals	2.16	985 932
Maintenance	0.58	263 050
Staff	0.62	282 600
Laboratory	0.04	20 000
SHEQ	0.04	20 000
Total Monthly Cost (excluding VAT)	**6.81**	**3 110 893**

The estimated O&M cost breakdown for full production is illustrated in Figure 2.5:

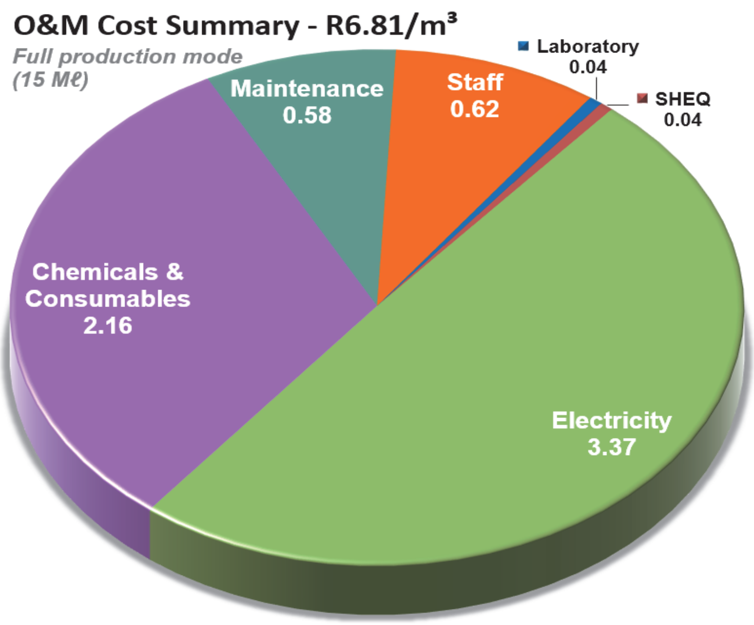

Figure 2.5: O&M Cost breakdown for the Mossel Bay SWRO plant (full production)

2.4 SEDGEFIELD SEAWATER DESALINATION PLANT

The Sedgefield SWRO plant was constructed in 2009 and is located at the Myoli Beach car park. The desalination plant equipment is housed in containers that are located in a paved and fenced area with shade cloth covering most of the outside equipment.

The Sedgefield seawater desalination plant is designed to produce 1.5 Mℓ/day of product water which is pumped to the Blombosnek reservoirs which supply the town of Sedgefield.

The general plant details are provided in the paragraphs that follow. Figure 2.6 shows the containerised units housing the RO plant.

Figure 2.6: Sedgefield SWRO plant

2.4.1 Funding and Institutional Arrangements

The Sedgefield desalination plant RO units were designed and installed by GrahamTek Systems.

The project was granted emergency funding of R11.2 million during the 2009 drought period and the balance was sourced from funds municipal and grant funding in the following year. The plant was built and commissioned within three months: the contract award being signed on 1 October 2009 and the plant producing first water on 18 December 2009, in time for the anticipated holiday peak in December 2009.

The plant is currently maintained in a zero production mode by Knysna Municipality with technical support from NuWater (successors to GrahamTek Systems as RO technology supplier).

2.4.2 Capital costs

The capital cost of the plant was R16 million (excluding VAT) in 2009, which included the civil work at the plant and the product water pipeline. The capital costs are summarised in Table 2.11.

Table 2.11: Sedgefield SWRO plant (1.5 Mℓ/d) capital costs

Sedgefield SWRO Plant Capital Costs	Cost (Rand) (2009)	% of Project	Cost (Rand) (2014/15)	Unit Cost (Rm/Mℓ/d) (2014/15)
Direct Costs				
Intake	1 333 000	8.3	1 826 326	1.22
Outfall	342 000	2.1	468 570	0.31
Pre-treatment	525 000	3.3	719 295	0.48
RO Plant	7 000 000	43.6	9 590 607	6.39
Post-treatment	50 000	0.3	68 504	0.05
Waste treatment and disposal	0.00	0.0	0.00	0.00
Electrical, electronic and control	1 148 230	7.2	1 573 175	1.05
Civil building and structures	730 735	4.6	1 001 170	0.67
Bulk electrical supply	1 095 519	6.8	1 500 956	1.00
Product pumpstation & pipelines	1 396 023	8.7	1 912 672	1.28
Subtotal Direct Costs	**13 620 507**	**84.9**	**18 661 275**	**12.44**
Indirect Costs				
Professional fees, site monitoring, disbursements	2 429 445	15.1	3 328 550	2.22
Environmental and specialist studies, etc.	0.00	0.0	0.00	0.00
Subtotal Indirect Costs	2 429 445	15.1	3 328 550	2.22
Total Cost (excluding VAT)	**16 049 952**	**100.0**	**21 989 825**	**14.66**

Note that this was a rapid deployment plant, housed in containers and with elements that were temporary installations to suit the emergency situation at the time. Further work has been carried out on the beach wells, beach discharge and feedwater system. These costs have not been taken into account here.

2.4.3 Process Description

The process train at the Sedgefield seawater desalination plant is described in Figure 2.7. At present, a new horizontal collector drain system is being installed at the beach to supply feedwater to the plant. The feedwater is pumped from Myoli Beach (or boreholes adjacent to the Myoli Beach car park) and stored in 2 x 10 000 ℓ plastic feedwater storage tanks. Pre-treatment consists of microfiltration and dosing of anti-scalant before entering the RO units. The RO units are housed in two 40-foot shipping containers interconnected by a third container housing the control room and product water pumps.

Partial remineralisation is carried out using soda ash. The partially remineralised permeate is chlorinated using sodium hypochlorite and stored in 2 x 10 000 ℓ product water tanks before being pumped to the Blombosnek reservoirs. The generated brine is stored in a 10 000 ℓ tank and pumped back to the beach for disposal in the sea.

2.4.3.1 *Source*

Seawater was initially abstracted from vertical beach wells located at the beach and naturally filtered by the beach sand. Although the water quality from the beach wells was excellent, winter storms caused large variations in sand levels and regularly damaged the beach well heads, the pipelines and the power cables buried in the beach sand. Access to the equipment at the beach for repairs and maintenance was difficult, costly and dependent on the weather and tidal cycles. In an attempt to remedy this, boreholes were drilled closer to the plant, away from the tidal surf zone region, and tested for yield and water quality.

The borehole water quality proved to be unacceptable without extensive pre-treatment, and the present status is that a pilot horizontal collector drain system has been successfully tested on the beach, with the pumping equipment positioned up the beach beyond the high water mark (for access to equipment). Based on these tests, a new horizontal collector drain system is to be installed to supply the RO plant with feed seawater.

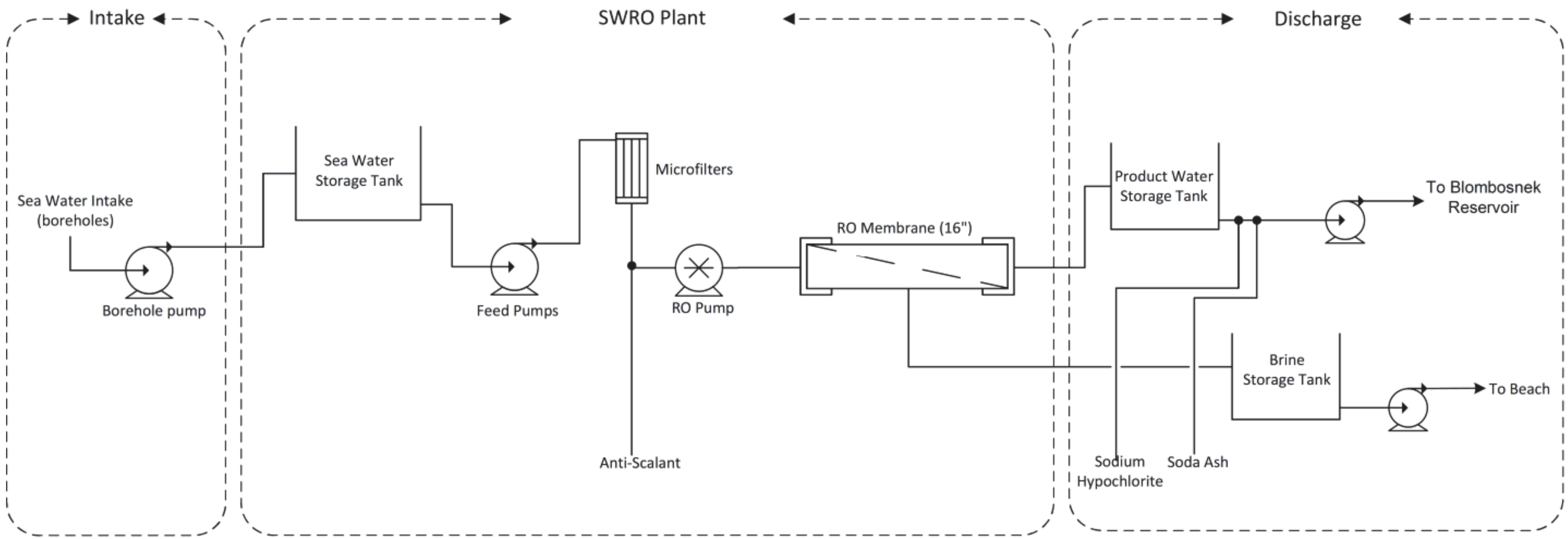

Figure 2.7: Process schematic of the Sedgefield SWRO plant

2.4.3.2 *Pre-treatment*

The feedwater is pumped through 5 µm micro-filters and dosed with an anti-scalant before being directed to the RO units.

A future additional pre-treatment step, consisting of multi-media filtration, is being considered, depending on the performance of the collector drain system.

2.4.3.3 *Reverse osmosis (RO)*

The containers housing the RO units are insulated to ensure that sound levels are contained, and air conditioned to prevent overheating of the motor driven equipment. The plant consists of two RO skid mounted units, each unit capable of producing 0.75 Mℓ/day of permeate and are able to operate independently of each other.

The pressure vessels and membrane units are 16 inch in diameter, which differ from the more common 8 inch systems, with each RO unit consisting of three pressure vessels in a taper configuration of two into one, thus the first two vessels' brine discharge feeds into the third vessel.

An energy recovery unit uses the residual brine pressure to boost a percentage of the feedwater into the RO feed line (with the help of a booster pump).

The main equipment items of the RO units are:

- Feedwater pumps and pipework;
- High pressure pump and secondary pump (booster pump – part of the energy recovery system);
- RO pressure vessels with membrane units and high pressure pipework;
- Energy recovery system;
- Anti-scalant dosing system;
- Control panel, wiring and on-line instrumentation;
- Compressor and valve actuator system;
- Low pressure pipe work for permeate, brine and CIP.

The RO process units generate two output streams, namely the permeate/product water and the concentrated brine. The permeate is supplied to the municipal reservoir and the concentrated brine stream is discharged back to the sea.

2.4.3.4 *Control system*

The instrumentation on the RO units monitor pressure, flow rate, conductivity, turbidity, pH and temperature. A small control room with local SCADA is housed in the middle container connecting the RO units. The SCADA system (using Adroit software) is normally operated in Automatic mode with specific settings and options available for operator inputs. Some equipment may be operated manually within the set parameters of the system.

2.4.3.5 *Disposal of wastewater*

The brine/wastewater is stored in the wastewater tanks and pumped via the brine pumps into two discharge pipelines which join together and discharge to an open outlet on the beach. Injection wells were originally installed on the beach, but met with various problems, and were replaced with the temporary open outlet.

A future sea outfall is planned which will discharge directly into or beyond the surf zone.

2.4.3.6 *Remineralisation*

Partial remineralisation of the permeate is carried out downstream of the RO units by the addition of approximately 40 mg/ℓ of soda ash in order to stabilise the product water before pumping it to the Blombosnek reservoirs for blending and supply to the potable water network.

2.4.3.7 *Disinfection*

The partially remineralised permeate is chlorinated by dosing sodium hypochlorite at a rate of 0.5 to 1.0 mg/ℓ to ensure an active chlorine residual concentration of at least 0.5 mg/ℓ in the product water.

2.4.3.8 *Product Water*

Two pumps (1 duty/1 standby) deliver the product water via a 200 mm diameter pipeline to the Blombosnek Reservoirs, where it is blended with water from the town's other sources (surface water and groundwater).

The required permeate quality leaving the works after desalination must comply with the SANS 241 drinking water specification (previously SANS 241:2006, now SANS 241:2011).

2.4.4 Operation and Maintenance Aspects

2.4.4.1 *Electricity*

The plant is supplied with electricity by Knysna Municipality using its own tariff structure, which is aligned with that of the bulk electricity supplier, Eskom. Using electricity account records, a summary of actual costs have been compiled for the first year of operation (five months shown) is shown in Table 2.12:

Table 2.12: Sedgefield SWRO plant energy cost at base date rates

Sedgefield SWRO Plant Electricity Costs	31-Jan-10	28-Feb-10	31-Mar-10	30-Apr-10	31-May-10
Product Water (m³)	2 216	9 164	19 286	27 976	17 311
Network access charge	20.88	20.88	20.88	20.88	20.88
Max kVA (previous 12 months)	350	350	350	350	350
Network access cost	7 308.00	7 308.00	7 308.00	7 308.00	7 308.00
Basic for kVA	500.00	500.00	500.00	500.00	500.00
Network kVA demand	266	292	288	288	290
unit kVA rate R (peak)	108.75	108.75	108.75	108.75	108.75
kVA cost R	28 927.50	31 755.00	31 320.00	31 320.00	31 537.50
Basic for Normal/rate3	500.00	500.00	500.00	500.00	500.00
Normal/rate3 meter kWh	30 448	72 382	151 798	278 368	358 082
Normal/rate3 cons kWh	13 468	41 934	79 416	126 570	79 714
Normal/rate3 tariff R/kWh	0.233	0.2308	0.2308	0.2308	0.2308
Normal/rate3 cost R	3 138.04	9 678.37	18 329.21	29 212.36	18 397.99
Total Cons kWh	13 468	41 934	79 416	126 570	79 714
Fixed Costs kVA + basic	37 235.50	40 063.00	39 628.00	39 628.00	39 845.50
Variable costs (Cons)	3 138.04	9 678.37	18 329.21	29 212.36	18 397.99
Total Electrical Cost	**40 373.54**	**49 741.37**	**57 957.21**	**68 840.36**	**58 243.49**
Specific energy cons kWh/m³	**6.08**	**4.58**	**4.12**	**4.52**	**4.60**
Total unit cost R/m³ (incl. kVA)	**18.22**	**5.43**	**3.01**	**2.46**	**3.36**

Note that the water unit cost decreases as production increases, which can be used to develop operating rules and strategy to optimise the cost of producing water at the rate required.

Applying the current 2014/15 rates, the costs for different operating modes are shown in Table 2.13.

Table 2.13: Sedgefield SWRO plant energy cost at current rates

Energy Costs at current date	Unit	Zero Production Mode	Production Mode (1 RO)	Production Mode (2 ROs)
Period (current 2014/15)		**2014/15**	**2014/15**	**2014/15**
Water produced average monthly	m³	439	8 191	19 286
Consumption Monthly average	kWh	3 460	56 471	79 714
kVA demand	kVA	152	158	288
Specific Energy consumption	kWh/m³	N/A	6.89	4.13
Unit kVA demand per Mℓ/d capacity (x)	kVA/x	202	211	192
Energy cost rate	R/kWh	0.6527	0.6527	0.6527
Average kVA unit rate	R/kVA	44.48	44.48	44.48
Fixed monthly rate	R/month	13 361.92	13 361.92	13 361.92
Consumption charge monthly average	R/month	2 258.00	36 857.00	52 028.00
kVA charge monthly average	R/month	6 739.00	7 028.00	12 810.00
Fixed charge monthly average	R/month	13 362.00	13 362.00	13 362.00
Total cost monthly average	**R/month**	**22 359.00**	**57 247.00**	**78 200.00**
Specific energy cost	**R/m³**	**N/A**	**6.99**	**4.06**

When the plant is maintained in zero production mode:

- the average monthly electrical consumption is approximately 3 500 kWh
- the maximum demand is up to 152 kVA in an average month
- The average electricity cost is approximately R22 500 per month (2014/15).

The plant maintenance and CIP procedure dictates that membrane performance checks are done periodically (typically every six months). The tables above show the associated electricity costs in a month when these performance tests are done.

For production mode with one RO unit running (50% design capacity) for limited hours per day:

- the average monthly electrical consumption is approximately 56 500 kWh
- the maximum demand is up to 158 kVA in an average month
- The average electricity cost is approximately R57 000 per month (2014/15).

When in production mode with 2 RO units running (100% design capacity) for limited hours per day:

- the average monthly electrical consumption is approximately 80 000 kWh
- the maximum demand is up to 288 kVA in an average month
- The average electricity cost is approximately R78 000 per month (2014/15).

The plant has not been operated in full production for any sustained periods, however the energy consumption of the plant can be calculated at the design capacity for different periods of production per day.

Using the current municipality rates and including all product water pumping, the monthly energy consumption and costs are calculated for three scenarios.

Table 2.14: Sedgefield SWRO plant energy cost at current date

Energy Consumption and Costs Calculation	Unit	7 hours/day	10 hours/day	24 hours/day
Daily production	m³/d	438	625	1 500
Monthly production	m³	13 316	19 023	45 656
Consumption Monthly average	kWh	54 757	78 224	187 739
kVA demand	kVA	286	286	286
Specific energy consumption	kWh/m³	4.11	4.11	4.11
Unit kVA demand per Mℓ/d capacity (x)	kVA/x	190	190	190
Average unit consumption rate	R/kWh	0.5621	0.5886	0.6527
Average kVA unit rate	R/kVA	44.48	44.48	44.48
Fixed monthly rate	R/month	13 361.92	13 361.92	13 361.92
Consumption charge monthly average	R/month	30 781.00	46 041.00	122 533 .00
kVA charge monthly average	R/month	12 702.00	12 702.00	12 702.00
Fixed charge monthly average	R/month	13 362.00	13 362.00	13 362.00
Total energy cost monthly	**R/month**	**56 845.00**	**72 104.00**	**148 596.00**
Average unit energy cost	**R/m³**	**4.27**	**3.79**	**3.26**

The estimated monthly cost of electricity when the plant is in continuous operation (24 hours/day) at full production is approximately R148 596.

Note also that the calculation above is based on a specific energy consumption of 4.11 kWh/m³, which is the best achieved by the plant in the production runs recorded to date and compares well to the figure of 3.97 kWh/m³, which is calculated from the installed equipment.

Energy Recovery

The plant's pressure exchanger energy recovery device contributes to lowering the calculated specific energy requirement (3.97 kWh/m³) of the actual equipment installed, which correlates well with the recorded specific energy figure above (4.11 kWh/m³) and is further broken down as indicated in Figure 2.8.

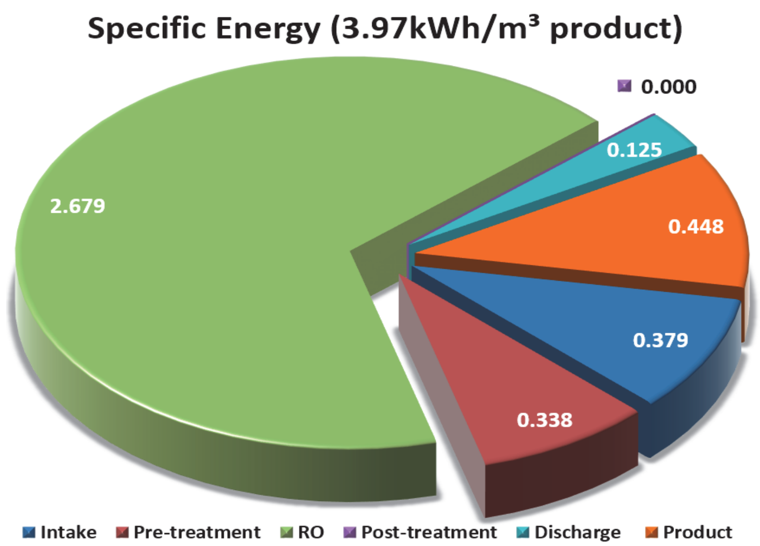

Figure 2.8: Specific energy requirements for Sedgefield SWRO plant (with pressure exchanger ERD)

The specific energy requirement calculated for full production running continuously includes the intake and product water pumping. If we then exclude the intake and product pumping energy requirements, the figure obtained for the plant alone is 3.14 kWh/m³, which includes the feedwater pumps, the RO units, and the brine discharge pumps.

The Sedgefield plant utilises a pressure exchanger type energy recovery device (ERD) and this results in an energy requirement of 3.97 kWh/m³.

Note that this would increase (substantially) to approximately 4.87 kWh/m³ if a turbocharger ERD (as at Mossel Bay) had been used. While this is a theoretical calculation, it shows a potential energy saving of approximately 23%.

2.4.4.2 *Water quality parameters*

Table 2.15 indicates the sea intake and treated potable water quality parameters for the Sedgefield desalination plant.

Table 2.15: Sedgefield SWRO plant intake and product water parameters

Parameter	Raw Seawater Intake	Treated Potable Water
Temperature (°C)	15-22	16-25
pH	7.2-7.8	8.0-9.0
Total Dissolved Solids (mg/ℓ)	32 550-36 500	195-450
*Conductivity (µS/cm)	45 000-55 000	< 200
Chlorine (ppm)	approx. 19 500	100-120

*conductivity varies with seasonal changes

2.4.4.3 *Monitoring results*

The following monitoring results have been obtained based on previous measurements.

Due the plant only being operated for limited periods during emergencies only, there is a lack of regular data with respect to monitoring results during live/continuous operation.

Table 2.16: Sedgefield SWRO plant final product water analysis results

Sedgefield SWRO PLANT	Treated Potable Water				
Parameter Description	15-Jan-10	11-Feb-10	19-Feb-10	30-Mar-10	14-Apr-10
pH	6.64	6.5	7.58	9.14	8.25
TDS	400	323	400	310	460
Turbidity (NTU)	1.6	0	0.35	0.29	0.57
Conductivity (at 25°C) (mS/m)	58.3	42.7	58.3	46	69
Chlorine (ppm)	223	123.36	45.1	151	176

2.4.4.4 *Cleaning in place and downtime*

Cleaning in Place (CIP) is carried out when required and only results in downtime during the peak holiday season, when full production is necessary.

2.4.4.5 *Operation and maintenance problems experienced*

The key problems experienced are the varying feedwater quality from the boreholes, and the discharge of brine at the beach, and these are being addressed as on-going projects by the Knysna Municipality. Other problems are typical of SWRO plants and can be dealt with by good O&M management, such as corrosion, minor leaks and drips, cleaning out (flushing) the system after maintenance works, monitoring and telemetry, and good housekeeping.

2.4.4.6 *Operational costs*

The estimated O&M cost breakdown based on full production, with 2014/15 escalation is indicated below.

Table 2.17: O&M estimated cost breakdown for the Sedgefield SWRO plant (full production)

O&M breakdown	Unit Cost (R/m³)	Cost (R/month)
Electricity	3.14	143 440
Chemicals & Consumables	0.70	31 972
Maintenance	0.52	23 715
Staff	2.58	117 750
Laboratory	0.11	5 000
SHEQ	0.11	5 000
Total Monthly Cost (Excl. VAT)	**7.16**	**326 876**

The estimated O&M cost breakdown for full production is illustrated in Figure 2.9:

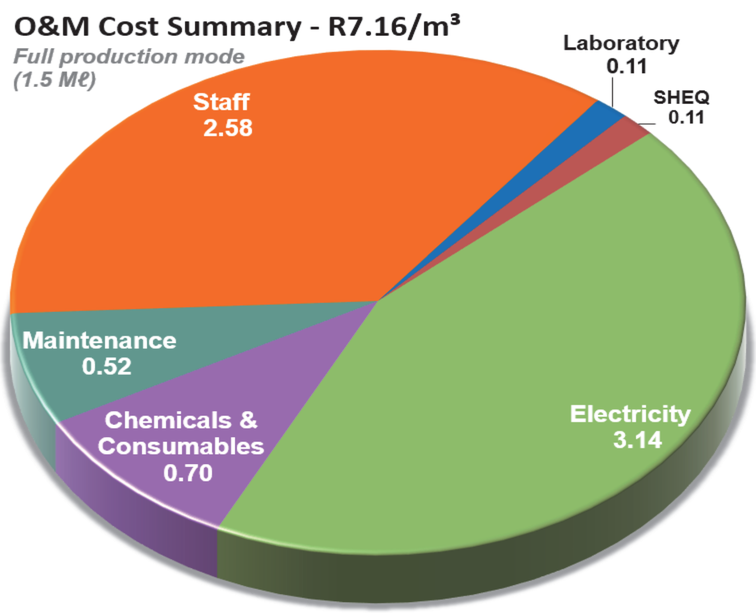

Figure 2.9: O&M Cost breakdown for the Sedgedield SWRO plant (full production)

2.5 ALBANY COAST SEAWATER DESALINATION PLANT

The Albany Seawater Treatment Plant is located at the Bushman's River Mouth in the Ndlambe Local Municipality which is situated approximately halfway between Port Elizabeth and East London. This is a water scarce region with limited access to freshwater dams and rivers. The scarcity is also increased by the geological conditions imposed by the Bokkeveld shale which limit the use of boreholes because of its imperviousness (limits the passage of water into the ground) and the releasing of salts into groundwater.

Figure 2.10: Albany Coast SWRO plant

The Albany Coast desalination plant abstracts raw water from beach wells and supplies treated desalinated water to the Bushmans River reservoir and Kenton-on-Sea settlements. Figure 2.11 shows the location of the Albany Coast SWRO plant and the Dias well field which supplements and is blended into the SWRO plant supply.

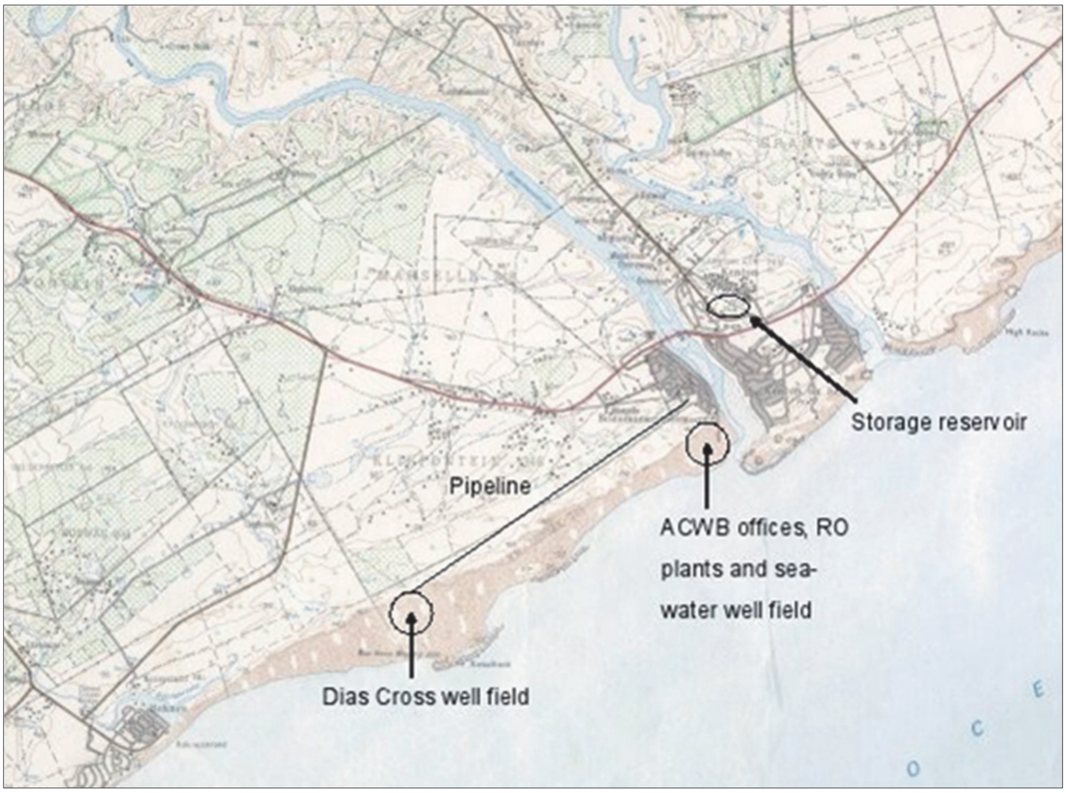

Figure 2.11: Location of beach wells

In addition to this, the quality of water sourced from the Diaz Cross Aquifer is deteriorating, which in turn has led to the Amatola Water Board relying on the only alternative and available water resource which is seawater. The plant is capable of supplying 1 800 m³ of potable water per day for the 50 000 population it services.

2.5.1 Funding and Institutional Arrangements

The Albany Coast Water Board's was incorporated into the Amatola Water Board after the reverse osmosis desalination plant has been upgraded from 500 m³ to 1 800 m³ after the successful completion of an extensive upgrade and 13-month's operation, optimisation and maintenance by Veolia Water Solutions. Amatola Water currently operates and maintains the Albany Coast desalination works.

The initial plant, RO_1, was commissioned in 1997 and expanded with the addition of RO_2 which was commissioned in 2008. In 2010, the two trains were combined and placed onto a single skid, called RO_{12}, with a capacity of approximately 1.4 Mℓ/d. An additional unit called RO_3 was installed using some of the original plant's equipment, and has an estimated capacity of 0.4 Mℓ/d.

The design is configured on a modular basis for ease of expansion when the potable water demand increases.

2.5.2 Capital costs

Due to the plant ownership and operational responsibility being transferred between parties, the exact capital costs for the plant RO_1, RO_{12} and RO_3 upgrades are not known, but the asset value of R19 million in 2010 is used as a base to calculate further.

The estimated capital costs for the overall plant are allocated into a typical SWRO plant breakdown and listed below in Table 2.18:

Table 2.18: Albany Coast SWRO plant (1.8 Mℓ/d) capital costs

Albany Coast SWRO Plant Capital Costs	Cost (Rand) (2010)	% of Project	Cost (Rand) (2014/15)	Unit Cost (Rm/ Mℓ/d) (2014/15)
Direct Costs				
Intake	1 676 471	6.0	2 156 723	1.30
Outfall	1 397 059	5.0	1 797 269	1.08
Pre-treatment	1 397 059	5.0	1 797 269	1.08
RO Plant	13 132 353	47.0	16 894 330	10.18
Post-treatment	558 824	2.0	718 908	0.43
Electrical, electronic and control	1 676 471	6.0	2 156 723	1.30
Civil building and structures	1 955 882	7.0	2 516 177	1.52
Bulk electrical supply	1 397 059	5.0	1 797 269	1.08
Product pumpstation & pipelines	558 823	2.0	718 908	0.43
Subtotal Direct Costs	**23 750 000**	**85.0**	**30 553 576**	**18.41**
Indirect Costs				
Professional fees, site monitoring, disbursements	4 191 176	15.0	5 391 807	3.25
Subtotal Indirect Costs	**4 191 176**	**15.0**	**5 391 807**	**3.25**
Total Cost (excluding VAT)	**27 941 176**	**100.0**	**35 945 383**	**21.65**

2.5.3 Process description

The Albany Coast water supply system, including the SWRO plant and nearby well fields, has a capacity of approximately 1.8 Mℓ/d RO and 1.2 Mℓ/d dune wells. The SWRO plant uses two feedwater sources: beach wells and brackish water abstracted from boreholes. The Diaz Cross Aquifer water is blended with the desalinated permeate, achieving the desired re-mineralisation naturally. The RO_{12} train features a higher throughput capacity and lower energy requirements, utilising a pressure exchanger and a turbine-based energy recovery system. Other upgrades included the integration of micro filters (using 5 micron filter bags) for pre-treatment, chemical dosing systems and a clean-in-place system for the RO membranes.

The process train at the Albany SWRO Plant is described in Figure 2.12.

2.5.3.1 *Source*

Seawater is abstracted from beach wells located at the Bushman's River Estuary. Seawater is naturally filtered as it passes through the sand. Only water from the beach wells is treated by reverse osmosis. Brackish water is also abstracted from 7 wells in the sand dunes above the Diaz Cross Aquifer and pumped to the reservoir at Albany Seawater Treatment Plant where it is blended with desalinated seawater.

2.5.3.2 *Pre-treatment*

The feedwater is pumped from the beach wells directly to a set of sand-filters and filtered for a second time before entering the RO plant. Raw water from the boreholes flows through a series of vertical chambers with filter bags and then into a 20 000 ℓ storage tank. The pre-filtered water then undergoes sand filtration, using a battery of horizontal sand filters for the new plant and a battery of vertical sand filters previously used for the older RO_1 plant. After sand filtration the water flows into a filtered water reservoir and is pumped via three (3) pumps through a final microfiltration step. Anti-scalant is dosed into the filtered water prior to entering the RO plant to prevent chemical scaling and lowered trans-membrane flux.

2.5.3.3 *Reverse osmosis (RO)*

The plant consists of two RO units with a capacity to produce up to 1.8 Mℓ/d. The equipment comprising the RO units consists of:

- Feedwater pumps and pipework;
- High pressure pump;
- Energy recovery system (installed by Veolia) for RO_{12} and RO_3;
- RO pressure vessels with membrane units and high pressure pipework;
- Anti-scalant dosing system;
- Control panel, wiring and on-line instrumentation;
- Compressor and valve actuator system;
- Low pressure pipe work for permeate, brine and CIP.

2.5.3.4 *Stabilisation*

The product water is disinfected by means of sodium hypochlorite dosing prior to transfer to 2 x 10 000 ℓ storage tanks which in turn supply the product water reservoir. These tanks also serve as a supply for backwash water for the sand filters.

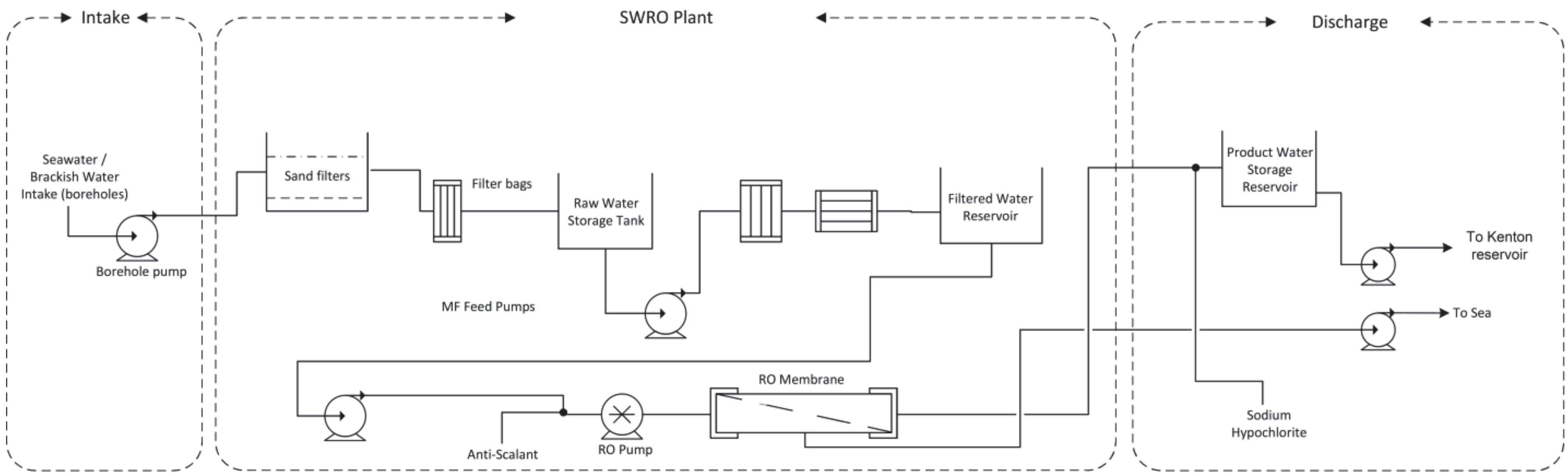

Figure 2.12: Process schematic of the Albany Coast SWRO Plant

2.5.3.5 *Distribution*

The RO process generates two streams, namely the desalinated or product water and the concentrated brine. Raw water drawn from the Diaz Cross well fields is pumped to the product water reservoir and blended with the product water before finally being pumped to storage reservoirs situated at Kenton. The concentrated brine stream is discharged back to the river.

2.5.4 Operation and Maintenance Aspects

2.5.4.1 *Electricity*

The Albany Coast SWRO plant is presently supplied with electricity by Eskom using the Ruralflex tariff having previously used the Nightsave rural tariff structure.

The implementation of energy recovery devices for the RO_{12} units significantly reduced the plant's total energy requirements (reportedly by as much as 30%). The average electricity consumption per m³ for the Albany Coast system, including the SWRO plant and other sources like boreholes, springs and wells, between July 2012 and June 2013 was 2.29 kWh/m³.

In 2014, the average energy consumption of the system was 2.67 kWh/m³ (Amatola, 2014). This figure is lower than that for normal SWRO systems, because the other sources have minimal energy requirements.

The values for the RO plant only are provided in the latest data obtained at the plant (including the beach wells feeding the plant and the product water pumps).

Table 2.19: Albany Coast SWRO plant energy consumption & cost data (2014/15)

Description	Unit	Amount *
Electrical consumption (Off-peak)	kWh	80 667
Electrical consumption (Peak)	kWh	24 904
Electrical consumption (Standard)	kWh	61 627
Total electrical consumption (per month)	kWh	167 197
Average unit consumption cost	R/kWh	R0.575
Average electrical consumption charge	R/month	R96 127.00
Reactive energy charge	R/month	R856.00
Admin monthly charge	R/month	R1 789.00
Network Access charge kVA	R/month	R19 980.00
Network Demand charge	R/month	R31 433.00
Reliability charge	R/month	R485.00
Service charge	R/month	R4 168.00
Total monthly energy cost	R/month	**R154 837.00**
Average water production per month	m³/month	R36 999
Average water production per day	m³/d	1 210
Specific Energy consumption	**kWh /m³**	**4.52**
Average energy cost	**R/m³**	**R4.18**

Note * Costs are based on current 2014 Eskom tariffs.

The specific energy consumption value of 4.52 kWh/m³ for the plant overall is well in line with figures for other SWRO plants of this nature.

Energy Recovery

At present, RO_{12} has an ERD (pressure exchanger type) and RO_3 has a turbo, which reduces the energy requirement of this part of the plant to approximately 3.79 kWh/m³. The specific energy requirement for the RO section only of RO_{12} is 2.68 kWh/m³ which is less than half of the 6.1 kWh/m³ of RO_3 (without an ERD).

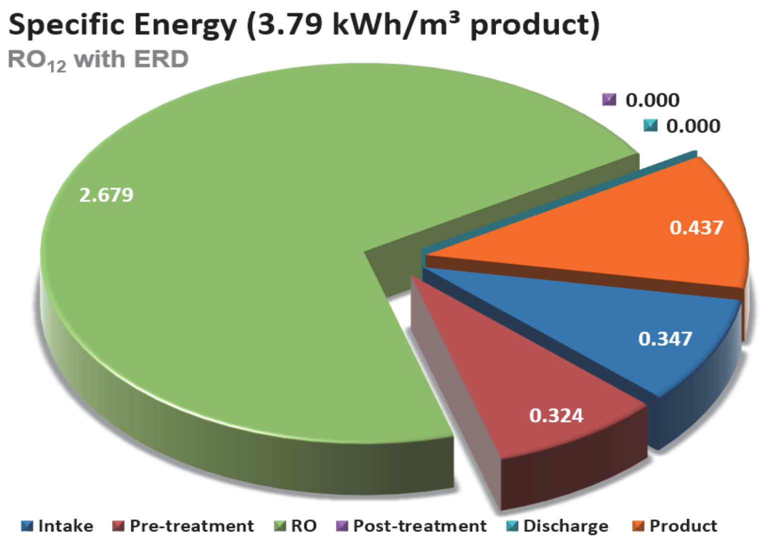

Figure 2.13: Specific energy requirements for RO_{12} (with pressure exchanger ERD)

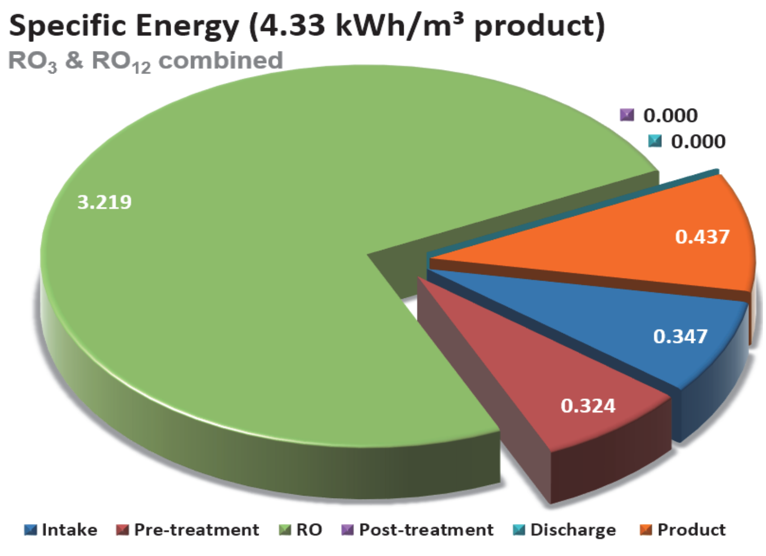

Figure 2.14: Specific energy requirements for the combination of RO_{12} & RO_3

The RO units are mostly run together and the overall plant specific energy requirement for the combined RO_{12} and RO_3 is estimated to be 4.33 kWh/m³, as illustrated in Figure 2.14.

This figure correlates well with the actual specific energy figure of 4.52 kWh/m³ recorded for a recent 7-month period.

2.5.4.2 *Water quality parameters*

Table 2.20 indicates the sea intake and treated potable water quality parameters for the Albany Coast desalination plant.

Table 2.20: Albany Coast SWRO plant intake and product water parameters

Parameter	Raw Seawater Intake	Treated Potable Water
Temperature (°C)	19.3	22
pH	7.1	6.2
Total Dissolved Solids (mg/ℓ)	2 670	136
Turbidity (NTU)	1.4	0.15
*Conductivity (µS/cm)	41 300	160
Chlorine (ppm)		0.53

*conductivity varies with seasonal changes

2.5.4.3 *Monitoring results*

The following monitoring results have been obtained based on previous measurements. Due the plant only being operated for limited periods during emergencies only, there is a lack of regular data with respect to monitoring results during live/continuous operation.

Table 2.21: Albany Coast SWRO plant final product water analysis results

Albany Coast SWRO Plant	Treated Potable Water				
Parameter Description	**21-09-2010**	**31-10-2011**	**18-07-2012**	**19-09-2013**	**13-02-2014**
pH	6.26	7.2	7.40	7.5	5.80
TDS	167	345	687	56	111
Turbidity (NTU)	0.12	0.17	0.29	0.37	0.11
Conductivity (at 25°C) (mS/m)	34	69	39	11	22
Chlorine (ppm)	0.34	0.50	0.46	0.48	0.18

2.5.4.4 *Cleaning in place and downtime*

Cleaning in Place (CIP) is carried out at Albany SWRO plant when required and only results in downtime during the peak holiday season, when full production is necessary.

2.5.4.5 *Operation and maintenance problems experienced*

The key problem experienced is the cost of production during the winter months when Eskom's tariffs are high. Also, Eskom's loadshedding adds its own unnecessary strains in the membranes with sudden pressure drops during uncontrolled shutdowns.

2.5.4.6 *Operational Costs*

The actual O&M breakdown based on current production figures of 1.2 Mℓ/d (74% of rated capacity) for the year 2014/15 is indicated in Table 2.22.

Table 2.22: O&M cost breakdown for Albany Coast SWRO plant 2014/15 (actual production)

Albany Coast O&M Costs	Unit Cost (R/m³)	Cost (R/month)	Cost (R/annum)
Electricity	4.18	211 444	2 537 333
Chemicals	0.39	19 697	236 369
Consumables	0.20	10 105	121 263
Maintenance	1.97	99 737	1 196 842
Staff	1.47	74 276	891 306
Laboratory	0.15	7 500	90 000
SHEQ	0.10	5 000	60 000
Subtotal costs (excluding ERD rental)	**8.47**	**427 759**	**5 133 113**
ERD rental	**0.53**	**20 000**	**240 000**
Total O&M Costs	**9.00**	**447 759**	**5 373 113**

The estimated O&M cost breakdown for the actual production is illustrated in Figure 2.15.

It is estimated that the pressure exchanger ERD and turbo units saves 45% of the energy consumed by RO_{12} and RO_3 when compared to having no ERD at all. This translates to a saving of approximately 3 kWh/m³. These units were hired from Veolia Water at a monthly cost of R20 000 and is covered more than three times by the energy cost savings of the units (R67 000) in a normal production month.

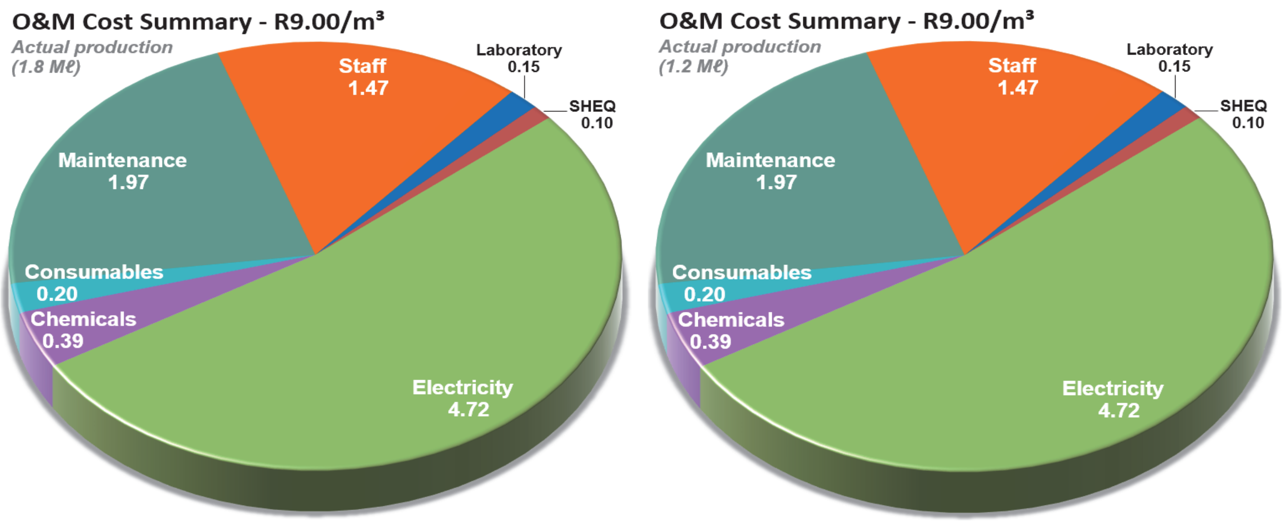

Figure 2.15: O&M Cost breakdown for the Albany Coast SWRO plant, including ERD rental (actual production)

CHAPTER 3: COST AND OPERATIONAL ASPECTS OF WATER REUSE PLANTS IN SOUTH AFRICA

3.1 INTRODUCTION

The sections that follow provide a comprehensive report on each of the water reuse plants including planning and institutional aspects, process descriptions, schematic drawings of the relevant technologies employed for the each of the plants. Information on influent and product water quality, operational and maintenance aspects, life cycle costs and best practices is also presented.

A detailed photo summary showing the general layout, process units and major equipment of each plant can be found in Appendix A.

The following water reuse plants were selected for investigation in this study, namely:

No.	Plant	Type of Plant	Operator
1	Beaufort West 2.1 Mℓ/d reclamation plant	Reuse – direct potable	Water & Wastewater Eng.
2	Windhoek 21 Mℓ/d Goreangab reclamation plant	Reuse – direct potable	Wingoc
3	George 10 Mℓ/d UF plant (full capacity tested at 8.5 Mℓ)	Reuse – indirect potable	Aqua Engineering
4	Mossel Bay 5 Mℓ/d UF/RO plant	Reuse – direct industrial	VWS (Veolia)

The George and Mossel Bay water reclamation plants were built during the 2010/11 drought period and have been included in the study to evaluate the costs associated with building and running these plants over the duration of the study period between 2012 and 2015. These projects were mostly undertaken under emergency conditions and considerable time pressure, which differentiate them from the projects not completed under such strict time constraints.

Although constructed during the same drought period, the Beaufort West water reclamation plant had been in the planning phase since 2007, forming part of the municipality's medium term plan to develop sustainable drinking water supplies.

The New Goreangab water reclamation plant has historical significance as the first direct potable reuse plant in the world. The Old Goreangab reclamation plant (Old Plant) was constructed in 1969, while the 21 Mℓ/d New Goreangab water reclamation plant (NGWRP) for direct potable use was commissioned in 2002 and built alongside the Old Plant.

These water reclamation plants were selected based on their location and importance with respect to augmenting water supply in the associated regions.

Each of the plants is further detailed under the relevant sections below.

Water Reuse Plants				
Plant	Beaufort West reclamation plant	Goreangab water reclamation plant	George UF plant	Mossel Bay UF/RO plant
Size of Plant	2.1 Mℓ/d	21 Mℓ/d	10 Mℓ/d (full capacity tested at 8.5 Mℓ)	5 Mℓ/d
Type of Plant	Reuse: Direct potable	Reuse: Direct potable	Reuse: Indirect potable	Reuse: Direct industrial
Owner	Beaufort West Municipality	Windhoek Municipality	George Municipality	Mossel Bay Municipality
Operator	Water & Wastewater Eng.	Wingoc	George Municipality	VWS (Veolia)
Operational Status	1.2 Mℓ/day	17.5 Mℓ/day	Zero mode	Zero mode
Completed	2010	2001	2010	2010
Capital Cost - at time of construction - Adjusted for 2014/15 - Per unit capacity	 R26.5 mill R34 mill R16.22 mill/Mℓ/day	 R122 mill R260 mill R12.38 mill/Mℓ/day	 R36 mill (plant) R46 mill R5.44 mill/Mℓ/day	 R40 mill R51 mill R10.19 mill/Mℓ/day
O&M Cost (2014/15)	R6.92/m³	R4.87/m³	R2.11/m³	R2.72/m³
Energy Use	2.07 kWh/m³	0.57 kWh/m³	0.23 kWh/m³	0.73 kWh/m³
Electricity Cost	R1.88/m³	R0.57/m³	R0.23/m³	R0.64/m³
Chemicals	R0.85/m³	R1.55/m³	R0.44/m³	R0.18/m³
Consumables	R0.50/m³	R1.00/m³	R0.50/m³	R0.50/m³
Maintenance	R1.01/m³	R0.78/m³	R0.23/m³	R0.49/m³
Staff	R1.96/m³	R0.88/m³	R0.49/m³	R0.79/m³
Laboratory cost	R0.47/m³	R0.06/m³	R0.15/m³	R0.07/m³
SHEQ	R0.23/m³	R0.03/m³	R0.08/m³	R0.05/m³

- Please note that all costs are quoted in South African Rand and exclude VAT.
- All O&M values are estimates based on variables (rates based on historical data, inflation, etc.) and represent the cost as at full production.
- George UF plant design specification was 10 Mℓ/day, but subsequently only tested up to 8.5 Mℓ/day. Throughout the report 8.5 Mℓ will be used as full production capacity.

3.2 A COSTING MODEL FOR WATER REUSE PLANTS (WRC PROJECT 2119)

The model was developed as part of a WRC project (no. 2119/1/14) “Guidelines for the Selection and Costing of Water Reclamation and Reuse Systems” (Swartz et al., 2014). The WRC Water Reuse Costing Model (REUSECOST) is illustrated in Figure 3.1. The user manual and list of features of the model can be found in the above mentioned WRC report, for the intents and purposes of this project, it is assumed that the reader has not read the above mentioned WRC report.

3.2.1 Input

This part of the model is simply a user interface which can be used to supply the necessary input parameters and boundary conditions for the model to use. It is important that the user reads the descriptions of each of the input parameters carefully in order to provide the correct information in the correct format and units. The following inputs are required by the model:

1. Flow rate
2. Raw water quality or already selected treatment processes or process configuration(s)
3. Project location
4. Supply of abstracted raw water to the treatment plant
5. Clean water storage
6. Distribution networks
7. Project life cycle (normally design period, in years)

With these inputs the model can start processing information in order to provide a final output that is of value to the user.

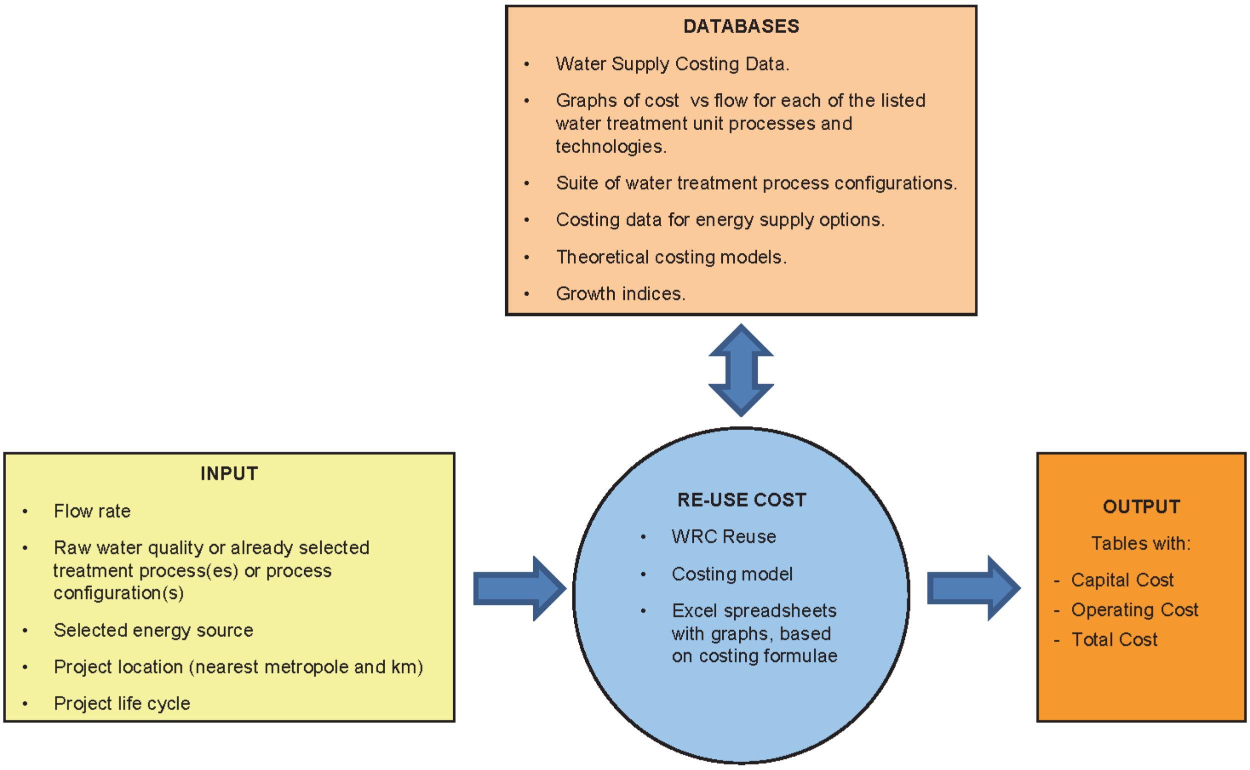

Figure 3.1: Schematic representation of the WRC Water Reuse Costing Model

From the above figure, it can be seen that the model primarily consists of four basic parts. Each one of these parts is crucial for the correct use and functioning of the model.

3.2.2 Database

The database is not accessible by the user but is used by the model in the background. The database simply consists of empirical costing data that was collected and processed into data graphs that shows the cost against flow rate of several process treatment units typically implemented at water reuse plants. From the graphs mathematical correlations can be obtained in order to be used in the calculations of the model. The following process treatment units are included in the database:

- Flocculation
- Primary sedimentation
- Clarification
- Pulsator Clarifiers
- Clariflocculation
- Rapid gravity filters
- UF
- RO
- DAF
- GAC
- UV disinfection
- Chlorination

The user has the option of selecting unit treatment processes one-by-one or as part of a pre-set plant configuration that makes use of several unit treatment processes that are automatically selected by the model when the user chooses to do so.

The database also includes indices that add certain cost factors to certain aspects of the project depending on the selections made by the user at the input. For instance, excavation can be multiplied by a certain cost factor depending on the soil type (hard, soft, and moderate) selected by the user.

3.2.3 Model (REUSECOST)

The model makes use of the information supplied by the user from the input as well as the information stored in the database to calculate the different cost aspects of the unit treatment processes that were selected by the user.

The model also makes use of the indices in the database to add cost factors where applicable. Finally after performing all the necessary calculations, the model provides an output.

3.2.4 Output

The output is simply a user friendly page that supplies all the results generated by the model. The output consists of three cost sections:

- Capital cost (with a per-unit breakdown)
- Operating cost (showing cost per day, year and kilolitre)
- Cost summary (sowing the total capital cost amortization as well as the operational cost)

3.2.5 Model example

The New Goreangab water reclamation plant (NGWRP) is an ideal plant to serve as an example to illustrate the REUSECOST model. The output of the model can be seen Figure 3.2. Since this is only an illustration, only the total cost summary is shown.

Total Capital Amortization			Million Rand
		TOTAL CAPITAL COST: Present value	R 207.21
		TOTAL CAPITAL COST: Future value (Amortized over 20 years at 6% interest)	R 1 161.30
Total Cost Summary	**Cost per day (Million)**	**Cost per year (Million)**	**Cost per kilolitre (R/kL)**
Total capital costs (Based on future value)	R 0.16	R 58.06	R 7.58
Total operating and maintenance costs	R 0.08	R 27.84	R 3.63
TOTAL PROJECT COSTS	**R 0.24**	**R 85.90**	**R 11.20**

Figure 3.2: Water Reuse Costing Model (REUSECOST) output with the NGWRP as example

As can be seen above, the total capital cost (present value) of the NGWRP figures compare relatively well, while noting that the exact breakdown of the capital cost figures for the NGWRP were not obtained.

3.3 BEAUFORT WEST WATER RECLAMATION PLANT

Beaufort West experienced water supply problems following a prolonged drought in 2010 and this affected drinking water supply. Beaufort West has two “natural” surface water sources, namely the Gamka and Springfontein dams, and various boreholes. There is no perennial river in the surrounding area making drought virtually inevitable. The drought resulted in approximately 50% drying up of both dams and boreholes and consequently drying up of the Gamka dam by the end of 2010, resulting in a lack of raw water supply. The supply of water from the boreholes was not enough to supply the town and thus drinking water had to be transported for the immediate needs of the population.

Figure 3.3: Beaufort West water reclamation plant

In addition, the existence of informal settlements and backyard dwellers led to increased demand for water and sanitation services. The municipality’s goal has been to provide good quality water to the informal areas. Future investments are needed to provide sufficient water services for the housing backlog and also supply both new and old households with sufficient drinking water and sanitation. These circumstances led the Beaufort West Municipality to embark on short term, medium term and long term strategies for water supply and management and some of the options included were:

- Managing water losses;
- Optimising existing aquifers;
- Exploring new groundwater sources;
- Water reclamation.

Water reclamation was identified as a suitable short to medium term option to counter the problem. This led to the first direct water reclamation plant in South Africa where treated effluent from the wastewater treatment works is further treated and pumped directly back into the town’s water supply all year round, effectively decreasing pressure on the Gamka and Springfontein dams and boreholes.

Beaufort West municipality was assigned a government grant from the Drought Relief Fund to finance the construction of the plant which has a production capacity of 2.1 Mℓ/d. The production rate was started at 1 Mℓ/d and there will be annual increases in production of 10% over a period of ten years. While the plant is owned by the Beaufort West Municipality, it is operated by Water & Wastewater Engineering. The Beaufort West water reclamation plant construction was completed within six months and the first reclaimed water was delivered on 15 January 2011. Water & Wastewater Engineering was assigned the contract to design, build and operate the plant under a 20-year service contract, where the municipality pays per cubic metre of treated reclaimed water under the O&M contract.

The plant currently produces approximately 1.2 Mℓ/d and is operational for 10 to 13 hours per day, producing some 96 m^3/h during normal operation. In the evening the plant remains in zero production mode, unless additional water supply requirements are needed.

3.3.1 Funding and institutional arrangements

Initially, the Beaufort West reclamation plant was to be constructed under a funding and capital redemption model, where the capital redemption value was included the overall price that the municipality pays per cubic metre of treated reclaimed water under the O&M contract.

These negotiations began in 2007 between Beaufort West Municipality and Water & Wastewater Engineering as part of the municipality's medium term plan to develop sustainable potable water supplies. This prior engagement has seen a long term relationship develop allowing for sufficient planning prior to the plant start-up. In 2010, the funding model for the plant was changed due to emergency funding being granted by the DWA due to the drought. The municipality currently pays R9.50/m³ of treated reclaimed water (under a 20-year service level agreement), as well as all electrical costs. All other costs (including chemicals, staff, membrane replacement, on site laboratory analyses, etc.) are covered by Water & Wastewater Engineering as part of the overall unit fee per cubic metre.

3.3.2 Capital Costs

The capital cost of the plant was approximately R26.5 million (excluding VAT) in 2010. The capital costs are summarised in Table 3.1.

Table 3.1: Beaufort West water reclamation plant (2.1 Mℓ/d) capital costs

Beaufort West Plant Capital Costs	Cost (Rand) (2010)	% of Project	Cost (Rand) (2014/15)	Unit Cost (Rm/Mℓ/d) (2014/15)
Direct Costs				
Filter equipment and electrical costs	3 105 164	11.7	3 994 689	1.90
UF and RO membranes	10 184 443	38.5	13 101 943	6.24
Civil work and buildings	8 953 647	33.8	11 518 566	5.49
Pipeline	1 506 630	5.7	1 938 229	0.92
Subtotal Direct Costs	**23 749 884**	**89.7**	**30 553 427**	**14.55**
Indirect Costs				
Professional fees, site monitoring, disbursements	2 266 518	8.6	2 915 799	1.39
Environmental and specialist studies, etc.	461 111	1.7	593 203	0.28
Subtotal Indirect Costs	**2 727 629**	**10.3**	**3 509 003**	**1.67**
Total Cost (excluding VAT)	**26 477 513**	**100.0**	**34 062 430**	**16.22**

In comparison, the REUSECOST model (Swartz et al., 2014), estimates the total capital cost at approximately R49 million (in year 2012/13), and R55 million (in year 2014/15). This is approximately 60% higher than the actual capital costs and requires further investigation and checking of the model.

Total Capital Amortization			**Million Rand**
TOTAL CAPITAL COST: Present value			R 49.08
TOTAL CAPITAL COST: Future value (Amortized over 20 years at 6% interest)			R 275.06

Total Cost Summary	**Cost per day (Million)**	**Cost per year (Million)**	**Cost per kilolitre (R/kL)**
Total capital costs (Based on future value)	R 0.04	R 13.75	R 17.94
Total operating and maintenance costs	R 0.01	R 3.13	R 4.07
TOTAL PROJECT COSTS	**R 0.05**	**R 16.88**	**R 22.02**

Figure 3.4: REUSECOST Model results for Beaufort West water reclamation plant

3.3.3 Process description

The Beaufort West water reclamation plant follows the multiple barrier principle which is differentiated into three types, namely non-treatment, treatment and operational barriers.

Non-treatment barriers are described as:

- No industrial effluent is diverted to the wastewater treatment plant.
- Rigorous and continuous raw and treated water quality monitoring to ensure corrective measures to be taken and continuous improvement of the operations to limit exposure of public to poorly treated water.
- Blending reclaimed water with conventional sources. The blending limits the reclaimed water percentage to 25% of the blended water.

Treatment barriers may either be partial or total:

- Partial barriers – limit specific contaminants progressively in the process train.
- Complete barriers – the contaminants targeted at each unit process differ and the mode of treatment determines the removal of the targeted contaminant.

Operational barriers are treatment processes that are not normally used but serve as standby processes in the event of failure by a duty treatment process. At the Beaufort West water reclamation plant there is the option to apply intermediate chlorination should enhanced disinfection be required. The water reclamation plant process includes the addition of ferric chloride ($FeCl_3$) into the existing activated sludge plant to remove orthophosphates from the final effluent. $FeCl_3$ is also used as a flocculent to improve the settling of suspended solids in the secondary settling tank. The treatment sequence at the wastewater treatment plant is summarised below:

- Screening and grit removal;
- Activated sludge treatment and
- Secondary Settling.

Final effluent from the secondary settling tanks (SST) is pre-chlorinated before flowing to the sedimentation tank which performs the following functions

- Buffering zone for flow variations;
- Dilute contaminant peaks;
- Increase the settling of particles due to the long retention time.

The process train at the Beaufort West water reclamation plant is described in Figure 3.5.

3.3.3.1 *Source*

Beaufort West WWTP final effluent from the sedimentation tank (post the SST's) which has an 18 hour hydraulic retention time.

3.3.3.2 *Pre-treatment*

Water from the sedimentation tank is treated by means of rapid gravity sand filtration. Intermediate chlorination can be carried out if further disinfection is required after the sedimentation tank. Sand filtration removes macro-organic matter and any remaining solids and also protects downstream membranes from fouling as a result of shock organic loads or excess flocculent dosing.

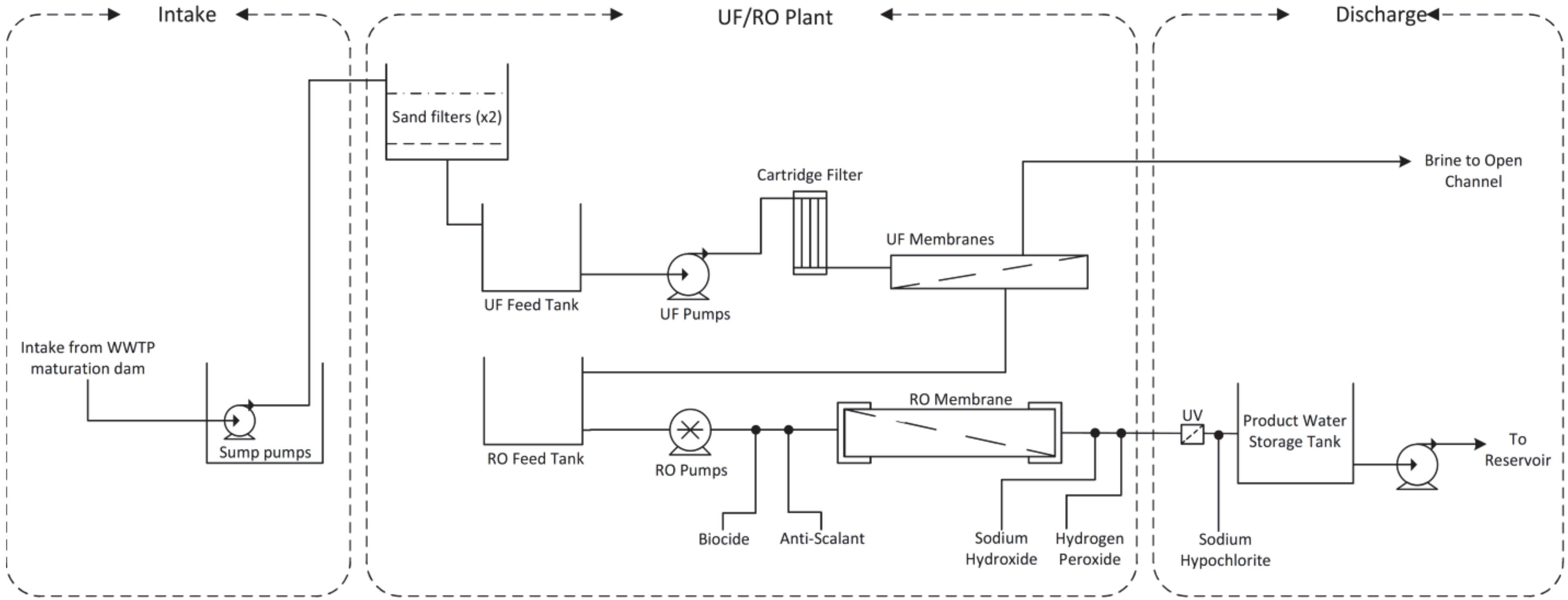

Figure 3.5: Process schematic of the Beaufort West water reclamation plant

3.3.3.3 *Ultra-filtration (UF)*

The filtered water is further filtered through ultra-filtration membranes (pore size approximately 0.01 μm in diameter). This pore size limits the passage of smaller colloids and particles, sediments, algae, protozoa, bacteria and viruses. Due of the nature of the feedwater, outside inflow membranes were selected and this aids in removing Giardia, cryptosporidium, bacteria and most viruses.

3.3.3.4 *Reverse osmosis*

The RO membranes at Beaufort West are operated using the cross-flow filtration technique which is ideal to reduce fouling and scaling when compared to dead-end operation since the sideways movement of the water continually scours deposits off the membranes. The RO treatment removes material listed below:

- Organics including pesticides and hormones;
- Other micro-pollutants;
- Dissolved salts;
- Metal ions.

3.3.3.5 *Advanced oxidation and disinfection using UV/H_2O_2*

UV/hydrogen peroxide (H_2O_2) is used for advanced oxidation and disinfection after the reverse osmosis process. UV reduces organic micro-pollutants and affects disinfection by photolysis and its action is further enhanced by the addition of hydrogen peroxide.

3.3.3.6 *Stabilisation*

Stabilisation is performed by addition of sodium hydroxide. A small chlorine dose is also applied to prevent microbial re-growth in the distribution network.

3.3.3.7 *Distribution and blending*

Reclaimed water is pumped to a service reservoir and blended with treated dam and borehole water from a second reservoir. The reclaimed water and borehole water is blended in a third reservoir which supplies the Beaufort West municipality.

The targeted mixing ratio is 1:4 and thus the current reclaimed water content of the blended water is 20%.

3.3.4 Operation and Maintenance Aspects

As mentioned earlier, the operation and maintenance of the Beaufort West Water Reclamation Plant is carried out by Water & Wastewater Engineering, and most of the data presented here is provided by them, and by the Beaufort West Municipality.

3.3.4.1 *Electricity*

The Beaufort West water reclamation plant is supplied with electricity by Beaufort West Municipality using its own tariff structure, which is aligned with that of the bulk electricity supplier, Eskom.

The average electricity consumption and cost over six months (July-December 2014) is presented in Table 3.2.

Table 3.2: Electricity costs for the Beaufort West water reclamation plant (actual production)

Consumption measured from Jul-Dec 2014	Rate	Consumption	Average Monthly Cost (Rand)
Average monthly kWh		75 551	
Peak season unit rate (3 months of year)	0.957		
Off-peak season unit rate (9 months of year)	0.597		
Average monthly rate	0.687		
Average monthly R/kWh			51 905.31
Average monthly kVA		184	
kVA unit charge	157.230		
Average monthly R/kVA			28 930.32
Fixed monthly charge			709.19
Total average monthly cost (excl. VAT)			**81 544.82**
Average cost/product water (R/m³)			**2.23**
Product water produced (m³)		**36 000**	
Electrical consumption/product water (kWh/m³)		**2.07**	

Under the current production mode of 1.2 Mℓ/d:

- The average monthly power consumption of the plant is approximately 75 551 kWh and average peak kVA demand is 184 kVA.
- The average electricity cost based is approximately R81 545 per month.
- The electrical consumption per m³ of product water is 2.07 kWh/m³.
- The average electrical cost per m³ of product water is R2.23/m³.

Assuming the plant is operating at full capacity (2.1 Mℓ/d), the estimated electricity costs are presented below.

Please note that these figures are estimations only based on current power consumptions. Actual figures will need to be verified when the plant is at full production capacity of 2.1 Mℓ/d.

Table 3.3: Estimated electricity costs for the Beaufort West water reclamation plant (full production)

Average Electricity Consumption for 2014	Rate	Consumption	Average Monthly Cost (Rand)
Average monthly kWh		132 214	
Peak season unit rate (3 months of year)	0.957		
Off-peak season unit rate (9 months of year)	0.597		
Average monthly rate	0.687		
Average monthly R/kWh			90 834.29
Average monthly kVA		184	
kVA unit charge	157.230		
Average monthly R/kVA			28 930.32
Fixed monthly charge			709.19
Total average monthly cost (excl. VAT)			**120 473.80**
Average cost/product water (R/m³)			**1.88**
Product water produced (m³)		**63 000**	
Electrical consumption/product water (kWh/m³)		**2.07**	

Under the full production of 2.1 Mℓ/d:

- The average monthly power consumption of the plant may be assumed to be approximately 132 214 kWh with an average peak kVA demand of 184 kVA.
- The average electricity cost based is approximately R120 474 per month.
- The electrical consumption per m³ of product water is 2.07 kWh/m³.
- The average electrical cost per m³ of product water is R1.88/m³.

Assuming the plant is maintained in a zero production mode, the estimated electricity costs are summarised in Table 3.4.

Note that these figures are estimations only based on current power consumptions. Actual figures will need to be verified when the plant is maintained in a zero production mode for an extended period to draw more accurate results.

Table 3.4: Estimated electricity costs for Beaufort West water reclamation plant (zero production mode)

Average Electricity Consumption for 2014	Rate	Consumption	Average Monthly Cost (Rand)
Average monthly kWh		13 221	
Peak season unit rate (3 months of year)	0.957		
Off-peak season unit rate (9 months of year)	0.597		
Average monthly rate	0.687		
Average monthly R/kWh			9 083.43
Average monthly kVA		18	
kVA unit charge	157.23		
Average monthly R/kVA			28 930.32
Fixed monthly charge			709.19
Total average monthly cost (excl. VAT)			**38 722.4**

While the plant is maintained in a zero production mode:

- The average monthly power consumption of the plant may be assumed to be approximately 13 221 kWh with the average peak kVA demand of 18 kVA. This is assuming a conservative 10% of the electrical power consumption compared to when the plant is in full operation.
- Based on the assumptions above, the average electricity cost while in zero production mode may be assumed to be in the region of R38 000 per month.

3.3.4.2 *Water quality parameters*

The water reclamation plan is designed to ensure optimal removal of organics and harmful pathogens and the “multiple barrier” principles applied are to ensure removal of:

- Macro-elements;
- Chemical determinands;
- Organic determinands;
- Micropollutants.

Table 3.5 indicates the effluent intake and treated potable water quality parameters for this plant.

Table 3.5: Beaufort West water reclamation plant intake water parameters

Parameter	Effluent Intake: General Limit	15-08-2014	23-09-2014	04-10-2014	10-11-2014
pH	5.5-9.5	7.4	7.2	7.3	7.3
COD (mg/ℓ)	75				
Faecal Coliforms (per 100 mℓ)	1 000	15	2	15	10
E. Coli (per 100 mℓ)		15	2	13	10
Ammonia as N (mg/ℓ)	6	29	0.2	0.14	0.17
Nitrate/Nitrite as N (mg/ℓ)	15	2.2	2.9	6.3	18
Chlorine (mg/ℓ)	0.25				
TSS (mg/ℓ)	25	22	13	33	26
Electrical conductivity (mS/m)	70-150 (max)	165	160	165	165
Ortho-phosphate as P (mg/ℓ)	21	0.34	0.05	0.14	1.1

3.3.4.3 *Monitoring results*

The following monitoring results have been obtained based on actual measurements.

Table 3.6: Beaufort West water reclamation plant final product water analysis results

Parameter	SANS 241: 2011 Special Limit	Treated Potable Water			
		15-08-2014	23-09-2014	04-10-2014	10-11-2014
Colour (mg/ℓ Pt)	≤ 15	5	5	5	5
Conductivity (at 25°C) (mS/m)	≤ 170	19	20	19	22
TDS (mg/ℓ)	≤ 1 200	122	128	122	141
pH	≥ 5 to ≤ 9.7	7.9	7.6	7.7	6.7
Turbidity (NTU)	≤ 1	0.3	0.2	0.4	0.2
Dissolved Organic Carbon (mg/ℓ)	≤ 10	1.5	1.1	0.9	0.5
Total Organic Carbon (TOC) (mg/ℓ)	≤ 10	1.5	1.1	0.9	0.5
Faecal Coliforms (per 100 mℓ)	Undetected	Undetected	Undetected	Undetected	Undetected
E. Coli (per 100 mℓ)	Undetected	Undetected	Undetected	Undetected	Undetected
Giardia (per 100 mℓ)	Undetected	Undetected	Undetected	Undetected	Undetected
Cytopathogenic viruses (per 100 mℓ)	Undetected	Undetected	Undetected	Undetected	Undetected
Cryptosporidium (per 100 mℓ)	Undetected	Undetected	Undetected	Undetected	Undetected
Ammonia as N (mg/ℓ)	≤ 1.5	4	0.75	0.29	0.05
Chloride (mg/ℓ)	≤ 300	28	34	30	27
Fluoride (mg/ℓ)	≤ 1.5	<0.1	<0.1	<0.1	<0.1
Nitrate/Nitrite as N (mg/ℓ)	≤ 11.9	0.2	1.1	2.8	11
Sodium (mg/ℓ)	≤ 200	28	28	36	36
Sulphate (mg/ℓ)	≤ 250	5.4	9.5	12	4.6
Zinc (mg/ℓ)	≤ 5	<5	0.02	0.01	0.01

3.3.4.4 *CIP and downtime*

Cleaning and maintenance is carried out regularly once a month, usually on the 1st day of the month. The plant is shut down for a period of 24 hours every month, where a chemical wash is done to clean to the UF membranes and an acid/alkaline wash is done to clean the RO membranes.

Any other maintenance activities and checks also occur during this shutdown. During normal operation there is a backwash every 15 min of the UF membranes consisting of an air scour, pulse, and rinse steps. No chemically enhanced back washes are done. Biocide is dosed into the RO membranes (when the plant is on standby) to further preserve it. Anti-scalant is dosed continuously during normal operation.

3.3.4.5 *Operation and maintenance problems experienced*

No major operational and maintenance issues have been encountered by the plant thus far.

The focus of plant operations and preventative maintenance is to ensure that the integrity of the UF and RO membranes are protected and kept in excellent condition at all times.

Final and intermediate streams are carefully monitored for signs of membrane integrity loss. The plant SCADA can also be monitored and controlled remotely via laptop.

A sixty-day buffer storage of consumable such as chemicals, lab consumables, etc. is kept on site. Critical spares such as UV lights, valves, seals, spare pumps, and other critical items are also kept on site for emergencies.

Original Equipment Manufacturer (OEM) vendors are brought on site to regularly service and inspect all equipment such as pumps, valves, calibrate instruments, etc.

Some minor (external) operational issues encountered thus far include:

1. Excess foam forming in the winter months over the biological reactor of the WWTW.
2. An old pipe burst in the downstream distribution network between the plant and storage reservoir.
3. Location/security issues, i.e. fencing, theft.
4. Wear and tear on mechanical seals on some rotating equipment.

3.3.4.6 *Operational costs*

Based on the data collected, estimated or calculated and compared to general reuse plant cost ranges, the estimated O&M cost breakdowns (based on full production) is presented below.

Table 3.7: O&M cost components for Beaufort West water reclamation in various production modes

O&M Parameters	**Actual production (1. 2 Mℓ)** Unit Cost (R/m³)	**Full production (2.1 Mℓ)** Unit Cost (R/m³)	**REUSECOST (2.1 Mℓ)** Unit Cost (R/m³)
Electricity	2.23	1.88	1.45
Chemicals	0.85	0.85	0.52
Consumables *	0.50	0.50	
Maintenance	1.38	1.01	0.53
Staff	2.61	1.96	1.21
Laboratory	0.55	0.47	
SHEQ	0.21	0.23	0.37
Total monthly cost (excl. VAT)	**8.33**	**6.92**	**4.07**

* In the absence of more accurate plant data for consumables, this value has been estimated based on reasonable assumptions from similar plants.

The estimated O&M cost breakdowns for the actual- and full production is illustrated in Figure 3.6

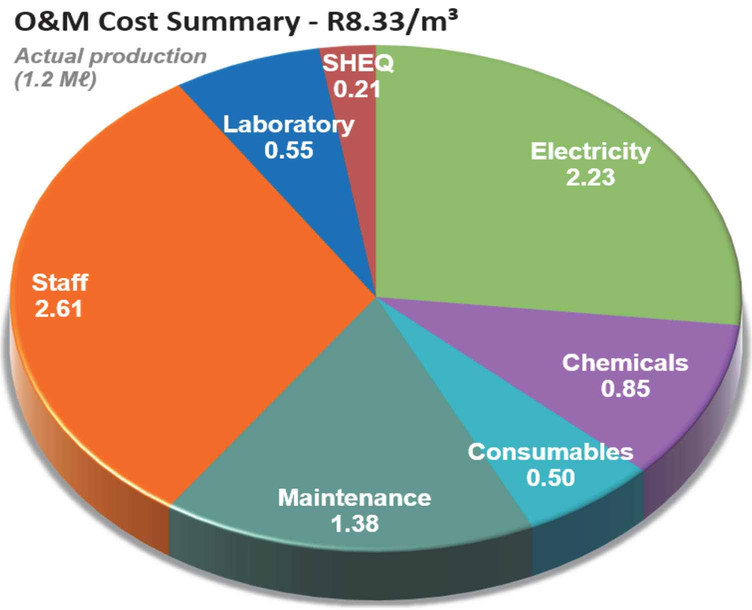

Figure 3.6: O&M Cost breakdown for the Beaufort West reclamation plant (actual production)

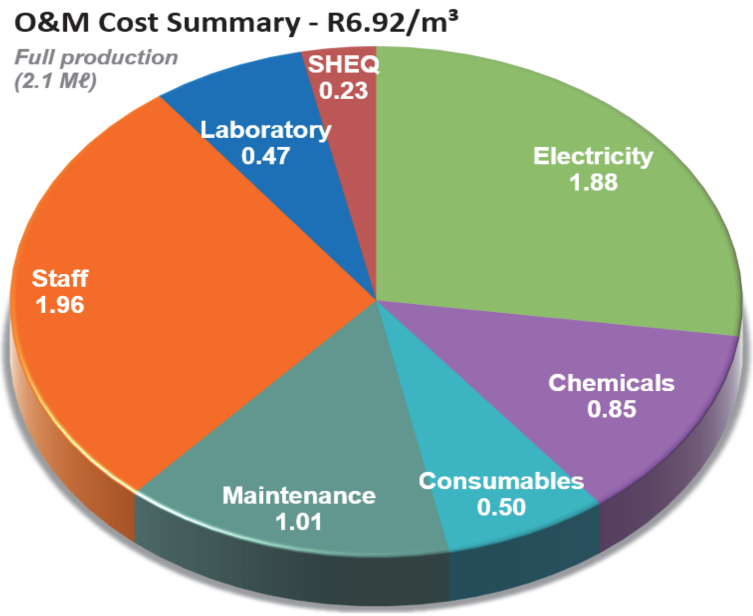

Figure 3.7: O&M Cost breakdown for the Beaufort West reclamation plant (full production)

Based on the REUSECOST model, the estimated O&M costs for full production is illustrated in Figure 2.4.

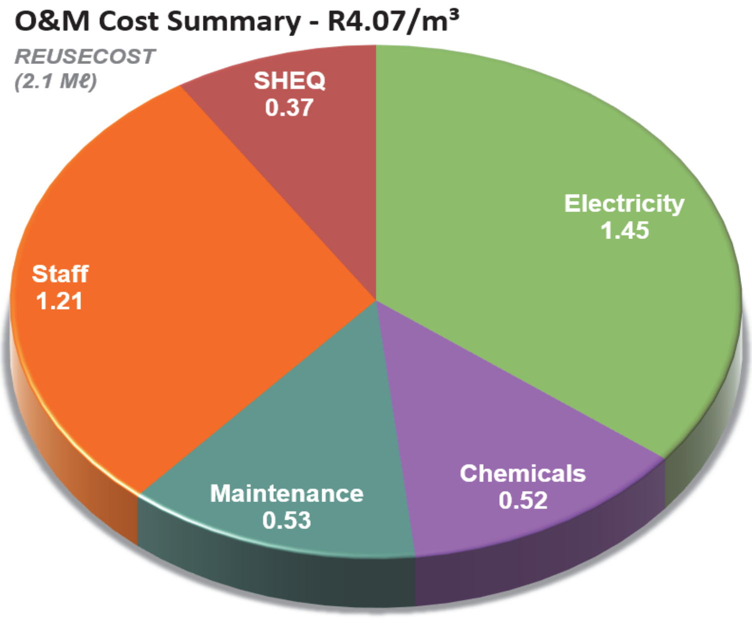

Figure 3.8: O&M Cost breakdown for the Beaufort West reclamation plant (REUSECOST full production)

Figure 3.9 provides an indication of the value range between the estimated O&M cost components for actual-, full production and the REUSECOST model results for the Beaufort West water reclamation plant.

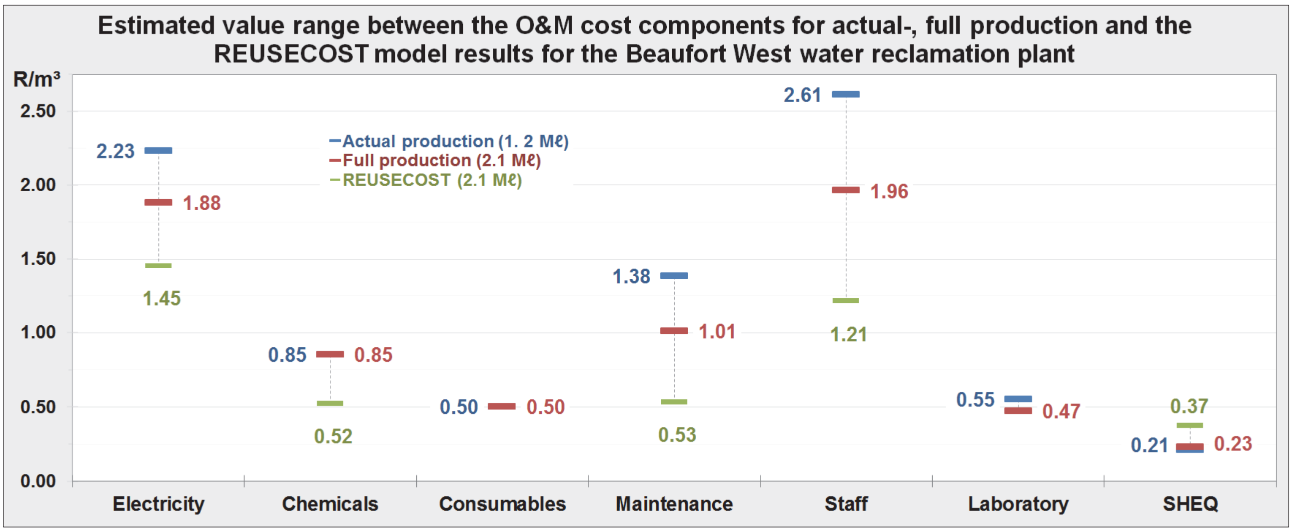

Figure 3.9: Range between O&M costs for various production modes and REUSECOST model results

3.4 NEW GOREANGAB WATER RECLAMATION PLANT

The City of Windhoek, situated in the centre of Namibia is one of the driest areas in the Southern African region, with an annual rainfall of about 370 mm/a and an evaporation rate of 3 000 to 3 500 mm/a. Windhoek's natural water resources include surface water from the Von Bach Dam and groundwater from 50 municipal boreholes. No further water resources are available within a radius of 500 km and the closest continuously running river, the Okavango River, is 700 km away. The rainfall is also uncertain, and long spells of severe droughts are frequently encountered. With a growth rate in population of 5% per annum (1.5% natural population growth and 3.5% urbanisation), the City of Windhoek approved an integrated Water Demand Management program, which includes policy matters, legislation, education, technical and financial measures in an effort to resolve the water shortage in the City.

The first water Goreangab reuse plant officially known as the Old Goreangab reclamation plant (Old Plant) was constructed in 1969 and the product water was used for agricultural purposes. The Old Plant was supplied with final effluent by the Gammams Wastewater Treatment Plant (GWWTP). This plant receives little if any industrial effluent with industry mainly being situated in the North of the city and discharging to the Northern Wastewater Treatment Works. By the end of the nineties the Old Plant was at the end of its useful lifespan. The 21 Mℓ/d New Goreangab water reclamation plant (NGWRP) for direct potable use was commissioned in 2002 and was built alongside the Old Plant. Initially, raw water for NGWRP was drawn from both the GWWTP and Goreangab Dam but with the water quality in the Goreangab Dam deteriorating rapidly (largely due to the high evaporation rate concentrating nutrients and salts on a continuous basis) the GWWTP was left as the sole source of raw feedwater for the NGWRP.

Figure 3.10: Gammams WWTP (left) and New Goreangab water reclamation plant (right)

Reclaimed water from the New Plant was originally blended with the existing freshwater sources in a ratio of 1:2 (i.e. 35% reclaimed water in the distribution network), but this has now been relaxed to 1:1 (50%). The initial blending limitation was based on the 5 mg/ℓ dissolved organic carbon (DOC) concentration produced by the Old Plant, but with the New Plant constantly achieving DOC values of ≤1 mg/ℓ due to improved processes and operation, this limitation was able to be relaxed.

3.4.1 Funding and Institutional Arrangements

The project was been financed by the Kreditanstalt fuer Wiederaufbau (40%), the European Investment Bank (55%) and the City of Windhoek (5%). the consultants were GFJ (South Africa), Multi Consult (Namibia) and Fichtner (Germany). The contractor consisted of a consortium made up of DB Thermal (at that stage representing WABAG technology in Southern Africa) and Stocks Structures. The technology incorporated in the plant is based on WABAG technology. The plant is operated and maintained by the Windhoek Goreangab Operating Company Ltd (WINGOC) through a 20-year service level agreement with the City of Windhoek. WINGOC is made up of three major international water treatment contractors, namely

Berlinwasser International, VA TECH WABAG and Veolia Water. New developments in monitoring systems and analytical techniques for drinking water supply systems were tested in a case study carried out at the New Goreangab water reclamation plant (NGWRP) in Windhoek, as part of the EU funded TECHNEAU project (Swartz et al., 2013).

3.4.2 Capital Costs

The investment costs for the New Goreangab water reclamation plant were approximately R122 125 000 (the average 2001/02 ZAR to € exchange rate was 9.77:1) with the electrical and mechanical equipment costing R81 091 000 and the civil works R41 034 000. The exchange rate between Namibian Dollars (NAD) and the South African Rand (ZAR) is 1:1 and so in the interest of uniformity, the cost values for the NGWRP are given in Rand (R). The breakdown of the abovementioned capital cost is estimated at this stage, using typical unit rates for similar processes and, where applicable, by aligning the process unit costs with the REUSECOST model referred to earlier. This breakdown, as well as an estimate of the current costs and unit rates (escalated for 2014/15), are also provided in Table 3.8.

Table 3.8: New Goreangab water reclamation plant (21 Mℓ/d) capital costs

NGWRP Capital Costs (breakdown estimated using typical rates)	Cost (Rand) (2001)	% of Project	Cost (Rand) (2014/15)	Unit Cost (Rm/Mℓ/d) (2014/15)
Direct Costs				
Intake	2 137 188	1.7	4 550 278	0.22
DAF	3 785 875	3.1	8 060 492	0.38
RG sand filters	4 885 000	4.0	10 400 635	0.50
Ozone	13 006 313	10.6	27 691 691	1.32
BAC	11 968 250	9.8	25 481 556	1.21
GAC	10 869 125	8.9	23 141 413	1.10
UF	13 128 438	10.7	27 951 707	1.33
Post-treatment	4 396 500	3.6	9 360 572	0.45
Waste treatment and disposal	1 221 250	1.0	2 600 159	0.12
Electrical, electronic and control	10 747 000	8.8	22 881 397	1.09
Civil building and structures	21 713 825	17.8	46 230 823	2.20
Bulk electrical supply	5 202 525	4.3	11 076 676	0.53
Product pumpstation & pipelines	5 495 625	4.5	11 700 715	0.56
Subtotal Direct Costs	**108 556 913**	**88.9**	**231 128 114**	**11.01**
Indirect Costs				
Professional fees, site monitoring, disbursements	13 569 444	11.1	28 890 653	1.38
Subtotal Indirect Costs	**13 569 444**	**11.1**	**28 890 653**	**1.38**
Total Cost (excluding VAT)	**122 126 357**	**100.0**	**260 018 768**	**12.38**

The REUSECOST model estimates the total capital cost at approximately R207 million (in the year 2012/13), and R235 million (in the year 2014/15). Therefore the calculated present capital cost is roughly 25% higher than the REUSECOST model estimate.

Total Capital Amortization			Million Rand
TOTAL CAPITAL COST: Present value			R 207.21
TOTAL CAPITAL COST: Future value (Amortized over 20 years at 6% interest)			R 1 161.30
Total Cost Summary	**Cost per day (Million)**	**Cost per year (Million)**	**Cost per kilolitre (R/kL)**
Total capital costs (Based on future value)	R 0.16	R 58.06	R 7.58
Total operating and maintenance costs	R 0.08	R 27.84	R 3.63
TOTAL PROJECT COSTS	**R 0.24**	**R 85.90**	**R 11.20**

Figure 3.11: REUSECOST Model results for New Goreangab water reclamation plant

3.4.3 Process description

The NGWRP follows the multiple barrier principle which is differentiated into three types, these are namely non-treatment, treatment and operational. Non-treatment barriers are described as:

- Diversion of industrial waste to the Northern Wastewater Treatment Works and policing of discharges to the Gammams Wastewater Treatment Plant.
- Rigorous and continuous raw and treated water quality monitoring to ensure that corrective measures are taken timeously and continuous improvement of the operations is maintained to limit or prevent exposure of the public to poor quality treated water.
- Blending reclaimed water with conventional sources. The blending limits reclaimed water to 35 to 50% of the blended water.

3.4.3.1 *Treatment barriers*

These are not absolute but rather limit specific contaminants progressively in the process train. The barriers may be partial or complete barriers. The contaminants targeted at each unit process differ and the mode of treatment determines the removal of the targeted contaminant.

3.4.3.2 *Operational barriers*

These are treatment processes that are not normally used but serve as standby processes in the event of failure by a duty treatment process, e.g. Powdered Activated Carbon for use in case of problems with the Granular Activated Carbon. The process train at the New Goreangab water reclamation plant is described in Figure 3.12.

3.4.3.3 *Source*

The feedwater is sourced from the maturation pond effluent of the Gammams WWTP.

3.4.3.4 *Powdered Activated Carbon (PAC)*

PAC can be added as a back-up for adsorption, should the ozone process fail, or for taste and odour treatment.

3.4.3.5 *Pre-ozonation*

Pre-ozonation is the current initial disinfection and oxidisation step at NGWRP. The raw feedwater is treated with excess ozone from the main ozonation step.

3.4.3.6 *Coagulation/flocculation*

Four coagulation and flocculation tanks are operated with ferric chloride ($FeCl_3$) being dosed as a coagulant to remove organics. Hydrochloric acid can also be added to adjust the pH and a polymeric flocculent aid can also be supplemented.

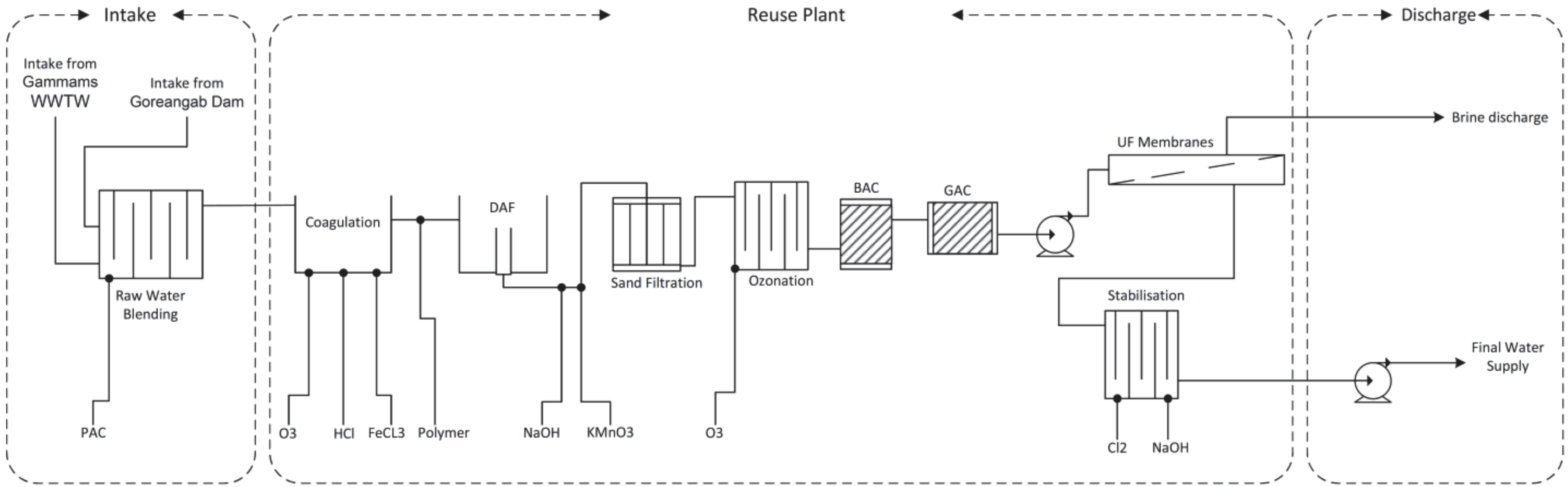

Figure 3.12: Process schematic of the New Goreangab water reclamation plant

3.4.3.7 *Dissolved Air Flotation (DAF)*

Four Dissolved Air Flotation (DAF) units containing plastic media to enhance mixing are used to assist the removal of flocs that generally settle poorly. By providing air saturated water at 5 bars, flocs are floated to the DAF tanks' surface, with the clarified underflow passing on to filtration.

Online monitoring for turbidity is performed on the water flowing to the filtration step. The following turbidity criteria allow the operators to take action on the treatment plant:

- 1 NTU – Ideal;
- 2 NTU – Penalised by the water authority;
- 3 NTU – Absolute, can't pass – water from the DAF will not be of a good quality to proceed in the process train.

The iron added at the coagulation step is removed by adding caustic soda (NaOH) which raises the pH and potassium permanganate ($KMnO_4$) that increases the rate of iron and manganese oxidation.

3.4.3.8 *Dual Media Filtration*

The dual media filtration consists of anthracite and fine sand. Five sand filters equipped with level sensors are housed in a low light building to prevent biomass growth.

A filter-to-waste option is available for enhanced cyst/oocyst removal should this be required due to failure of the upstream processes or for maintenance purposes.

3.4.3.9 *Main ozonation*

Ozone is generated on site with oxygen being produced at the plants' Pressurised Swing Adsorption (PSA) plant where oxygen (O_2)/air is extracted through filter cartridges. A molecular sieve separates carbon dioxide (CO_2) and nitrogen (N_2) to yield a minimum of 90% oxygen. A high voltage discharge through the oxygen stream forms the ozone, O_3. Hydrogen peroxide (H_2O_2) is dosed together with the ozone to further enhance its oxidising abilities. Ozone oxidises large/complex organic material such as pharmaceuticals rendering them more biodegradable. The excess ozone is vented to the atmosphere via an ozone destructor.

3.4.3.10 *Biological Activated Carbon (BAC)*

The ozonated water is passed through biologically activated carbon where the biodegradable organics are either directly consumed by the biomass, or alternatively absorbed and then broken down by biomass. Hydrogen peroxide is dosed to destroy any remaining ozone molecules before entering the BAC.

3.4.3.11 *Granular Activated Carbon (GAC)*

Water is pumped from the BAC to the GAC filters where organic molecules are removed. The seven filters consist of primary and secondary filter beds (14 singular beds).

The primary filter removes residual organics that are adsorbed to the filter, whilst the secondary filter polishes any residual organics from the primary filter.

3.4.3.12 *Ultrafiltration (UF)*

Water is pumped to the five UF units via a feedwater sump. The water is filtered through the UF membranes with pore size of 0.025 µm. Ultrafiltration removes bacteria, colloidal material, some viruses and organics.

3.4.3.13 *Disinfection*

The filtered product water is disinfected using chlorine.

3.4.3.14 *Stabilisation*

Caustic soda is added to raise pH and stabilise the treated water.

3.4.3.15 *Distribution*

The disinfected and stabilised water pumped to a 10 Mℓ intermediate reservoir from where high lift pumps transfer it to the New Western Pump Station where it is blended with surface water from the Von Bach scheme at a ratio of 1:3 and introduced into the distribution system.

3.4.4 Operation and Maintenance Aspects

Due to the relatively complex funding and institutional arrangements surrounding the operation and maintenance of the New Goreangab Water Reclamation Plant, actual plant consumption data and relative costs are not readily available/accessible unless approved by all stakeholders in the project. The figures presented in this report shall be reviewed and updated as more accurate data becomes available.

3.4.4.1 *Electricity*

The New Goreangab water reclamation plant is supplied with electricity by Windhoek municipality using its own tariff structure, which is aligned with that of the bulk electricity supplier, NamPower.

The average power consumption of the plant is approximately 1 kWh/m³, based on the full production of 21 Mℓ/d (Els, 2013). However, it should be noted that approximately 43% (0.43 kWh/m³) of the energy consumed is used for product water pumping requirements. As a result, the plant uses only 0.57 kWh/m³.

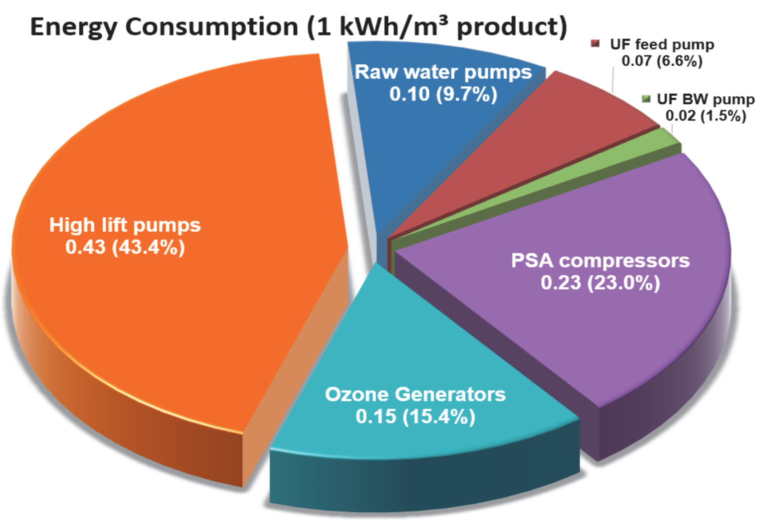

Figure 3.13: Energy consumption for the New Goreangab reclamation plant (including product pumping)

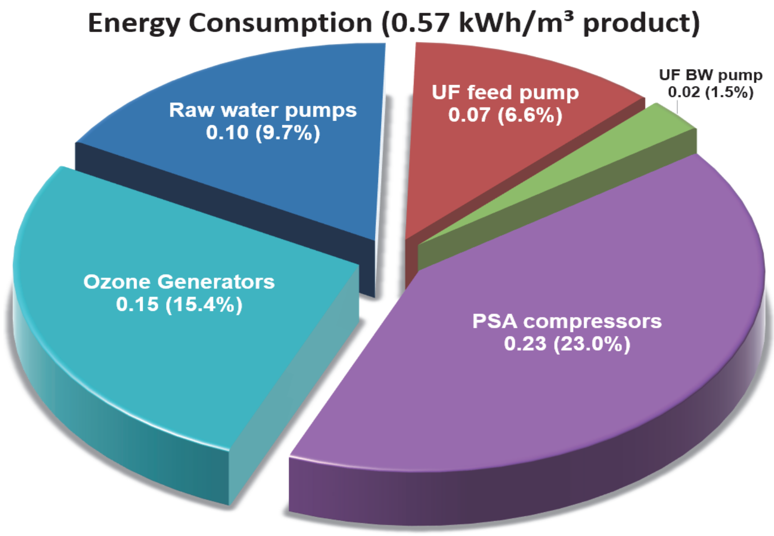

Figure 3.14: Energy consumption for the New Goreangab water reclamation plant (for the plant only)

3.4.4.2 *Water quality parameters*

Table 3.9 indicates the sea intake and treated potable water quality parameters for the New Goreangab water reclamation plant.

Table 3.9: New Goreangab water reclamation plant intake and product water parameters

Parameter	Raw Feed	Treated Potable Water
Turbidity (NTU)	53	-0.08
COD (mg/ℓ) – dichromate	43	12.6
THM (µg/ℓ)	169	11
Giardia (per 100 mℓ)	214	0
Cryptosporidium (per 100 mℓ)	334	0
E. Coli (per 100 mℓ)	20 000	0
Heterotrophic Plate Count 37°C (per 1 mℓ)	330 000	8
Iron (mg/ℓ)	2.8	<0.05
Manganese (mg/ℓ)	0.9	<0.005

3.4.4.3 *Monitoring results*

The following monitoring results indicate average values for the raw water and final treated water for the Goreangab water reclamation plant (Lahnsteiner, 2007).

Table 3.10: New Goreangab water reclamation plant final product water analysis results

Parameter	Raw Water (design values)	Treated Potable Water
Date		**2005 (average)**
Turbidity (NTU)	53	0.11
Dissolved Organic Carbon (mg/ℓ)	15	2.6
Giardia (per 100 mℓ)	214	-
Cryptosporidium (per 100 mℓ)	334	-
E. Coli (per 100 mℓ)	20 347	-
Iron (mg/ℓ)	2.8	0.06
Manganese (mg/ℓ)	0.9	0.015

3.4.4.4 *Applying quality control methods*

The water quality for the New Goreangab water reclamation plant follows the guidelines stipulated by the World Health Organisation (WHO), Rand Water (South Africa) and Department of Water Affairs (Namibia).

Control water samples at the plant are taken for analysis every four hours, while composite samples are taken twice a week and a comprehensive analysis of all water quality constituents are carried out.

3.4.4.5 *Cleaning in Place*

The concept and principle of performing the CIP at the NGWRP described below.

The CIP is run in 3 categories

- High pH CIP using caustic soda and sodium hypochlorite (pH 11.5) to remove bio-solids.
- Low pH CIP using citric acid to remove scaling.
- Final flush with clean water to rinse out the CIP reagents.

3.4.4.6 *Operation and maintenance problems experienced*

Initially, 50% of NGWRP feedwater was provided by the Goreangab Dam and the balance from the GWWTP. The Goreangab Dam water quality has deteriorated to such an extent that it is not usable for drinking purposes. This has resulted in NGWRP relying on the GWWTP secondary effluent for feedwater. Treating water from the dam would be expensive and a more robust treatment method would have to be implemented.

No major operational and maintenance problems have been encountered by the NGWRP. One of the operational problems expressed is the transition (bypassing) of certain types of algae through the pre-treatment steps (coagulation/flocculation, DAF, sand filters, etc.) causing blockages/under performance of the UF membranes and downstream equipment.

3.4.4.7 *Operational Costs*

The following table summarise quoted references from various sources indicating overall O&M cost in unit reference values, including capital redemption.

Table 3.11: New Goreangab water reclamation plant (21 Mℓ/d) capital & O&M cost references

Source/Reference	Operating Costs * (R/m³)	Capital Redemption (R/m³)	Total Costs (R/m³)	Operational Year
du Pisani, 2006	2.76 (5.52)	1.84	4.69	2002 (2013)
Lahnsteiner, 2007	3.71 (6.96)	2.44	6.15	2003 (2013)
Swartz et al., 2013	6.44	1.84	8.28	2013

* Operating Costs escalated at 6.5% pa to 2013. Using outputs from the REUSECOST model as a reference, a high level breakdown of the estimated O&M costs when the plant is in full production, is provided in Table 3.12.

These values are based on the database values captured within the REUSECOST model. In collaboration with Chris Swartz Water Utilization Engineers, the model configuration inputs and outputs are being further refined. The database values will be further updated as more accurate input data becomes available.

Table 3.12: O&M cost breakdown for the New Goreangab water reclamation plant

O&M Parameters	Actual production (17.5 Mℓ) Unit Cost (R/m³)	Full production (21 Mℓ) Unit Cost (R/m³)	REUSECOST (21 Mℓ) Unit Cost (R/m³)
Electricity	0.57	0.57	1.00
Chemicals	1.55	1.55	0.52
Consumables *	1.00	1.00	
Maintenance	0.94	0.78	0.53
Staff	1.05	0.88	1.21
Laboratory	0.08	0.06	
SHEQ	0.04	0.03	0.37
Total cost (excluding VAT)	**5.22**	**4.87**	**3.63**

* In the absence of more accurate plant data for consumables, this value has been estimated based on reasonable assumptions from similar plants.

The estimated O&M cost breakdown for actual and full production is illustrated below.

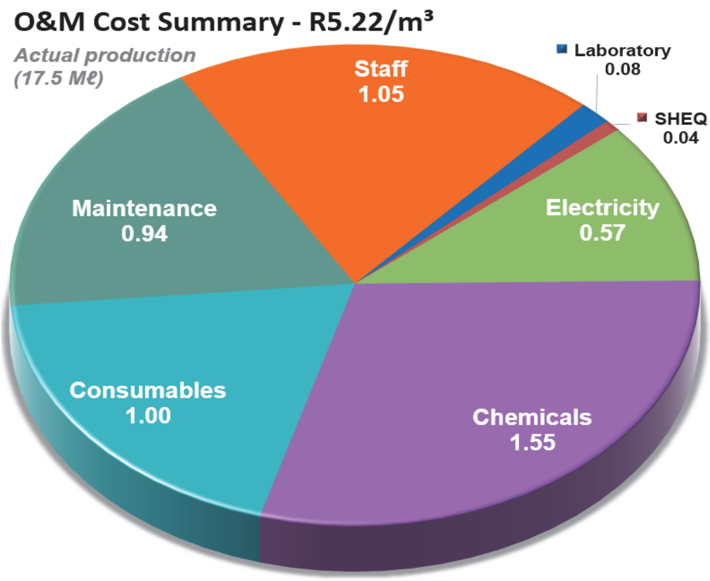

Figure 3.15: O&M Cost breakdown for the New Goreangab reclamation plant (actual production)

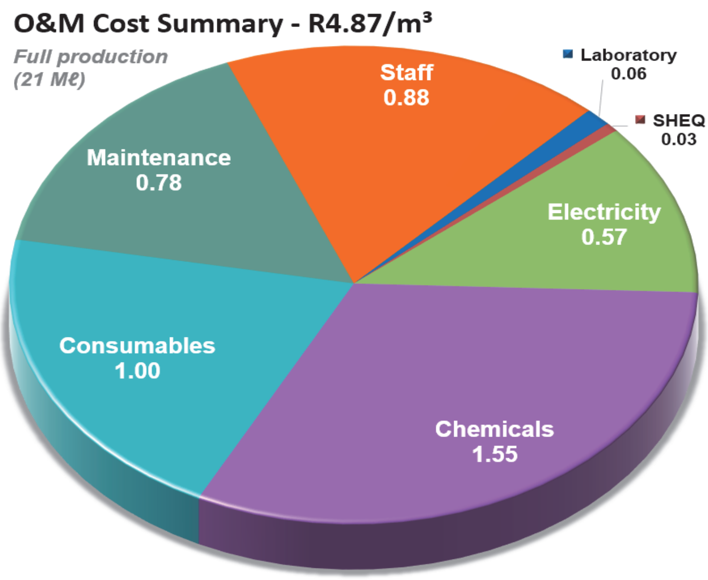

Figure 3.16: O&M Cost breakdown for the New Goreangab reclamation plant (full production)

The estimated O&M cost breakdown for full production, based on the REUSECOST model, is illustrated in Figure 3.17:

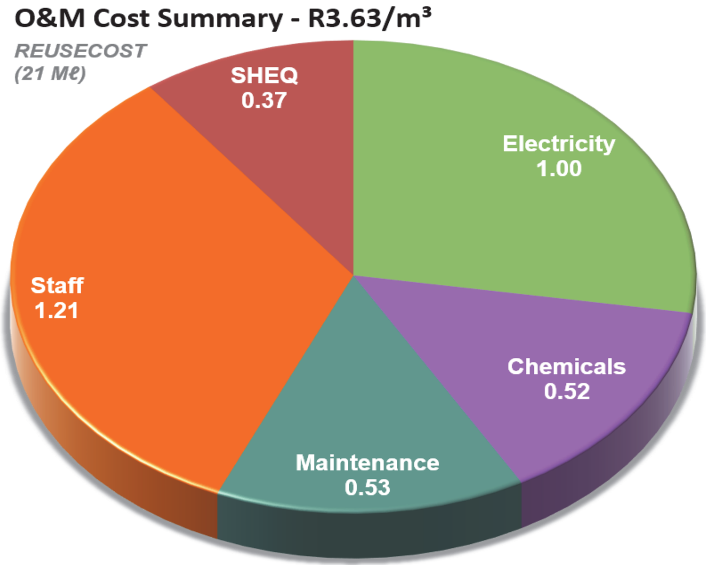

Figure 3.17: O&M Cost breakdown for the New Goreangab water reclamation plant (REUSECOST full production)

The graph below provides an indication of the value range between the estimated O&M cost components for full production and the REUSECOST model results for the New Goreangab water reclamation plant.

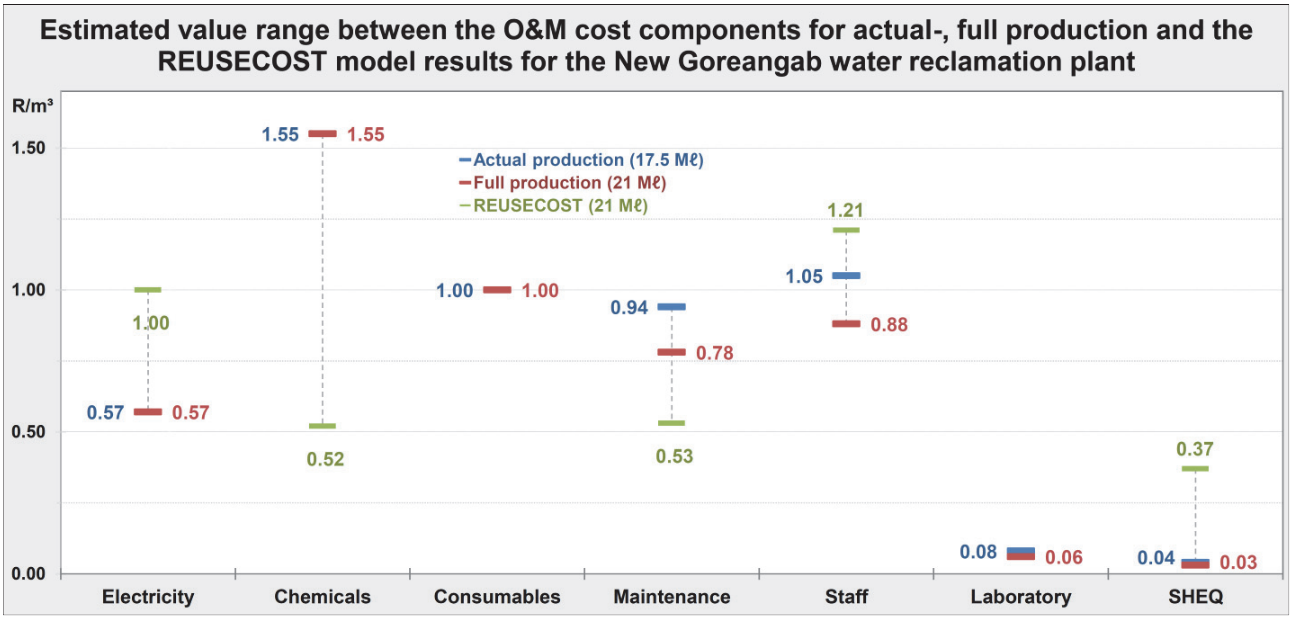

Figure 3.18: Range between O&M costs for various production modes and REUSECOST model results

3.5 GEORGE WATER RECLAMATION PLANT

Certain areas in the Southern Cape, which include the George Municipal area, experienced extreme drought and were declared a disaster area in November 2009.

As the largest town on the Garden Route, George also faced water shortages and decided to investigate and then implement an indirect water reuse strategy where the final effluent from the Outeniqua Waste Water Treatment Works is treated to a very high quality through ultra-filtration and disinfection, prior to it being returned to the main storage facility, the Garden Route Dam. This initiative supplemented the existing supply by an additional 9 to 10 Mℓ/day which contributed approximately one third towards meeting the town's drinking water demand. Based thereon, the water from the waste water treatment works is treated in the George water reclamation plant to a standard similar or better than the quality of the water in the Garden Route Dam.

Figure 3.19: George water reclamation plant

The treatment process was designed with an ultrafiltration barrier and fail safe system to avoid contamination of the water source to which the treated water is being returned.

3.5.1 Funding and Institutional Arrangements

The plant was funded by the George municipality through emergency funding granted by the DWA during the 2009/10 drought period. The plant was designed and built by Aqua Engineering and thereafter operated by Garchem Technologies until mid-November 2011 where after it was handed over to the George municipality to operate and maintain under the existing municipal water treatment works.

The George municipality supplies all resources: personnel, chemicals, electricity, equipment spares, etc. to maintain the plant which is currently maintained in a zero production mode.

3.5.2 Capital Costs

The capital cost of the plant and associated work at the WWTW was approximately R36 million (excluding VAT) in 2010. The estimated total cost, including a pipe line to the Garden Route Dam, is approximately R77 million.

The capital cost of the plant only is summarised in Table 3.13 and escalated for the year 2014/15. Unit rate values are based on the actual plant capacity of 8.5 Mℓ/d.

Table 3.13: George water reclamation plant (8.5 Mℓ) capital costs

George Water Reclamation Plant Capital Costs	Cost (Rand) (2010)	% of Project	Cost (Rand) (2014/15)	Unit Cost (Rm/Mℓ/d) (2014/15)
Direct Costs				
Intake and balancing storage	1 598 776	4.4	2 056 771	0.24
UF mechanical	3 757 123	10.4	4 833 412	0.57
UF membranes and pipework	11 191 430	31.1	14 397 398	1.69
Post-treatment	319 755	0.9	411 354	0.05
Waste treatment and disposal	383 706	1.1	493 625	0.06
Electrical, electronic and control	2 877 796	8.0	3 702 188	0.44
Civil building and structures	8 953 144	24.9	11 517 918	1.36
Bulk electrical supply	255 804	0.7	329 083	0.04
Product storage & pipework (not pumps, pipelines)	799 388	2.2	1 028 386	0.12
Monitoring and testing equipment	1 199 082	3.3	1 542 578	0.18
O&M manual, training, first fill chemicals	639 510	1.8	822 708	0.10
Subtotal Direct Costs	**31 975 514**	**88.9**	**41 135 423**	**4.84**
Indirect Costs	**3 996 939**	**11.1**	**5 141 928**	
Professional fees, site monitoring, disbursements				
Environmental and specialist studies, etc.				
Subtotal Indirect Costs	**3 996 939**	**11.1**	**5 141 928**	**0.60**
Total Cost (excluding VAT)	**35 972 453**	**100.0**	**46 277 351**	**5.44**

Based on the REUSECOST model, the estimated total capital cost is approximately R42 million (in the year 2012/13), and R48 million (in the year 2014/15). Therefore the calculated present capital cost is roughly 5% lower than the REUSECOST model estimate, which is a good correlation.

Total Capital Amortization			Million Rand
		TOTAL CAPITAL COST: Present value	R 42.35
		TOTAL CAPITAL COST: Future value (Amortized over 20 years at 6% interest)	R 135.82
Total Cost Summary	**Cost per day (Million)**	**Cost per year (Million)**	**Cost per kilolitre (R/kL)**
Total capital costs (Based on future value)	R 0.02	R 6.79	R 1.86
Total operating and maintenance costs	R 0.03	R 11.43	R 3.13
TOTAL PROJECT COSTS	**R 0.05**	**R 18.22**	**R 4.99**

Figure 3.20: REUSECOST Model results for George water reclamation plant

3.5.3 Process description

The initial Phase 1 water volume that was required for the augmentation of the raw water source had been determined as 10 Mℓ/day. This was close to the present inflow to the water treatment works of 13 Mℓ/day. Flow equalisation was required to ensure that 10 Mℓ/day can be harvested from the works on a continuous basis. A multi-barrier approach to the treatment of the final effluent water before lifting the storage dam was adopted. Although the plant is designed for a capacity of 10 Mℓ/d, the actual production figures achieved during the performance testing/commissioning period was at maximum up to 8.5 Mℓ/d. The process train at the George water reclamation plant is described in Figure 3.21.

3.5.3.1 *Source*

The water reclamation plant treats tertiary effluent from the Outeniqua WWTW, at a feed flow of up to 12.9 Mℓ/day, and produces up to 8.5 Mℓ/day of treated water, using ultrafiltration technology.

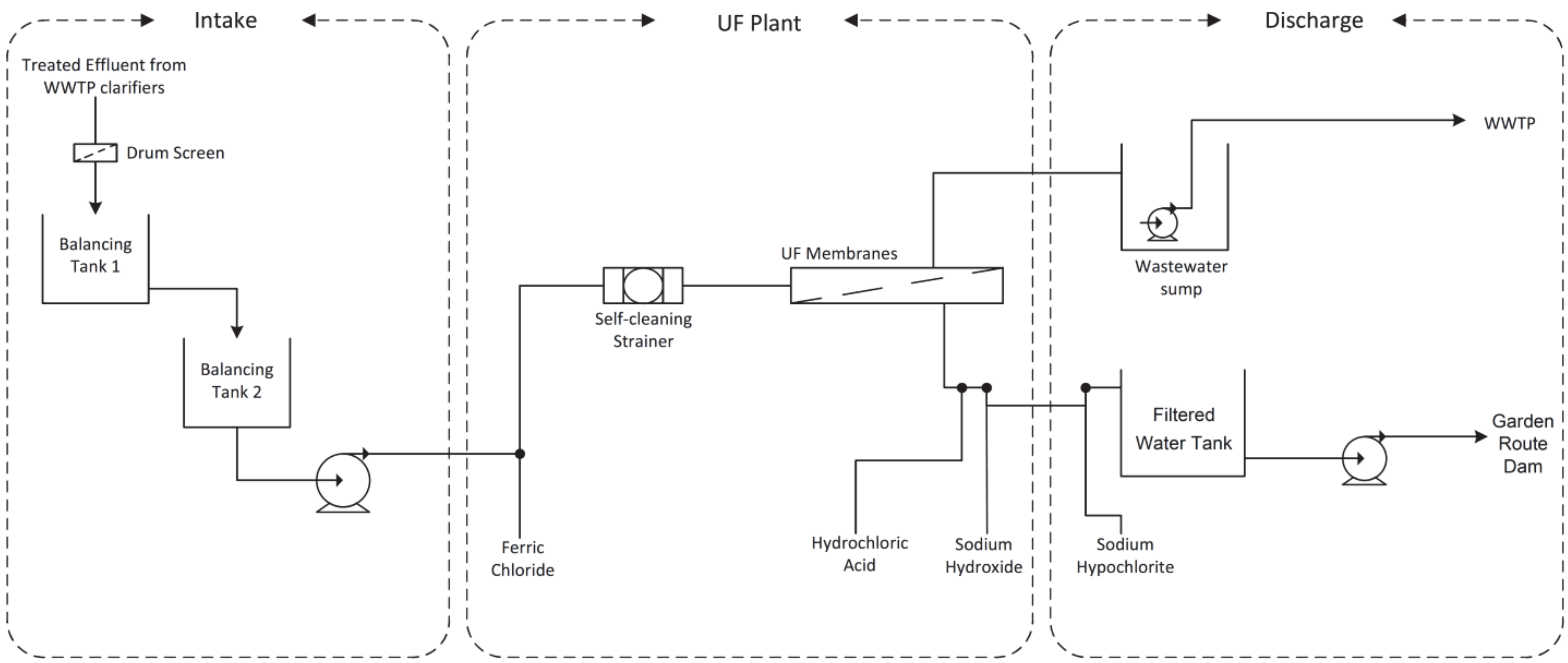

Figure 3.21: Process schematic of the George water reclamation plant

3.5.3.2 *Drum screens*

The overflow from the existing WWTW clarifiers flows into the inlet channel in which a 1 400 mm diameter rotating drum screen was placed. The drum screen removes particles larger than the 6 mm screen aperture from the raw water. This protects the UF feed pumps and the UF membranes from blockages and fouling.

A turbidity meter installed before the drum screen monitors the turbidity of the clarifier overflow.

3.5.3.3 *Balancing tanks*

The filtered water from the drum screen flows into two 1 500 m³ balancing tanks placed in series. A level transmitter has been installed on each of the balancing tank to control the flow of water to the balancing tanks.

3.5.3.4 *UF feed pumps*

Three UF feed pumps (2 duty and one standby with a capacity of 268 m³/h at 2.9 bar each) supply feedwater from the balancing tanks to the UF membranes. During the operation of the plant, two (2) pumps are on duty and one (1) on standby. Each pump has been equipped with soft starters to prevent water hammer during start-up.

3.5.3.5 *Coagulant dosing*

A recycle line taps off at the common discharge of the UF feed pumps, and goes back to the suction of the pumps. A coagulant, ferric chloride ($FeCl_3$) is dosed in the recycle line. The pump impellers assist in mixing the coagulant with the water so as to form flocs.

The formation of flocs improves the removal efficiently of the suspended and colloidal matter from the water. The coagulant also works to precipitate phosphates in the water. The dosing rate of the coagulant is dependent on the suspended solids and phosphates content of the water.

3.5.3.6 *Self-cleaning strainer*

The water is pumped through a 200 ɥm carbon steel self-cleaning strainer before it enters the UF unit. The self-cleaning strainer has been sized to handle the full flow from the UF pumps. An inline strainer is on standby if the self-cleansing strainer should be maintained.

3.5.3.7 *UF membrane unit*

The UF unit is used to remove suspended and colloidal matter from the water. There are three UF membrane skids that contain 100 membranes each treating a third of the total feed flow of 180 m³/h. Some information on the UF membranes is given below:

- Membrane type: Norit X-flow, Aquaflex SXL225
- Membrane material: A blend of polyethersulphone and polyvinylpyrrolidone
- Membrane module dimensions: 200 mm diameter x 1 537 mm length
- Membrane configuration: Hollow fibre, with lumen = 0.8 mm
- Membrane nominal pore size: 0.01 ɥm
- Membrane surface area: 40 m²
- Gross flux per UF membrane unit: 45 ℓ/m²/h
- Maximum feedwater suspended solids: 100 mg/ℓ

3.5.3.8 *Filtered water tank*

The final treated water or permeate from the UF unit, flows into a permeate tank (22.2 m diameter and 3.6 m water depth).

3.5.3.9 *UF membrane cleaning*

The UF membranes require periodic cleaning to remove the contaminants that have been filtered during the filtration cycle.

Failure to clean the membranes will result in the membranes performance decline. These are done through three backwash pumps with a capacity of 500 m³/h at 290 kPa(g).

3.5.3.10 *Distribution*

The permeate is pumped to the Garden Route Dam. This will supplement the water in the dam and then treated so as to supply to the town of George with potable water. The brine wastewater from the UF membranes is sent back to WWTW.

3.5.4 Operation and Maintenance Aspects

3.5.4.1 *Electricity*

The actual electricity consumptions of the UF plant are difficult to determine due to the fact that the UF plant shares a combined electricity account with the George water treatment works. In the absence of more accurate power consumption data, this is estimated based on different operating modes from design specifications (where possible) and compared with results in the REUSECOST model.

3.5.4.2 *Ultra filtrated water parameters*

The following table presents the raw effluent quality parameters for George water reclamation plant.

Table 3.14: George water reclamation plant intake water parameters

Parameter	Average
Alkalinity (mg $CaCO_3$/ℓ)	136
Ammonia (mg/ℓ N)	2.4
Chloride (mg/ℓ)	192
COD (mg/ℓ)	65
Conductivity (at 25°C) (mS/m)	62
Chlorine (mg/ℓ Cl_2)	0.4
Iron (mg/ℓ)	0.4
Nitrate (mg/ℓ)	3.3
Ortho-P (mg/ℓ)	4.5
pH	7.2
TSS (mg/ℓ)	20

3.5.4.3 *Monitoring results*

Due the plant only being operated for limited periods during commissioning/start-up only, there is a lack of data with respect to monitoring results during actual/normal production operation. The initial commissioning report was also not updated due plant capacities not being met and was rejected.

The target water treatment parameters are detailed in Table 3.15.

Table 3.15: George water reclamation plant product water parameters

Constituent	Treated water quality	Garden Route Dam	SANS241 Class 1 potable water
Alkalinity (mg $CaCO_3/\ell$)	100	20	NS
Ammonia (mg N/ℓ)	0.5	0.9	< 1
Chloride (mg Cl/ℓ)	192	150	< 200
COD (mg/ℓ)	45	60	NS
Conductivity (mS/m)	62	17	< 150
Free chlorine (mg Cl/ℓ)	0	0	0.5
Total chlorine (mg Cl/ℓ)	0	0	NS
Iron (mg Fe/ℓ)	< 0.2	6.3	< 0.2
Nitrate (mg N/ℓ)	3.3	0.7	< 10
Ortho-P (mg P/ℓ)	0.2	1.0	NS
pH	7.2	7.2	5.0 to 9.5
TSS (mg/ℓ)	< 1	NS	NS
Turbidity (NTU)	< 1	139	< 1
Faecal coliforms (count/100 mℓ)	< 1	850	0

3.5.4.4 *CIP and down time*

Due to the drought breaking in 2010 the plant is in zero production mode. The concept and principle of performing the CIP at the George water reclamation plant is described below.

- CIP will be performed when the TMP increases to 0.8 bar during filtration runs, despite regular hydraulic cleaning and CEB operations.
- The chemicals used during a CIP will be determined by the type foulants in the membranes.
- Before a CIP can be performed on the membranes, it is recommended that a CEB (Chemical Enhanced Backwash) be performed.

In zero production mode, a CEB is currently performed two times per week to clean the UF membranes.

3.5.4.5 *Operation and maintenance problems experienced*

The plant is currently maintained by two dedicated operators for two days per week. During this time maintenance checks and CEB is done (twice per week). Operational problems experienced by the plant operators to date are as follow:

- Hammering on self-cleansing strainer.
- Air valves on skids that doesn't close properly and switch to manual automatically.
- Backwash pumps switch to manual during backwash mode and CEBs that result in halting the backwash process.
- Turbidity levels populate incorrect readings.
- Pipe leakages that include chemical piping. Replace PVC piping with stainless steel.
- Outeniqua WWTW effluent quality not up to DWS standards due to low plant capacity and during stormy weather causing high feedwater turbidity.
- Corrosion on some pipe lines caused by Ferric chloride.
- Flow meters operation and calibration (flow per skid).
- The plant is not being run continuously and this is causing blockages of the strainer due to pressure changes and inadequate monitoring.
- No equipment spares available.

3.5.4.6 *Operational costs*

The following tables summarise the estimated breakdown of O&M costs for zero and full production mode. In the absence of more accurate plant data, these values have been estimated based on reasonable assumptions from similar plants. It should be noted that George water reclamation plant shares resources with Outeniqua WWTW, which was not taken into consideration in the values below.

Table 3.16: O&M cost breakdown for George water reclamation plant (zero production mode)

O&M Parameters	Unit Cost (R/month)
Electricity	30 000.00
Chemicals & Consumables	10 000.00
Maintenance	10 000.00
Staff	50 000.00
SHEQ	5 000.00
Total cost (excluding VAT)	**105 000.00**

Table 3.17: Operational cost components for George water reclamation in various production modes

O&M Parameters	**Full production(8.5 Mℓ)** Unit Cost (R/m³)	**REUSECOST (8.5 Mℓ)** Unit Cost (R/m³)
Electricity	0.23	1.00
Chemicals	0.44	0.52
Consumables *	0.50	
Maintenance	0.23	0.53
Staff	0.49	1.21
Laboratory	0.15	
SHEQ	0.08	0.37
Total cost (excluding VAT)	**2.11**	**3.63**

* In the absence of more accurate plant data for consumables, this value has been estimated based on reasonable assumptions from similar plants.

The estimated O&M cost breakdown for full production is illustrated in Figure 3.22:

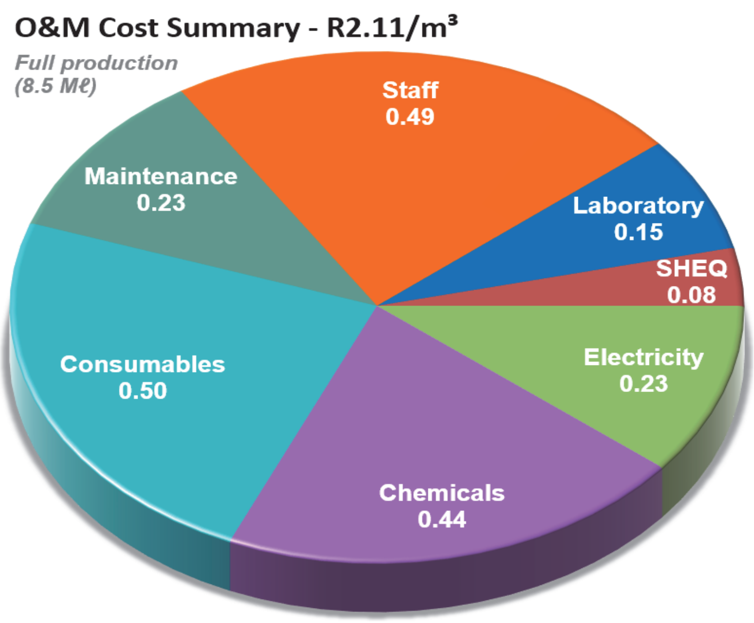

Figure 3.22: O&M Cost breakdown for the George water reclamation plant (full production)

Based on the REUSECOST model results for full production, the estimated O&M cost breakdown is illustrated in Figure 3.23:

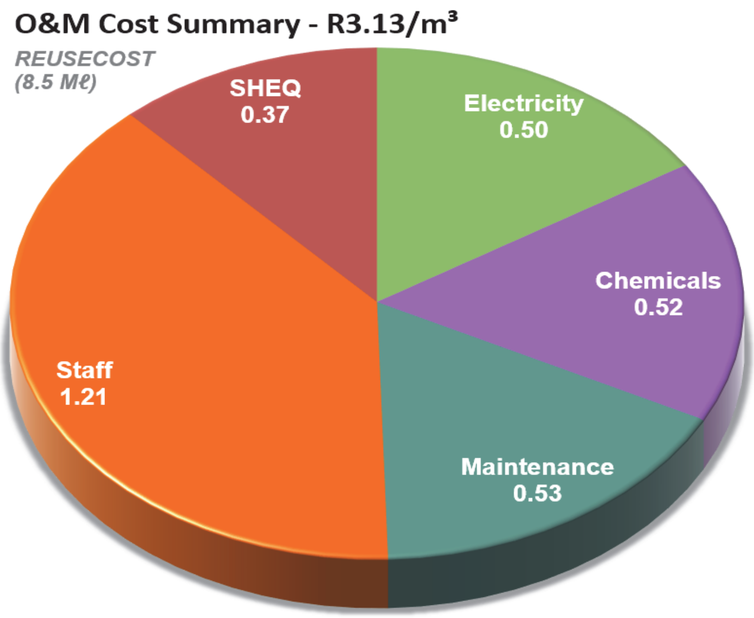

Figure 3.23: O&M Cost breakdown for the George water reclamation plant (REUSECOST full production)

The following graph provides an indication of the range between the estimated O&M cost components for full production and the REUSECOST model results for the George water reclamation plant.

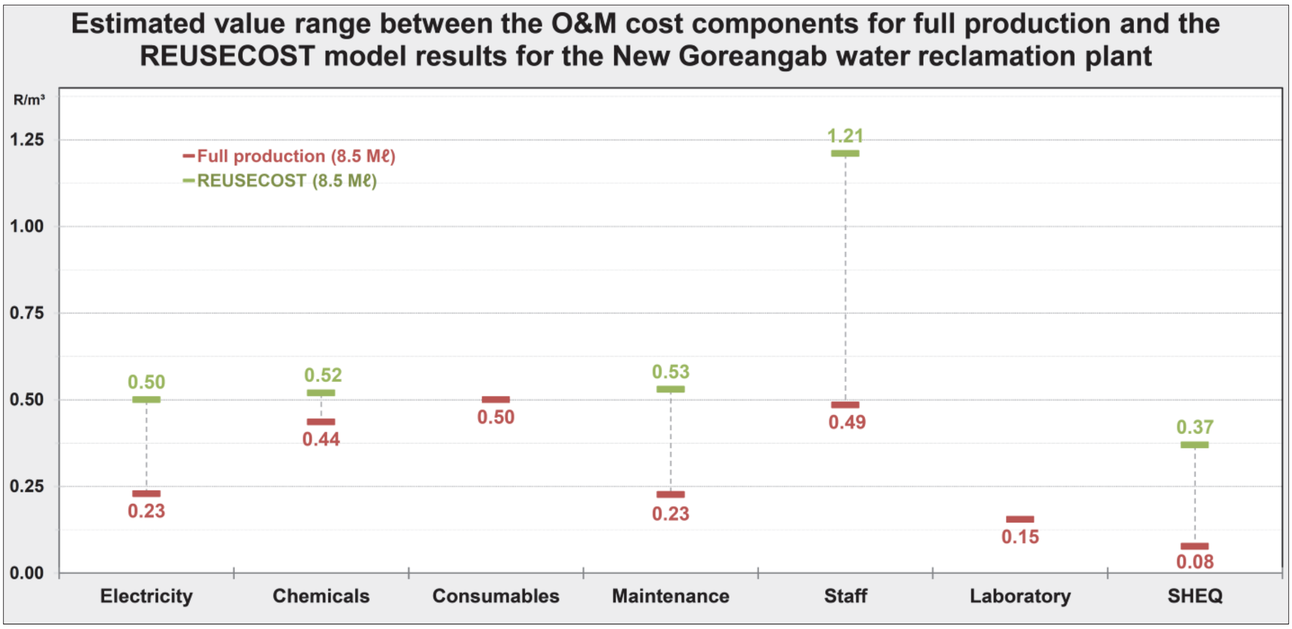

Figure 3.24: Range between O&M costs for various production modes and REUSECOST model results

3.6 MOSSEL BAY WATER RECLAMATION PLANT

The Mossel Bay water reclamation plant was commissioned in 2010 and is operated by Veolia Water, who was also the main contractor on the plant. The plant is designed to produce 5.5 Mℓ/d of treated domestic secondary effluent supplied from the Hartenbos Wastewater Treatment Works located on the same site. The initiative for this reuse plant was to substitute water from the Wolwedans Dam with upgraded final effluent for industrial reuse, effectively making more water available for urban potable water supply.

Figure 3.25: Mossel Bay water reclamation plant

3.6.1 Funding and Institutional arrangements

The Mossel Bay reclamation plant was built in less than five months and completed end of June 2010. The plant cost of R40 million was funded by PetroSA (R22.5 million) the National Treasury (R16.5 million) and the balance by the Mossel Bay Municipality from its own sources. The plant is currently operated and maintained in a zero production mode by Veolia Water on a contract basis.

3.6.2 Capital costs

The capital cost of the plant was approximately R40 million (excluding VAT) in 2010, as per Table 3.18:

Table 3.18: Mossel Bay water reclamation plant (5 Mℓ/d) capital costs

Mossel Bay Water Reclamation Plant Capital Costs	Cost (Rand) (2010)	% of Project	Cost (Rand) (2014/15)	Unit Cost Rm/Mℓ/d (2014/15)
Direct Costs				
Intake and balancing storage	1 385 992	3.5	1 783 032	0.36
UF mechanical	791 996	2.0	1 018 876	0.20
UF membranes and pipework	9 107 949	23.0	11 717 070	2.34
RO units	6 929 961	17.5	8 915 162	1.78
Post-treatment	791 996	2.0	1 018 876	0.20
Waste treatment and disposal	593 997	1.5	764 157	0.15
Electrical, electronic and control	2 375 987	6.0	3 056 627	0.61
Civil building and structures	6 335 965	16.0	8 151 005	1.63
Bulk electrical supply	791 996	2.0	1 018 876	0.20
Product storage and pipework (not pumps/pipelines)	3 959 978	10.0	5 094 378	1.02
Monitoring and testing equipment	1 484 992	3.8	1 910 392	0.38
O&M manual, training, first fill chemicals	395 998	1.0	509 438	0.10
Subtotal Direct Costs	**34 946 805**	**88.3**	**44 957 888**	**8.99**
Subtotal Indirect Costs	**4 652 974**	**11.8**	**5 985 894**	**1.20**
Total Cost (excluding VAT)	**39 599 779**	**100.0**	**50 943 783**	**10.19**

In comparison, the REUSECOST model estimates a total capital cost of approximately R51 million (in the year 2012/13), and R55.6 million (in the year 2014/15). Therefore the calculated present capital cost is roughly 10% lower than the REUSECOST model estimate.

Total Capital Amortization			Million Rand
		TOTAL CAPITAL COST: Present value	R 92.89
		TOTAL CAPITAL COST: Future value (Amortized over 20 years at 6% interest)	R 297.92
Total Cost Summary	**Cost per day (Million)**	**Cost per year (Million)**	**Cost per kilolitre (R/kL)**
Total capital costs (Based on future value)	R 0.04	R 14.90	R 8.16
Total operating and maintenance costs	R 0.02	R 7.58	R 4.15
TOTAL PROJECT COSTS	**R 0.06**	**R 22.47**	**R 12.31**

Figure 3.26: REUSECOST Model results for Mossel Bay water reclamation plant

3.6.3 Process description

The Mossel Bay water reclamation plant uses feedwater from secondary effluent ponds of the Hartenbos WWTW. The feedwater is then screened and pre-treated with chemicals before entering the UF membranes. After ultra-filtration, a portion of the filtered water enters the RO units for further treatment. The product water is stored in storage tanks and used as a supplement to the conventional PetroSA fresh water supply as and when required.

The process train at the Mossel Bay water reclamation plant is described in Figure 3.27.

3.6.3.1 *Source*

Effluent from the Mossel Bay WWTW maturation ponds (24-hour retention time) is drawn using two submersible pumps and pumped to the flocculation and coagulation tank.

3.6.3.2 *Coagulation/Flocculation*

Disc filters screening material up to 10 µm with cleaning sprays are used to screen the intake water abstracted from the maturation ponds. Coagulant and chlorine is dosed online.

Biocide and anti-scalant are dosed after the coagulation step to prevent biological growth on the Ultra-Filtration (UF) membranes and scaling of the pipe work. Sulphuric acid (H_2SO_4) is also dosed to enhance flocculation by adjusting pH to an optimum range of 6 to 7 pH units. Finally sodium meta-bisulphite (SMBS) is dosed to neutralise the biocide dosed.

3.6.3.3 *Ultra-filtration (UF)*

Prior to UF the water is passes through a basket strainer that captures any residual foreign matter arriving from the coagulation tank. The strainers have a 2 mm perforation and can be removed for cleaning during backwash. Water is pumped by two stage pumps to two UF filter units operated at low pressure. Automated backwash is conducted every 20 minutes which includes an air scouring system to improve the backwash efficiency.

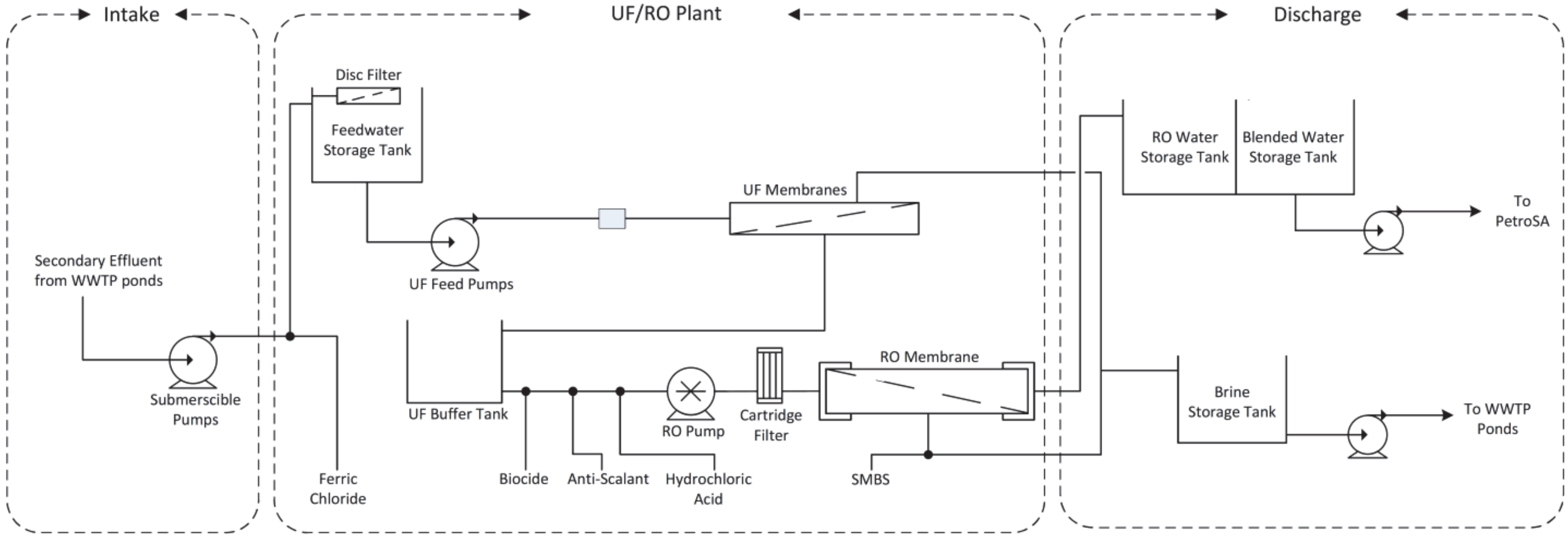

Figure 3.27: Process schematic of the Mossel Bay water reclamation plant

3.6.3.4 *Reverse osmosis (RO)*

Water from the UF membranes is pumped at a rate of 128 m³/h by two 3-stage pumps to the RO units at a maximum pressure of 12 bar(g). The RO stage comprises of two reverse osmosis units that are operated sequentially. Each RO system has a brine valve and a flow meter installed. The RO process yields 75% water and 25% brine.

3.6.3.5 *Distribution*

Product water is generally stored and used as a supplement to the conventional PetroSA fresh water supply. Two high pressure lift pumps are available for pumping the product water to PetroSA.

3.6.4 Operation and Maintenance Aspects

3.6.4.1 *Electricity*

The Mossel Bay water reclamation plant is supplied with electricity by Mossel Bay Municipality using its own tariff structure, which is aligned with that of the bulk electricity supplier, Eskom.

The average power consumption of the plant is approximately 1.52 kWh/m³ during full production (Els, 2013). During commissioning/plant start-up, the average power consumption in the plant was 3 400 kWh/day. This was for maximum production and excludes the high lift pump station.

Average electricity consumption when the plant is in zero production mode ranges from 6 000 to 9 000 kWh. This includes weekly cleaning and flushing of the UF and RO membranes. The average monthly charge was approximately R7 000 to R9 000 over 2012/13.

These figures are based on Eskom's TOU tariffs (Eskom, 2014) and exclude kVA charges, which are shared with the WWTW.

Figure 3.28 indicates the electricity consumption breakdown for the Mossel Bay water reclamation plant.

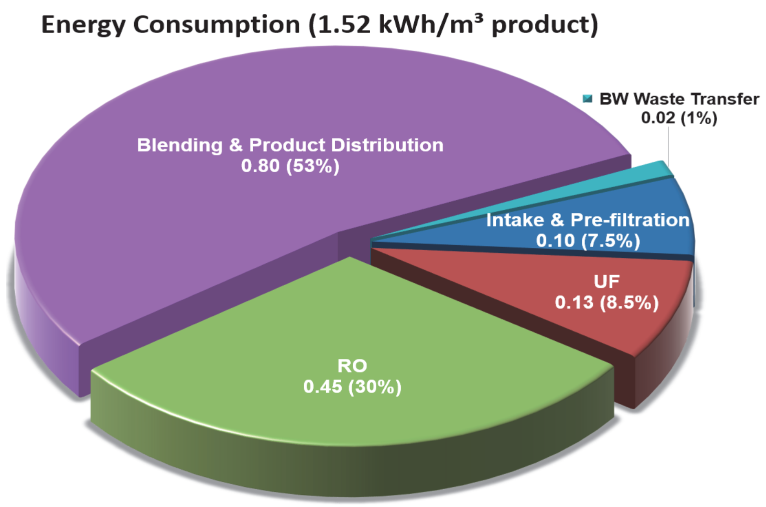

Figure 3.28: Energy consumption for the Mossel Bay water reclamation plant (full production)

3.6.4.2 *Water quality parameters*

Table 3.19 indicates the sea intake and treated potable water quality parameters for the Mossel Bay water reclamation plant.

Table 3.19: Mossel Bay water reclamation plant intake water parameters

Parameter	Average Values (23-06-2010)
COD (mg/ℓ)	45
TSS (mg/ℓ)	4.3
Ammonia (mg N/ℓ)	0.29
Nitrates (mg N/ℓ)	5.18
Ortho Phosphate (mg P/ℓ)	1.34
Conductivity (mS/m)	133
TDS (mg/ℓ)	988
M Alkalinity (mg/ℓ)	173
pH	7.9
Calcium (mg/ℓ)	32
Magnesium (mg/ℓ)	12.3
Chlorides (mg/ℓ)	327
Sodium (mg/ℓ)	201
Potassium (mg/ℓ)	17.6
Sulphate (mg/ℓ)	56
Silica (mg/ℓ)	1.46
Iron (mg/ℓ)	0.06
Manganese (mg/ℓ)	0.03
Boron (mg/ℓ)	0.11
Copper (mg/ℓ)	0.04
Zinc (mg/ℓ)	0.04

3.6.4.3 *Monitoring results*

The following monitoring results have been obtained based on previous measurements.

Due the plant only being operated for limited periods during emergencies only, there is a lack of regular data with respect to monitoring results during live/continuous operation.

Table 3.20: Mossel Bay water reclamation plant final product water analysis results

Parameter	29-06-2010	30-06-2010	01-07-2010	02-07-2010
TSS (mg/ℓ)	-	<0.1	-	-
Conductivity (at 25°C) (mS/m)	137	144.8	157	165
pH	6.8	6.7	6.94	6.87
Turbidity (NTU)	0.09	0.09	0.07	0.07
Temperature (°C)	16.5	16	15.9	15.1

Table 3.21: Product water compared to Wolwedans Dam water (VWS, 2010)

Parameter	Wolwedans Dam Water(Typical)	Treated water after blending
Aluminium (mg/ℓ)	2.270	< 0.1
Barium (mg/ℓ)	0.030	< 0.1
Boron (mg/ℓ)	0.030	< 0.1
Cadmium (mg/ℓ)	0.060	< 0.1
Calcium (mg/ℓ)	0.50	6
Chlorides (mg/ℓ)	75.2	47.8
Chromium (mg/ℓ)	0.060	< 0.1
COD (mg/ℓ)	52	2
Conductivity (mS/m)	23.6	21.4
Copper (mg/ℓ)	0.020	< 0.1
Iron (mg/ℓ)	2.460	< 0.1
Langelier Saturation Index	3.09	2.3
Lead (mg/ℓ)	0.010	< 0.1
M Alkalinity (mg/ℓ) CaCO3	20.1	20
Magnesium (mg/ℓ)	4.54	0.88
Manganese (mg/ℓ)	0.045	< 0.1
Nickel (mg/ℓ)	0.060	< 0.1
Nitrates (mg N/ℓ)	5	0.8
Ortho Phosphate (mg P/ℓ)	0.025	<0.5
pH	7.52	6.5-7.0
Potassium (mg/ℓ)	1.8	1.8
Silica (mg/ℓ)	2.270	0.1
Sodium (mg/ℓ)	37.4	40
Strontium (mg/ℓ)	0.033	< 0.1
Sulphates (mg S/ℓ)	4.15	3
TDS (mg/ℓ)	177	167
Total Phosphorus (mg P/ℓ)	0.04	<0.5
TSS (mg/ℓ)	5.8	1
Zinc (mg/ℓ)	0.250	< 0.1

3.6.4.4 *CIP and downtime*

As a result of improved rainfall in the Southern Cape, the drought experienced came to an end and consequently the plant is not presently in operation. Thus the plant is now in standby mode with the membranes being stored in a 2% SMBS solution to preserve the idle membranes. This solution is replaced every six weeks and the pH is monitored and maintained above 3. A single CIP unit is used for both the UF and RO units and each RO unit is cleaned separately. SMBS is dosed to neutralise hypochlorite.

The CIP is run in 3 categories:

- Clean water flush: High pH CIP at pH 11 using Hydrex 4502 to remove bio-solids and a second flush with freshwater.
- Low pH CIP in a pH range of 3 to 4 using Hydrex 4503, this is to remove scaling.
- Final flush using product water.
- During a continuous operation the membranes go back into use but currently the plant is not in operation hence the membranes in preservation using SMBS.

3.6.4.5 *Operation and maintenance problems experienced*

The problems experienced at the reuse plant during their operating prior to the end of the drought were:

- Poor secondary effluent quality from the wastewater treatment works
- Poor secondary effluent quality during stormy weather causing high feedwater turbidity

The following problems are being experienced at the plant due to it being in zero production mode at present:

- The plant is not being run continuously and this is causing blockages of the strainers due to pressure changes and inadequate monitoring.
- Long-term preservation of the membranes may cause damage to the membranes which could result in the municipality's loss of warrantees.

3.6.4.6 *Operational costs*

The actual operational costs (2014) associated with running the plant in zero production mode may be distributed as per Table 3.22.

This is an estimated which includes certain shared personnel resources with the Mossel Bay SWRO plant.

Table 3.22: O&M cost breakdown for Mossel Bay water reclamation plant (zero production mode)*

O&M breakdown	Average Monthly Cost (R/month)
Electricity	10 000.00
Chemicals & Consumables	20 000.00
Maintenance	5 000.00
Staff	25 000.00
SHEQ	2 000.00
Total Monthly Cost (Excl. VAT)	**62 000.00**

The O&M cost breakdown for zero production mode is illustrated in Figure 3.29.

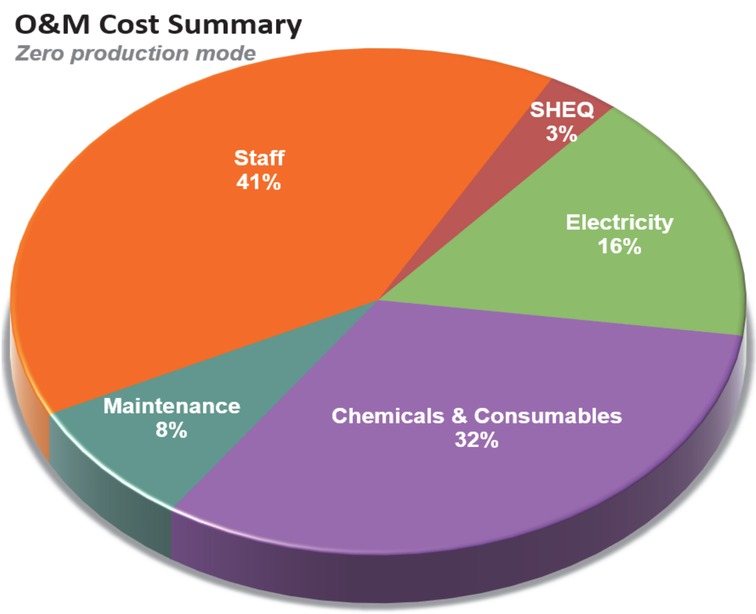

Figure 3.29: O&M cost breakdown for Mossel Bay water reclamation (zero production mode)

Table 3.23 summarises the estimated breakdown of O&M costs. These figures are estimated for full production mode and are compared to the outputs of the REUSECOST model.

Table 3.23: O&M cost breakdown for Mossel Bay water reclamation (full production)

O&M Parameters	Full production (5 Mℓ) Unit Cost (R/m³)	REUSECOST (5 Mℓ) Unit Cost (R/m³)
Electricity	0.64	1.52
Chemicals	0.18	0.52
Consumables *	0.50	
Maintenance	0.49	0.53
Staff	0.79	1.21
Laboratory	0.07	
SHEQ	0.05	0.37
Total monthly cost (excluding VAT)	**2.72**	**4.15**

* In the absence of more accurate plant data for consumables, this value has been estimated based on reasonable assumptions from similar plants.

The estimated O&M cost breakdown for full production is illustrated in Figure 3.22.

As indicated above, in zero production mode, the main cost components are personnel/staff costs and chemical costs (primarily for regular membrane maintenance and upkeep).

In full production mode, the main cost components are energy, consumables, staff, and maintenance.

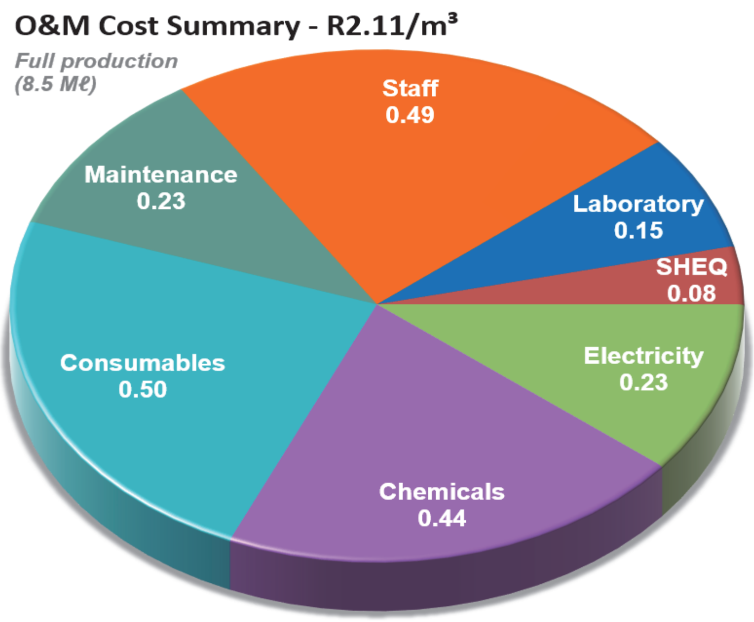

Figure 3.30: O&M Cost breakdown for the Mossel Bay water reclamation plant (full production)

The estimated O&M cost breakdown for full production, based on the REUSECOST model, is illustrated in Figure 3.23:

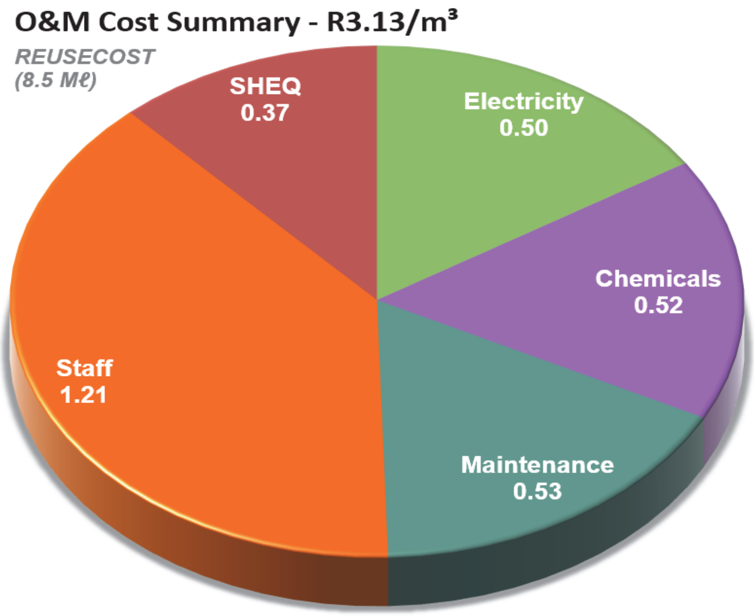

Figure 3.31: O&M Cost breakdown for the Mossel Bay water reclamation plant (REUSECOST full production)

CHAPTER 4: BEST PRACTICE CONSIDERATIONS

4.1 INTRODUCTION

This chapter focuses on general and common planning, design and operational problems and challenges experienced at the individual plants investigated, as well as other plants where issues were raised., The objective is to further improve the planning, design, decision making and implementation (including operation and maintenance) of future desalination and water reuse projects by capturing issues of concern and lessons learned.

4.2 GENERAL CONSIDERATIONS

The following general considerations are applicable to both desalination and water reuse plants and include funding considerations, project planning, design, implementation, operational and maintenance issues. Specific O&M aspects relating to desalination and water reuse plants are detailed further in Chapter 2 and 3. The issues and risks are specific for each case through the range of seawater desalination plants to the different categories of water reuse plants. Particularly careful consideration should be given to the case of direct potable reuse (DPR) of wastewater effluent.

4.2.1 Planning considerations

The following are key planning considerations.

- Develop projects as part of a long term integrated water resource plan to meet the water demand and water quality requirements of the user. This is, in most cases, the determining factor in the financial and technical feasibility and overall success of these projects.
- Appropriate risk management of water quality is required for the plants' successful operation, and therefore risk based planning should be developed in the form of a detailed water safety plan and/or wastewater risk abatement plan and/or catchment management plan that is plant specific and reviewed annually.
- Compile and update (and keep updating) a catchment and water cycle monitoring plan
- Provide adequate planning, budget, training, and skills development required to cost effectively operate and maintain water reuse and desalination facilities.

4.2.2 Design considerations

The design of the plant is very important in meeting the technical goals of the project, and a 'fit-for-purpose' design approach should be the minimum consideration on which to build further. From early on in the project cycle, the following aspects are critical.

- Sufficient sampling and testing of raw water (whether wastewater, treated effluent, seawater or water from other sources)
- Process design to cover all risk factors, including likely future changes in source water quality
- In-depth analysis of product water quality requirements

4.2.3 Funding and Institutional Considerations

In considering the various funding mechanisms and institutional arrangements, the following are fundamental to the success of these types of projects:

- Accurate capital and operational expenditure estimates and detailed life cycle costing are required and should include adequate risk factors that allow for unexpected changes in water quality, demand, escalation and changes in rates and availability of consumables (especially electricity), etc.
- Clear and concrete take-off agreements (and other associated operational, maintenance and other agreements) are required for successful implementation and operation.
- Revenues from water rates should be adequate to cover annual operating, maintenance and repair costs, replacement and improvement costs, adequate working capital and servicing of debt finance (if applicable) as well as some reserves. This should also take into consideration the cost of specialist support services.
- Budgeting of the operational phase should include sufficient allowances for asset management, preventative maintenance and future infrastructure replacement and/or re-investment.
- Cost of quality materials, as well as training and skills development should be included in the financial and implementation models.

Equitable distribution of rates when implementing a water reuse or desalination plant into a water resource portfolio should be clearly detailed and communicated to end consumers.

There are five preferred institutional options to finance/fund and implement water sector projects, namely Public Funding, Project/Infrastructure Financing Utility, Independent Water Utility, Public Private Partnerships (PPPs) and Concessions. Of these, the most successfully demonstrated option is a PPP.

The NGWRP and Beaufort West plants are prime examples of where this type of Public Private Partnerships has been successfully implemented as part of the long term planning and sustainability of the plant. The Mossel Bay desalination and reuse plants, although currently maintained in a zero production mode, also demonstrate the utilisation of PPP's (PetroSA and Mossel Bay Municipality) to successfully implement projects of this nature, particularly under the emergency conditions and considerable time pressure in which these projects were undertaken.

4.2.4 Operation and Maintenance Challenges

Two of the seawater desalination plants (Mossel Bay, Sedgefield) and two of the water reuse plants (George, Mossel Bay-Hartenbos) were built during the 2010/11 drought period and were undertaken under emergency conditions, which differentiate them from the other plants not completed under such strict time constraints. The Beaufort West plant, although constructed during the same drought period, had been in the planning phase since 2007, forming part of the municipality's medium term plan to develop sustainable drinking water supplies.

The emergency plants, namely the Sedgefield and Mossel Bay desalination plants, and the George and Mossel Bay water reuse plants, are mostly maintained in a zero production mode. Although these plants are not producing much product water, there are (substantial) costs and challenges associated with maintaining these plants in a zero or low production mode.

From an operational (and membrane maintenance) point of view, it is preferred to have these plants in continuous operation, or at least to have a rigorous flushing, cleaning and monitoring schedule. The stopstart operation of these types of plants may even lead to a reduced membrane lifespan in spite of low total hours of use. Where the plants are not being run continuously, or being well maintained, there is increased likelihood of blockages of the strainers and other equipment due to pressure changes, inadequate cleaning, monitoring and maintenance while the plant is in a zero production mode.

From a resourcing perspective it is preferable that the plant is operated by personnel of the water supply authority (municipality or water board). However, there is a shortage of experienced and knowledgeable water treatment operators in South Africa, particularly with respect to complex UF/RO water treatment processes. The tendency is currently towards using PPP or similar type agreements for management and operation of desalination plants. It is advisable that at least one personnel member of the water supply authority has an adequate understanding and knowledge of membrane treatment processes and advanced oxidation processes (Swart et al., 2013). Sufficient training from commissioning to start-up and operation of the plant is essential, particularly when the plant is handed over to operational personnel of the water supply authority. A comprehensive and practical operating manual should accompany any reuse plant. Strict supervision, monitoring and continuous training should be implemented as standard practice.

In South Africa, it is a quite common at water supply facilities that insufficient funds are budgeted for maintenance of the facilities. (Swart et al., 2013).

4.2.4.1 *Pre-treatment*

Pre-treatment steps in desalination and water reuse are important design considerations which can have a significant impact on the capital costs, as well as the operational and maintenance costs over the life cycle of the plant, particularly in terms of membrane fouling, replacement costs, etc. This is demonstrated by the New Goreangab water reclamation plant with its multiple treatment steps upstream of the UF membranes.

Pre-treatment steps of the desalination and reuse plants are summarised below:

- **Mossel Bay desalination plant:** multimedia filters;
- **Sedgefield desalination plant:** micro-filters;
- **Albany Coast desalination plant:** horizontal and vertical sand filters followed by microfiltration;
- **Beaufort West reclamation plant:** rapid gravity sand filtration followed by Ultra-Filtration,
- **NGWRP:** PAC, pre-ozonation, coagulation/flocculation, DAF, dual media filtration, ozonation, BAC filtration, GAC filtration, with the final step being Ultra-Filtration (no RO);
- **George reuse plant:** drum screen, strainer with the final step being Ultra-Filtration (no RO);
- **Mossel Bay reuse plant:** disc filter followed by Ultra-Filtration.

The pre-treatment steps selected are highly dependent on the quality of the feedwater entering the desalination or water reuse plant. In general, one may propose, as a starting point, that multi-media filtration followed by micro- or ultra-filtration and RO may be acceptable to treat most seawater or wastewater types.

4.2.4.2 *Membranes*

Membrane upkeep and maintenance is a critical factor in the long term operation and sustainability of desalination and water reuse plants employing UF/RO membrane systems. Long term preservation may cause damage to the membranes which could result in the municipality's loss of warrantees as well as the substantial costs associated with membrane replacements. Ensuring membrane integrity is maintained in optimal condition for as long as possible is a vital factor in the life cycle of desalination and water reuse plants. Membrane replacement has major financial implications in the operation and maintenance of these plants. Typically the membrane lifespan of UF/RO units is in the region of 4 to 5 years on average. Extending the period between membrane replacements has a significant impact on overall cost effectiveness, sustainability and lifespan of the plant. This can be achieved by proper monitoring, cleaning and preventative maintenance procedures and protocols. The implementation of an effective monitoring program is essential to ensuring the plant (and the UF/RO membranes) is in optimal operating condition.

4.2.4.3 *Contractual Arrangements*

Should the desalination or water reuse plant be operated under contract (via private entity or third party), it is preferable that the plant is operated in a long term service level agreement. This is the case with the Beaufort West and New Goreangab water reclamation plants. These plants are run very successfully in collaboration with the water supply authority they service. In these instances, a long-term relationship has been built and the plant is maintained with the best interests of all stakeholders. Proper planning, commitment, clearly defined roles and responsibilities, agreed milestones, a sense of openness and trust were key factors identified in building this long-term relationship and ensuring the quality and availability of water supply is maintained throughout the plant life cycle.

In the case studies where water desalination and reuse was in the long-term water supply strategy of the relevant water supply authority (municipality or water board) as was the case with the Beaufort West, Albany Coast and New Goreangab plants, this lead to a more successful and sustainable solution to augmenting water supplies in communities they service for the long-term.

4.2.5 Energy Efficiency

Energy costs are still a major cost contributor in any water treatment processes involved UF/RO systems. However, in comparison with desalination plants, water reuse plants have significantly lower power consumptions. In the case studies of Mossel Bay reuse plant and NGWRP, the average consumption is 1.5 kWh/m^3 and 0.57 kWh/m^3 treated water respectively, while typical SWRO desalination plants range from are in the region of 3 to 4.5 kWh/m^3. In order to be more cost effective under normal operation, it is recommended that plants are run at higher capacities during off-peak times where TOU tariffs are lower than during peak hours. This can lead to significant reduction in the power costs associated with running these plants during standard/peak hours.

In the case of Beaufort West, the plant is run for is operational for 10 to 13 hours per day, producing some 96 m^3/h during normal day time operation. In the evening the plant remains in zero production mode, unless additional water supply requirements are needed.

The implementation of energy recovery devices, particularly in desalination plants has a major impact on energy efficiency and significantly reduced the plant's total energy requirements, reportedly by as much as 30% in the case of the Albany Coast desalination plant.

Plants that are maintained in a zero production mode such as the Sedgefield, Mossel Bay desalination, George and Mossel Bay water reuse plants, may also benefit from performing their regular maintenance procedures such as CIP's, CEB's (during cleaning and flushing of membranes) and performance tests during off-peak tariff hours.

The costs of electricity at the set tariffs can be calculated for different production rates and TOU scenarios for the individual plants.

The TOU tariffs also include seasonal rates (increased rates in winter due to higher electrical demand) as shown in Table 4.1.

Table 4.1: Electricity Costs Tariffs for the Sedgefield SWRO plant

Sedgefield SWRO	Normal tariff			TOU tariffs High demand		TOU tariffs Low demand	
Costs and Tariff	Zero Mode	1 x RO	2 x RO	1 x RO	2 x RO	1 x RO	2 x RO
	(R/month)						
Basic charges	1 000	1 000	1 000	1 000	1 000	1 000	1 000
Network Access (kVA)	6 264	6 264	6 264	6 264	6 264	6 264	6 264
Network Demand (actual kVA)		17 400	31 755	3 786	6 909	3 786	6 909
Fixed Electricity Costs	7 264	24 664	39 019	11 050	14 173	11 050	14 173
Consumption (kWh)							
Normal tariffs		18 521	37 043				
TOU tariffs				21 789	43 577	16 636	33 271
Variable Electricity Costs	0	18 521	37 043	21 789	43 577	16 636	33 271
Total Electrical Costs (R/month)	**7 264**	**43 185**	**76 062**	**32 838**	**57 750**	**27 685**	**47 444**
Water Produced (Mℓ/month)	**0**	**15.7**	**31.3**	**15.7**	**31.3**	**15.7**	**31.3**
Unit electrical cost (R/m³)*	**-**	**2.76**	**2.43**	**2.10**	**1.84**	**1.77**	**1.52**

*Colour coding: green = least cost, red = most cost

This calculation can be applied to different production rate scenarios (plant utilization/hours of operation) to determine the most economical schedule of operation. As shown in the Table 4.2, the TOU tariffs produce the least cost at all production rates in the low season. In the high season, the reduced production rates (rows 2 to 4) also benefit by using the TOU tariff.

Table 4.2: Electricity Cost Tariffs for the Sedgefield SWRO plant

Sedgefield SWRO		Normal tariff			TOU tariff High demand		TOU tariffs Low demand	
Unit Cost and Tariff TOU production	Unit	Zero Mode	1 x RO	2 x RO	1 x RO	2 x RO	1 x RO	2 x RO
1. All times used	Mℓ/month	0	20.5	41.1	20.5	41.1	20.5	41.1
Maximum Production	R/m³	-	2.38	2.13	3.04	2.84	1.80	1.61
2. Standard and Off-peak	Mℓ/month	0	16.9	33.8	16.9	33.8	16.9	33.8
Medium Production	R/m³	-	2.64	2.34	2.09	1.85	1.73	1.50
3. Off peak only	Mℓ/month	0	9.9	19.8	9.9	19.8	9.9	19.8
Minimum Production	R/m³	-	3.67	3.15	2.18	1.78	2.04	1.64
4. Standard and Off-peak	Mℓ/month	0	15.7	31.3	15.7	31.3	15.7	31.3
1.0 Mg/ℓ avg. production	R/m³	-	2.76	2.43	2.10	1.84	1.77	1.52

*Colour coding: green = least cost, red = most cost

However, the maximum production rate (row 1) does not benefit from the TOU tariff in winter (high season). Fortunately in the southern cape, the high electrical demand in winter usually corresponds with increased rainfall and surface water availability, and less water demand. Therefore, for the foreseeable future, it is possible to run the plant at reduced production (or not all all) and carry out annual maintenance in winter.

4.2.6 Environmental and Social Considerations

The social and environmental aspects of any desalination and water reuse plant are a major factor to the success and sustainability of the plant within the local community it services. The importance of public acceptance of any water supply scheme is widely recognised. This holds true particularly in direct potable reuse plants using wastewater from water treatment works. Recognising the impact of public perception (whether real or envisaged) is an important consideration throughout the life cycle of the plant. Public engagement, marketing and public relations are critical success factors in ensuring the plant is accepted and supported by the local community in a positive light. The need for extensive engagement of the local community (and relevant authorities) through EIA's, public workshops, tours, meetings and marketing campaigns should not be underestimated. Proper planning and comprehensive EIA studies are essential in planning phases.

4.3 DESALINATION PLANTS

The sections that follow summarise some of the O&M aspects, best practices and lessons learnt relating to the desalination plants investigated under this study. The plant owner and operator for the individual desalination plants are as follows:

No.	Plant	Owner	Operator
1	Mossel Bay 15 Mℓ/d SWRO plant	Mossel Bay Municipality	VWS (now Veolia Water)
2	Sedgefield 1.5 Mℓ/d SWRO plant	Knysna Municipality	Knysna Municipality
3	Albany Coast 1.8 Mℓ/d SWRO plant	Amatola Water	Amatola Water

4.3.1 Engineering (Concept, Feasibility, Design), Procurement, Construction, Commissioning

The following considerations should be taken into account during the design phase of desalination plants:

- Feedwater (seawater) quality: red tides, algal blooms, etc. may cause blockages of membranes.
- Degree of recovery in each of unit process steps (dependent on feedwater quality)
- Materials of construction: harsh seawater environment (corrosion is a major issue)
- Where possible, local service providers with long term service level agreements and warrantees (particularly with respect to membrane lifespans) are preferred.
- Degree of and costs associated with pre-treatment steps and water distribution network.
- Environment aspects (EIA's)
- Social aspects
- Commissioning and start-up procedures should be clearly documented and defined.
- O&M manuals clearly defined
- Preventative maintenance procedures clearly defined
- Membrane cleaning, monitoring, performance checks defined
- Proper training and knowledge transfer to operational team
- Effective monitoring system
- Specialist support

4.3.2 Operations

The Mossel Bay desalination plant is operated and maintained by VWS, while the Sedgefield and Albany Coast plants are operated by their respective municipalities or water authority, namely Knysna Municipality and Amatola Water. As previously stated, the Mossel Bay and Sedgefield desalination plants are currently maintained in a zero production mode.

These plants operate in harsh seawater environments where proper maintenance of equipment is essential. It is imperative that these plants are maintained in a correct and functional state when not in operation. Regular cleaning, flushing of membranes, monitoring and preventative maintenance protocols are essential should these plants require start-up in an emergency.

In general, membranes have an expected lifespan of five years and a maximum of seven after which they are normally replaced. An important factor in achieving an extended lifespan is the operating regime, as the plant should ideally be run continuously. Frequent starting and stopping of the plant while the plant is in a zero production mode (or to minimise running costs) is not optimal for membrane life. The long-term preservation may also cause damage to the membranes and result in membrane warrantee issues. This is particularly evident in the Sedgefield plant housed in inter-connected shipping containers where materials used in the construction has suffered severe corrosion (from welding activities, ad-hoc modifications, etc.). This is primarily due to the fast track nature of the project where sufficient time was not allowed for during the planning and implementation phases. The humidity and corrosive environment at the coast has had a detrimental effect on the PLC, electronics, wiring and computer systems, which may need to be refurbished/replaced should the plant go back into production mode.

Accurate feedwater quality measurements are an important consideration in the design phase of desalination plants. Feedwater quality plays and important role in the design and selection of pre-treatment processes these plants. The degree and associated cost of pre-retreatment steps is a critical consideration. This is evident in the varying quality of the seawater from the boreholes at the Sedgefield plant.

The Mossel Bay desalination plant operated and maintained by VWS is generally kept in a good state with regular cleaning and flushing of membranes together with membrane performance checks. Monthly reports are generated which provide feedback on operations and maintenance activities done at the plant. It is recommended that accurate records and monthly reports are kept for all desalination plants whether in full production or maintained in a zero production mode.

4.3.3 Maintenance

The materials of construction, preventative maintenance procedures and protocols are critical to the sustainable operation and maintainability of seawater desalination plants. This is vital in ensuring optimal membrane performance and upkeep of the RO membranes. A detailed operational and maintenance schedule should be put in place from plant start-up. Maintenance issues that are typical of SWRO plants can often be dealt with by good O&M management: corrosion, minor leaks and drips, cleaning out (flushing) the system after maintenance works, monitoring and telemetry and good housekeeping. A brief summary of some maintenance issues relating to the individual plants are summarised below:

Mossel Bay Desalination Plant

- High sand (and organics) in the feedwater (as a result of stormy weather conditions) causing mechanical damage, e.g. damage to the turbochargers.
- Blockages of the sea intake caused by poor sea intake conditions.
- Blockages in multi-media filters due to poor seawater quality.

Sedgefield Desalination Plant

The key problems experienced are the varying feedwater quality from the boreholes and the discharge of brine at the beach. These are being addressed as on-going projects by the Knysna Municipality.

Albany Coast Desalination Plant

One the key problems experienced is the cost of water production during the winter months when Eskom's tariffs are high. In addition to this, water cannot be distributed directly from the water works because of a past fire that damaged the three distribution pumps on the site.

4.3.4 Environmental and Social Aspects

In the seawater desalination projects detailed in this study, some of the important environmental and social considerations include, but not limited to the following:

- Disposal of brine through deep-sea outfalls;
- Impacts of the installation on the natural marine/beach environment (sea tides, position of boreholes, visual effects on public, etc.);
- Distance from distribution networks;
- Quality of feedwater (possibility of red tides, algal blooms, seasonal changes, etc.);
- Community engagement;
- EIA studies.

4.4 WATER REUSE PLANTS

The sections that follow summarise some of the O&M aspects, best practices and lessons learnt relating to the water reuse plants investigated under this study. The plant owner and operator for the individual water reuse plants are as follows:

No.	Plant	Owner	Operator
1	Beaufort West 2.1 Mℓ/d reclamation plant	Beaufort Municipality	Water & Wastewater Eng.
2	Windhoek 21 Mℓ/d Goreangab reclamation plant	Windhoek Municipality	Wingoc
3	George 10 Mℓ/d UF plant (full capacity tested at 8.5 Mℓ)	George Municipality	Aqua Engineering
4	Mossel Bay 5 Mℓ/d UF/RO plant	Mossel Bay Municipality	VWS (Veolia)

4.4.1 Engineering (Concept, Feasibility, Design), Procurement, Construction, Commissioning

The following considerations should be taken into account during the design phase of water reuse plants:

- Feedwater (seawater) quality: red tides, algal blooms, etc. may cause blockages of membranes.
- Degree of recovery in each of unit process steps (dependent on feedwater quality)
- Materials of construction: harsh seawater environment (corrosion is a major issue)
- Where possible, local service providers with long term service level agreements and warrantees (particularly with respect to membrane lifespans) are preferred.
- Degree of and costs associated with pre-treatment steps and water distribution network.
- Environment aspects (EIA's)
- Social aspects
- Commissioning and start-up procedures should be clearly documented and defined.
- O&M manuals clearly defined
- Preventative maintenance procedures clearly defined
- Membrane cleaning, monitoring, performance checks defined
- Proper training and knowledge transfer to operational team
- Effective monitoring system
- Specialist support

4.4.2 Operations

It is common practice for many reuse plants to be performed under contract by a third party (typically the plant designers), as is the case with the Beaufort West, New Goreangab and Mossel Bay reuse plants. The George reuse plant is operated in a zero production mode by George municipality since November 2011, and prior to that it was operated by Garchem Technologies. The Mossel Bay and George reuse plants are currently maintained in zero production mode. As previously stated, it is imperative that these plants employing UF/RO are maintained in a correct and functional state when not in operation. Regular cleaning, flushing of membranes, monitoring, preventative maintenance, regular membrane performance checks should be carried out to ensure the membranes are kept in there optimal condition should the plant be restarted.

In direct potable reuse plants such as Beaufort West and New Goreangab, regular monitoring of feedwater quality is an important parameter and has a direct impact on the quality of the product water produced. Hence, a critical component of direct potable reuse plants, as in the case studies of the Beaufort West, New Goreangab and Mossel Bay (direct industrial) reuse plants, is the operational monitoring program.

Continuous and effective monitoring of these plants is essential to their daily operation not only as an operational (and legal) requirement for meeting the potable water standard (SANS 241), but also to ensure membrane integrity and process efficiency is always at its optimal. This is crucial in maintaining the cost effectiveness (and business case) for running these plants (as well as expanding, refurbishing or build new ones) which may be often compared to conventional treatment plants in terms of their unit consumptions/costs per cubic meter (R/m³) of treated water. In developing an operational monitoring program, the following are important considerations (Swartz et al., 2013) in reclamation and reuse plants:

- Evaluate current wastewater treatment plant monitoring systems.
- Minimize the potential for fouling during advanced treatment.
- Develop a list of constituents to be measured for operational monitoring.
- Make sure that allowance is made for measurement and monitoring of pollutants and chemicals that may be present in industrial effluent streams that are discharged to the wastewater treatment works.
- For membranes, include membrane integrity monitoring for pathogens and chemicals (which is dependent upon the expectations of process performance).
- Incorporate online monitoring, where possible.
- Optimize AOPs through monitoring for performance and reliability.
- For testing membrane performance and integrity, consider using dye as a surrogate for viruses.
- Evaluate the removal of EDCs and other CECs by membranes and advanced oxidation processes (AOPs).
- Develop a rationale for regulators and the public as to why agencies are treating recycled water to a greater degree than other sources (because the source is from wastewater rather than surface water).
- In view of the potential health impacts in water reuse, it is important to apply real-time online monitoring for constituents and/or parameters with existing technology
- Examine the use of side stream treatment rather than returning the untreated waste stream to the head of the plant and recycling constituents.

- The New Goreangab water reclamation plant has historical significance as the first direct potable reuse plant in the world. The Old Goreangab reclamation plant (Old Plant) was constructed in 1969, while the 21 Mℓ/d New Goreangab water reclamation plant (NGWRP) for direct potable use was commissioned in 2002 and built alongside the Old Plant.

The degree and associated cost of pre-retreatment steps is a critical consideration in the multi-barrier approach adopted by typical water reuse plants. As previously mentioned above, the NGWRP has multiple pre-treatment steps with the final step being ultra-filtration. Due to the multi-barrier (chemical-physical) pre-treatment steps involved in the NGWRP process, the electricity costs are significantly lower in comparison with reuse plants without these steps.

Pre-treatment typically incurs additional capital costs, however the degree of pre-treatment has a significant impact on the operational and maintenance costs (in terms of membrane replacement, fouling,.) during the life cycle of the plant.

Initially 50% of NGWRP feedwater was from the Goreangab Dam and the other 50% from the GWWTP. The Goreangab Dam water quality has deteriorated to such an extent that it is not usable for drinking purposes this has resulted in NGWRP relying on the GWWTP secondary effluent for feedwater. Treating water from the dam would be expensive and a more robust treatment method would have to be implemented. No major operational and maintenance problems have been encountered by the NGWRP.

The Mossel Bay water reuse plant, although maintained in a zero production mode by VWS, is generally kept in a good state with regular cleaning and flushing of membranes together with membrane performance checks.

Monthly reports are generated which provide feedback on operations and maintenance activities done at the plant. It is recommended that accurate records and monthly reports are kept for all water reuse plants whether in full production or maintained in a zero production mode.

- The George reuse plant is maintained in a zero production mode by the municipality and shares resources with the George wastewater treatment works from which it receives its feedwater. The plant was designed and built by Aqua Engineering. Although it was originally designed to produce 10 Mℓ/d of product water, the plant was only able to supply 8.5 Mℓ/d during commissioning/start-up. In general, the plant maintained in a reasonable condition by two dedicated operators that perform maintenance checks and CEB's (twice per week) to clean and flush the UF membranes. However, a number of operational problems experienced at the plant include: leaking pipes/valves, low levels in membrane casing due to leaks, incorrect flow meter readings, among others. Poor handover and knowledge transfer from the plant designers to the current operators is a common issue. It is recommended that plant be reviewed by a specialist company to identify and correct any operational issues that may prevent the plant from starting up again.

- In the case of the Beaufort West reclamation plant, the focus of plant operations and preventative maintenance is to ensure that the integrity of the UF and RO membranes are protected and kept in excellent condition at all times. Final and intermediate streams are carefully monitored for signs of membrane integrity loss. The plant SCADA can also be monitored and controlled remotely via laptop. No major operational and maintenance issues have been encountered by the plant thus far.

4.4.3 Maintenance

Preventative and regular maintenance is critical at water reuse plants, particularly to ensure good performance of the treatment barriers. The materials of construction, preventative maintenance procedures and protocols are just as critical to the sustainable operation and maintainability of water reuse plants, as with desalination plants. A detailed operational and maintenance schedule should be put in place from plant start-up. Knowledge transfer between the plant designer and plant operator is essential. As previously stated, maintenance issues can often be dealt with by good O&M management: minor leaks and drips, cleaning out (flushing) the system after maintenance works, monitoring and telemetry, and good housekeeping. A brief summary of some maintenance issues relating to the individual plants are summarised below:

Beaufort West Reclamation Plant

Some minor (external) operational issues encountered thus far include:

- Excess foam forming in the winter months over the biological reactor of the WWTW.
- An old pipe that burst in the downstream distribution network between the plant and the storage reservoir.
- Location/security issues, i.e. fencing, theft.
- Wear and tear on mechanical seals on some rotating equipment.

Some of the O&M lessons learnt may include:

- Critical spares such as UV lights, valves, seals, spare pumps, and other critical items are kept on site for emergencies.
- A sixty-day buffer storage of consumable such as chemicals, lab consumables, etc. is kept on site. This is sufficient for current maintenance and upkeep of the plant.
- OEM vendors are brought on site to regularly service and inspect all equipment such as pumps, valves, calibrate instruments, etc.

New Goreangab Water Reclamation Plant

No major operational and maintenance problems have been encountered by the NGWRP.

George Water Reuse Plant

- Hammering on self-cleansing strainer.
- Air valves on skids that doesn’t close properly and switch to manual automatically.
- Backwash pumps switch to manual during backwash mode and CEBs that result in halting the backwash process.
- Turbidity levels populate incorrect readings.
- Pipe leakages that include chemical piping. Replace PVC piping with stainless steel.
- Outeniqua WWTW effluent quality not up to DWS standards due to low plant capacity and during stormy weather causing high feedwater turbidity.
- Corrosion on some pipe lines caused by Ferric chloride.
- Flow meters operation and calibration (flow per skid).
- The plant is not being run continuously and this is causing blockages of the strainer due to pressure changes and inadequate monitoring.
- No equipment spares available.

Mossel Bay Water Reuse Plant

- Poor secondary effluent quality from the wastewater treatment works;
- Poor secondary effluent quality during stormy weather causing high feedwater turbidity.
- The plant is not being run continuously and this is causing blockages of the strainers due to pressure changes and inadequate monitoring.

4.4.4 Environmental and Social Aspects

The environmental and social aspects of any reuse plant are a major factor to the success and sustainability of the plant within the local community it services. The importance of public acceptance of direct potable reuse plants using wastewater from water treatment works is a common issue. Recognising the impact of public perception (whether real or envisaged) is an important consideration throughout the life cycle of the plant. Public engagement, marketing and public relations are critical success factors in ensuring the plant is accepted and supported by the local community in a positive light. In the case of the Beaufort West plant, extensive engagement of the local community (and relevant authorities) through EIA's, public workshops, tours, meetings and marketing campaigns were initiated from the planning phase.

In the water reuse projects detailed in this study, some of the important environmental and social considerations include, but not limited to the following:

- Disposal of brine;
- Impacts of the installation on the natural environment and local community;
- Distance from distribution networks;
- Quality of feedwater (this has a direct impact on product water quality);
- Community engagement;
- EIA studies.

Environmental Considerations for Desalination Plants

The environmental impacts of operating a seawater or brackish water desalination plant have many similarities to those of operating a conventional water treatment plant. Desalination facilities and conventional water treatment plants use many of the same chemicals for source water conditioning, and therefore generate similar waste streams. In addition, desalination facilities, like conventional water treatment plants, incorporate equipment (i.e. pumps, motors, air compressors, valves, etc.) and treatment processes that generate noise pollution, consume electricity, release waste and directly or indirectly emit greenhouse gases.

Similar to conventional water supply projects, the construction of desalination plants generates traffic, noise, and other auxiliary environmental impacts. Such impacts are only temporary in nature and typically are minimized by detailed project planning and coordination with local agencies and residents of the areas impacted by construction-related activities.

Despite many of the similarities of their environmental impacts, desalination plants have several distinctive differences from conventional water treatment plants:

- It typically uses more source water to produce the same volume of fresh water;
- It generates discharges of elevated salinity – typically 1.5 to 10 times higher total dissolved solids (TDS) concentration than the source water; and
- It uses 2 to 10 times more electricity to produce the same volume of freshwater.

Renewable energy sources (such as solar) could be considered during the design, construction phase to reduce the energy footprints of desalination and water reuse plants and built into their overall plant life cycle cost. One enhancement of the green building design is the installation of a rooftop photovoltaic system for generating solar power.

Environmental Considerations for Water Reuse Plants

Comparison of water reuse options is also affected by the direct or indirect impact of the water supply scheme on the environment. The main impact is the discharge of waste streams to the environment (often to water courses). Disposal options dictated by strict control of wastewater charges and associated rights have a significant effect on the overall cost of drinking water supply schemes. A second important component of environmental factors is energy consumption.

Energy efficiency is currently high on the agenda and is a main consideration when evaluating different water supply options. Pumping requirements in particular constitutes the largest fraction of the operating costs (apart from human resource cost) (Swartz et al, 2013). Water desalination and reuse projects may have an environmental footprint and significant energy usage depending on the technologies employed.

Reuse of water also has positive environmental benefits, specifically on the water environment through protection of aquatic ecosystems by not having to abstract more water from a natural source, and avoiding degradation of natural waters by not discharging wastewater, but rather using reclaimed water.

The two most important problems with DPR treatment schemes employing RO are the management of brine, especially in inland locations, and the high energy usage. To deal with the brine disposal issue, a variety of new advanced treatment processes are currently under development for the oxidation of trace organics, without the removal of dissolved solids. For reducing the energy usage, new and enhanced biological treatment systems are also under development. As new technologies become available in the future, it is anticipated that constituent removal effectiveness will improve with a concomitant reduction in energy and resource usage.

In Southern Africa there are numerous problems with the delivery of adequate water supply services in the country as whole. It is clear that local government and specifically municipalities in South Africa need to find ways to balance development against the environment to ensure sustainability. The environment therefore needs to be an integrated part of the decision making process when considering the development or the upgrade of water treatment facilities. Various pieces of legislation have been developed to enable the implementation of these requirements, namely;

- National Heritage Resource Act (NHRA) (Act No. 25 of 1999)
- The National Water Act (NWA) (Act 36 of 1998)
- The National Environmental Management: Waste Act (NEM: Waste Act) (Act 59 of 2008)
- The National Environmental Management Act (NEMA) (Act 107 of 1998)

Compliance with the above legislation is mandatory and forms part and parcel of any EIA study involving desalination and water reuse projects in South Africa.

4.5 LESSONS LEARNED

- Sufficient planning and scenario analysis of future water demands should be implemented in the medium to long term operation of existing desalination and water reuse plants, as well as in the strategic planning of new plants.

- Ensure that the long term operation and maintenance of the plant is part of the design and implementation strategy

- Where possible, develop projects through Public Private Partnerships (PPP) or similar partnerships between O&M contractor and water supply authority, municipality or water board.

- Long term service level agreements between O&M contractor water supply authority, municipality or water board are preferred. This encourages a long term, mutually beneficial relationship between the parties concerned.

- In reviewing cost considerations both CAPEX and OPEX should be considered equally important when analysing the feasibility and life cycle costs of desalination and water reuse plants. Operating costs can be significantly higher than anticipated (or understood) in relation to the initial capital costs.

- Various operating modes and scenarios should be considered when evaluating O&M costs, i.e. zero production mode, different production modes, etc. before considering mothballing of any plant.

- It is recommended to run plants periodically during off-peak periods to maintain plant operational integrity. Scenario planning, treating the cause instead of symptoms, etc. are important considerations.

- UF/RO membranes have an expected lifespan of five years and a maximum of seven after which they are normally replaced. The key factor in achieving an extended lifespan is the operating regime, as the plant should ideally, be run continuously. Frequent starting and stopping of the plant, to minimise running costs, is not optimal for membrane life.

- Time of use (TOU) tariffs can be used to optimise cost effectiveness and responsible energy use.

- In order to be more cost effective under normal operation, it is recommended that plants are run at higher capacities during off-peak times where TOU tariffs are lower than during peak hours.

- O&M problems associated with SWRO plants (such as corrosion, minor leaks and drips, cleaning out/flushing the system after maintenance works, monitoring, telemetry, housekeeping, etc.) can often be dealt with by good O&M practices.

- Periodic reviews of O&M procedures, regular reporting of O&M activities, an online monitoring system with regular analysis of membrane performance is recommended for all desalination and water reuse plants in operation (or while in zero production mode).

- On-going training and development of operational staff. This particularly includes skills & knowledge transfer during the handover, commissioning, start-up phases.

- Social and environmental aspects, particularly in water reuse plants are vital to the successful acceptance and sustainability of these plants in the communities they service. Public engagement is a critical process in the planning of water reuse and desalination plants.

- Quality control, particularly in the case of direct potable reuse (DPR), but applicable to all plants as follows (Menge, 2015):

  - Accreditation of the plant operation (ISO)

  - Water safety plan based on HACCP (WHO-WSP)

  - A proper risk assessment and risk management plan for

    - Mechanical maintenance of the plant
    - Microbial and chemical hazards that might enter the plant, and the barriers to remove them
    - Fluctuations in water sources that enter, or may in future enter, the water cycle

  - A catchment and water cycle monitoring plan

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

The section reviews the conclusions and recommendations presented in this report. These conclusions are based on the information gathered from site visits, investigations, interpretation of information received from the plant operator, plant design contractor, local municipality, historical data and/or calculations. Where more accurate information is not available or accessible, relevant assumptions have been made based on historical data or past performance in order to obtain meaningful results. Where gaps occur in data collected/presented, the plant database shall be updated as data becomes available.

5.2 CONCLUSIONS

The desalination and water reuse plants in this study were selected based on their location and importance with respect to augmenting water supply in the regions. Some of these projects were mostly undertaken under emergency conditions (during the 2009/10 drought period) with considerable time pressure, which differentiate them from the projects not completed under such strict time constraints. Since the initiation of this study, the George, Sedgefield, Mossel Bay desalination and water reuse plants have been maintained in a zero production mode. Typically CEB's, cleaning and flushing of membranes and performance checks are done regularly to ensure the UF/RO membranes are properly maintained and the plant is ready for start-up should there be any emergency demands. The Beaufort West plant, although constructed during the same drought period, had been in the planning phase since 2007, forming part of the municipality's medium term plan to develop sustainable drinking water supplies. The New Goreangab water reclamation plant has historical significance as the first direct potable reuse plant in the world. In the case studies where water desalination and reuse was in the medium- to long-term water supply strategy of the relevant water supply authority (municipality or water board) as was the case with the Beaufort West, Albany Coast and New Goreangab plants, this lead to a more successful and sustainable solution to augmenting water supplies in communities they service for the long term. One can conclude that strategic (medium/long term) planning is an essential component in the success and sustainability of desalination and water reuse plants.

The capital and operational costs associated with these plants are greatly influenced by the type of unit processes involved. The selection of the pre-treatment processes and distribution works has a significant impact on the associated capital and operating costs. In all cases the unit cost of water decreases as the water production increases. This rule of thumb may be used to develop operating rules and a strategy to optimise the cost of producing water at the rate required. The cost of electricity at the set tariffs can be calculated for different production rates and TOU scenarios. In this way, the most efficient operational mode relevant to the specific plant circumstances and water demand requirements can be selected to maximise energy and thus cost efficiency of the selected plant.

Energy consumption is one the major contributors in the process selection and operation of seawater desalination plants. Typically, seawater RO plants consume in the region 3.5 to 4.5 kWh per cubic meter of product water. In comparison with conventional physical-chemical processes associated with reuse plants (e.g. New Goreangab Reclamation Plant), seawater desalination plants are much more energy intensive. In the case studies of Mossel Bay reuse plant and NGWRP, the average consumption is 1.5 kWh/m³ and 0.57 kWh/m³ treated water respectively, while typical SWRO desalination plants range from are in the region of 3 to 4.5 kWh/m³. The energy consumption of desalination and water reuse plants has a major impact on the overall O&M cost of running and maintaining these plants. In seawater desalination particularly, electricity consumption is typically in excess of 50% of the total O&M costs.

The membranes of UF/RO systems typically have an expected lifespan of five years and a maximum of seven after which they are normally replaced. The key factor in achieving an extended lifespan is the operating regime, as the plant should ideally, be run continuously. Frequent starting and stopping of the plant, to minimise running costs, is not optimal for membrane life.

Lessons learnt and best practices from the case studies are detailed in Chapter 4 and include:

- Where possible, develop projects through Public Private Partnerships (PPP) or similar partnerships between O&M contractor and water supply authority, municipality or water board.

- Long term service level agreements between O&M contractor water supply authority, municipality or water board are preferred.

- Plants that are maintained in a zero production mode may benefit from doing their regular maintenance procedures such as CIP's, CEB's during cleaning and flushing of membranes and performance tests during off-peak tariff hours.

- Using off-peak TOU tariffs to the advantage of plant operational modes to improve cost effectiveness and energy efficiency.

- O&M problems associated with SWRO plants (such as corrosion, minor leaks and drips, cleaning out/flushing the system after maintenance works, monitoring, telemetry, housekeeping, etc.) can often be dealt with by good O&M practices.

- Extending the period between membrane replacements has significant impact on overall cost effectiveness, sustainability and lifespan of the plant. This can be achieved through an effective online monitoring system, preventative maintenance protocols, regular membrane performance checks, etc.

- The implementation of an effective monitoring program is essential to ensuring the plant (and the UF/RO membranes) is in optimal operating condition.

In most water reuse systems the multi-barrier approach has been commonly used to successfully treat wastewater to meet potable water requirements (SANS 241) as demonstrated with the New Goreangab with its multiple pre-treatment steps. Regular monitoring, recording and interpretation of lab analyses and plant measurements is an essential part of day-to-day operations and troubleshooting. This is to ensure the plant operates at its optimal and that all physical (and chemical) barriers are maintained. No major operational and maintenance issues have been encountered by the plants thus far. The focus of plant operations and preventative maintenance is to ensure that the integrity of the UF and RO membranes are protected and kept in excellent condition at all times. Final and intermediate streams should be carefully monitored for signs of membrane integrity loss. Some of the maintenance lessons learnt are detailed further for the individual plants in Chapter 4. In the case of desalination plants, these include, amongst others:

- Blockages of the sea intake caused by poor sea intake conditions;
- Blockages in multi-media filters due to poor seawater quality;
- Varying feedwater quality from the beach boreholes;
- Possibility of red tides and algal blooms causing blockages and affecting UF/RO membrane performance.

Some of the maintenance issues experienced with the water reuse plants include:

- Environmental issues relating to brine disposal;
- Quality of feedwater from water treatment works, as this has a direct impacts on the quality of product water produced;
- Lack of on-site equipment spares;
- Effective monitoring program.

A brief summary for each of the plants in the case studies is presented in the tables below:

Desalination Plants			
Plant	Mossel Bay SWRO plant	Sedgefield SWRO plant	Albany Coast SWRO plant
Size of Plant	15 Mℓ/d	1.5 Mℓ/d	1.8 Mℓ/d
Type of Plant	Desalination: Direct potable	Desalination: Direct potable	Desalination: Direct potable
Owner	Mossel Bay Municipality	Knysna Municipality	Amatola Water
Operator	VWS (Veolia)	Knysna Municipality	Amatola Water
Operational Status	Zero mode	Zero mode	1.8 Mℓ/day
Completed	2010/11	2009	1997, extension 2008
Capital Cost - at time of construction - Adjusted for 2014/15 - Per unit capacity	 R207 mill R266 mill R17.74 mill/Mℓ/day	 R16 mill R22 mill R14.66 mill/Mℓ/day	 R28 mill R36 mill R21.65 mill/Mℓ/day
O&M Cost (2014/15)	R6.81/m³	R7.16/m³	R9.00/m³
Energy Use	4.39 kWh/m³	3.97	4.52 kWh/m³
Electricity Cost	R3.37/m³	R3.14/m³	R4.18/m³ (excl. ERD rental R0.53/m³)
Chemicals	R2.16/m³	R0.70/m³	R0.39/m³
Consumables			R0.20/m³
Maintenance	R0.58/m³	R0.52/m³	R1.97/m³
Staff	R0.62/m³	R2.58/m³	R1.47/m³
Laboratory Cost	R0.04/m³	R0.11/m³	R0.15/m³
SHEQ	R0.04/m³	R0.11/m³	R0.10/m³

Water Reuse Plants				
Plant	Beaufort West reclamation plant	Windhoek Goreangab reclamation plant	George UF plant	Mossel Bay UF/RO plant
Size of Plant	2.1 Mℓ/d	21 Mℓ/d	10 Mℓ/d (full capacity tested at 8.5 Mℓ)	5 Mℓ/d
Type of Plant	Reuse: Direct potable	Reuse: Direct potable	Reuse: Indirect potable	Reuse: Direct industrial
Owner	Beaufort West Municipality	Windhoek Municipality	George Municipality	Mossel Bay Municipality
Operator	Water & Wastewater Eng.	Wingoc		VWS (Veolia)
Operational Status	1.2 Mℓ/day	17.5 Mℓ/day	Zero mode	Zero mode
Completed	2010	2001	2010	2010
Capital Cost - at time of construction - Adjusted for 2014/15 - Per unit capacity	 R26.5 mill R34 mill R16.22 mill/Mℓ/day	 R122 mill R260 mill R12.38 mill/Mℓ/day	 R36 mill (plant) R46 mill R5.14 mill/Mℓ/day	 R40 mill R51 mill R10.19 mill/Mℓ/day
O&M Cost (2014/15)	R6.92/m³	R4.87/m³	R2.11/m³	R2.72/m³
Energy Use	2.07 kWh/m³	0.57 kWh/m³	0.23 kWk/m³	0.73 kWh/m³
Electricity Cost	R1.88/m³	R0.57/m³	R0.23/m³	R0.64/m³
Chemicals	R0.85/m³	R1.55/m³	R0.44/m³	R0.18/m³
Consumables	R0.50/m³	R1.00/m³	R0.50/m³	R0.50/m³
Maintenance	R1.01/m³	R0.78/m³	R0.23/m³	R0.49/m³
Staff	R1.96/m³	R0.88/m³	R0.49/m³	R0.79/m³
Laboratory cost	R0.47/m³	R0.06/m³	R0.15/m³	R0.07/m³
SHEQ	R0.23/m³	R0.03/m³	R0.08/m³	R0.05/m³

- Please note that all costs are quoted in South African Rand and exclude VAT.
- All O&M values are estimates based on variables (rates based on historical data, inflation, etc.) and represent the cost as at full production.
- George UF plant design specification was 10 Mℓ/day, but subsequently only tested 8.5 Mℓ/day. Throughout the report 8.5 Mℓ will be used as the full production capacity.

5.3 RECOMMENDATIONS

This aim of this study is to capture some of the actual operational and maintenance aspects, including the associated costs, of desalination and water reuse plants in Southern Africa. Where possible, actual plant costs have been simplified to unit consumption rates (unit reference values, e.g. kWh/m³). Where possible this data has been reviewed, checked and compared with similar desalination and water reuse plants, and other reference data, for consistency. Where possible, baseline costs have also been calculated in unit consumptions (e.g. R/m³) which may vary from year to year. To allow comparisons, relevant plant cost data has been escalated to the year 2014 (from the year of implementation) where possible. In many of the case studies presented in this report, the plants were built under emergency circumstances during the 2009/10 drought period with very little/no planning. This was the case with the George, Mossel Bay and Sedgefield plants. The plants currently in active operation, namely Beaufort West, Albany Coast and NGWRP, may have certain gaps missing over their operational lifespan due to poor records, handover between plant designer and plant operator, or proprietary information under the current SLA arrangements between the plant operator and water service authority or municipality. Based on the data collected for the case studies under investigation in this report, the following recommendations may be considered:

- Using off-peak TOU tariffs to the advantage of plant operational modes to improve cost effectiveness and energy efficiency.
- In order to be more cost effective under normal operation, it is recommended that plants are run at higher capacities during off-peak times where TOU tariffs are lower than during peak hours.
- Where possible, develop projects through Public Private Partnerships (PPP) or similar partnerships between O&M contractor and water supply authority, municipality or water board.
- Long term service level agreements between O&M contractor water supply authority, municipality or water board are preferred. This encourages a long term, mutually beneficial relationship between the parties concerned. This relationship should be built on openness, trust and commitment from all stakeholders.
- O&M problems associated with SWRO plants (such as corrosion, minor leaks and drips, cleaning out (flushing) the system after maintenance works, monitoring, telemetry, housekeeping, etc.) can often be dealt with by good O&M practices. Periodic reviews of O&M procedures is recommended for all desalination and water reuse plants in operation (or while in zero production mode).
- On-going training and development of operational staff. This particularly includes skills & knowledge transfer during the handover, commissioning, start-up phase.
- Sufficient planning and scenario analyses to identify future water demand needs should be implemented in the medium to long term operation of existing desalination and water reuse plants, as well as in the strategic planning of new plants.
- In reviewing cost considerations both CAPEX and OPEX should be considered equally important when analysing the feasibility and life cycle costs of desalination and water reuse plants. Operating costs can be significantly higher than anticipated (or understood) in relation to the initial capital costs.
- Various operating modes and scenarios should be considered when evaluating O&M costs, i.e. zero production mode, different production modes, etc. before considering mothballing of any plant.
- UF/RO membranes have an expected lifespan of five years and a maximum of seven after which they are normally replaced. The key factor in achieving an extended lifespan is the operating regime, as the plant should ideally, be run continuously. While frequent starting and stopping of the desalination or water reuse plant can minimise running costs, is not optimal for the membrane lifespan.

- It is recommended to run plants periodically during off-peak periods to maintain plant operational integrity. Scenario planning, treating the cause instead of the symptoms, etc. are important considerations.
- Social aspects in water reuse plants are vital to the successful acceptance and sustainability of these plants in the communities they service. Public engagement is a critical process in the planning of desalination and water reuse plants.
- It is recommended to further develop and populate the Royal HaskoningDHV in-house developed database to capture data from other plants not included in this study.
- It is recommended to further develop the database and costing models referenced in this study. Further collaboration with CD Swartz Water Utilisation Engineers is recommended to further develop the REUSECOST model and include the outputs/results in this report for various operating scenarios.
- It is recommended to further develop the database tools for base lining and predicting O&M costs for various operating scenarios and plants. This will assist the relevant authorities' with improved planning for O&M aspects associated with current, new or planned desalination and water reuse plants.

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APPENDIX A: DETAILED PHOTO SUMMARY WITH EQUIPMENT AND LAYOUT OF EACH PLANT

A1: MOSSEL BAY SWRO PLANT
Unit Processes & Associated Equipment

Aerial view of the plant

View of plant

Intake line and brine line (Brine line submerged)

Feed water from sea intake 900m offshore

Chemical conditioning & multi-media filtration

Seawater pump station (floor level 2 m+MSL)

A1: MOSSEL BAY SWRO PLANT
Unit Processes & Associated Equipment

Seawater pump station 4 x seawater pumps (3 duty, 1 standby)

Single pass seawater reverse osmosis (6 x 2.5 Mℓ/d)

Turbo energy recovery system
High pressure pump 40 bar

Product Water Pumps

Remineralisation by soda ash & calcium chloride, disinfection by chlorination

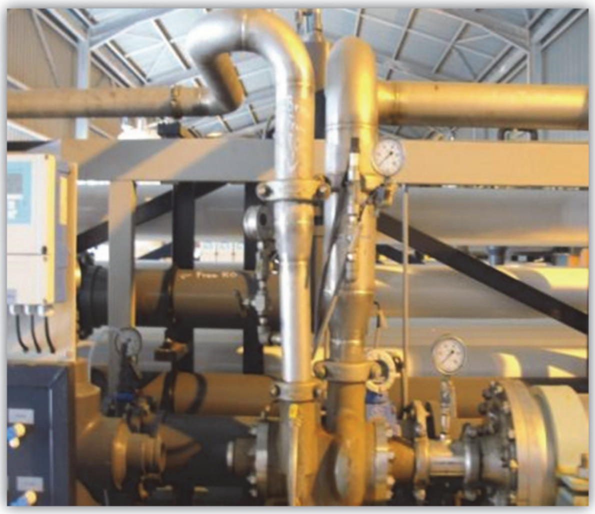
SMBS and Anti-scalant storage and dosing units

A1: MOSSEL BAY SWRO PLANT
Unit Processes & Associated Equipment

Six sand-filters

$FeCl_3$ Tank

RO intake and outlet pipework



1 of 2 CIP tanks – 1 per 3 RO membrane units

RO cartridge filters, pressure vessels and pipework

A1: MOSSEL BAY SWRO PLANT
Unit Processes & Associated Equipment

Two backwash pumps

Backwash water storage tank

Brine discharge to sea with diffuser 450m offshore

A2: SEDGEFIELD SWRO PLANT
Unit Processes & Associated Equipment

Overview of Sedgefield Desalination Plant

Feed water from beach wells

Cartridge filtration – Micro-filters (5 µm)

Pressure exchanger energy recovery system

A2: SEDGEFIELD SWRO PLANT
Unit Processes & Associated Equipment

Partial remineralisation by soda ash addition, disinfection by chlorination and blending with town water supply

Brine discharge by injection wells on beach

A2: SEDGEFIELD SWRO PLANT
Unit Processes & Associated Equipment

Anti-scalant dosing system

RO Train (1) with high pressure pump

RO Train (2) with high pressure pump

Pressure exchange recovery device

A3: ALBANY COAST SWRO PLANT
Unit Processes & Associated Equipment

Feed water from beach wells

Main intake well

Sand filtration for water from main intake well

Cartridge filtration

Single pass seawater reverse osmosis (1.4 Mℓ/d + 0.26 Mℓ/d)

Pressure exchanger energy recovery system (part 80%)

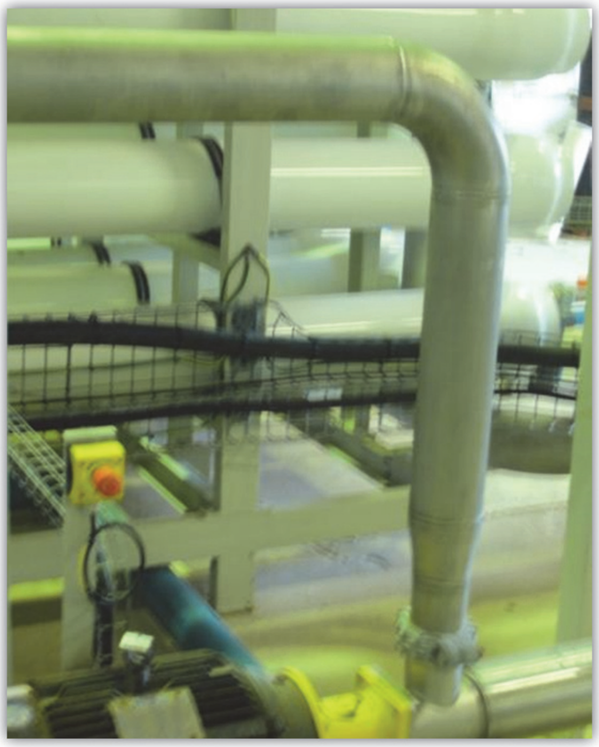
A3: ALBANY COAST SWRO PLANT
Unit Processes & Associated Equipment

Blending with other sources

Product water pumps

Brine discharge by open outlet to estuary

RO membranes intake pipe



Energy recovery unit

Filters

A3: ALBANY COAST SWRO PLANT
Unit Processes & Associated Equipment

RO units

Dosing chemicals Intake pumps

Dosing chemicals

CIP Tanks

Control room – PLC

A4: BEAUFORT WEST WATER RECLAMATION PLANT
Unit Processes & Associated Equipment

Re-Use Plant

Inlet works of water treatment plant

Trickling filter

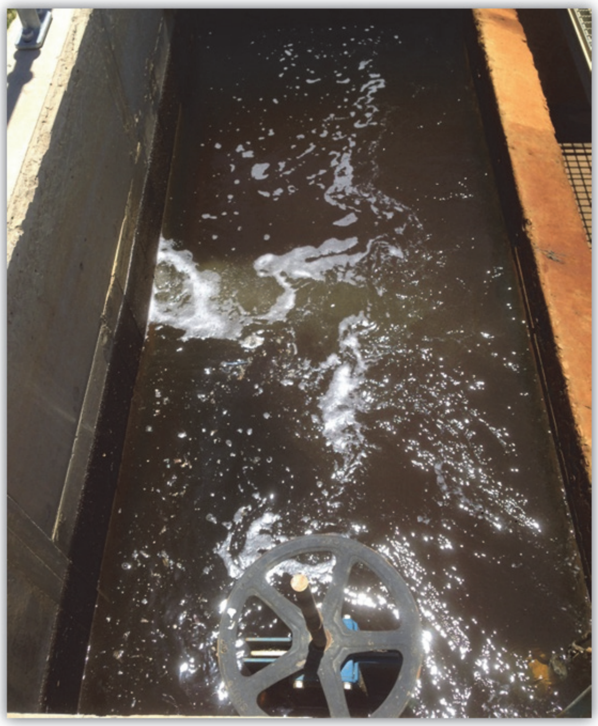
Splitter box

Final settling tanks

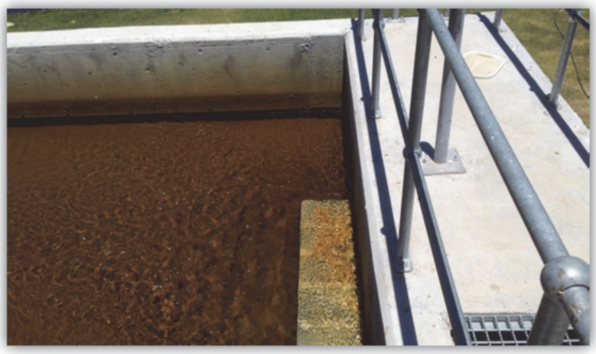
Maturation Dam

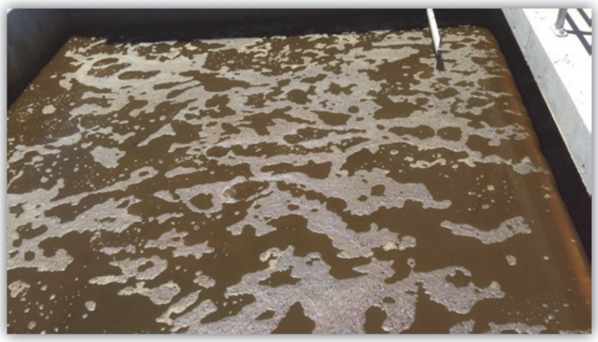
A4: BEAUFORT WEST WATER RECLAMATION PLANT
Unit Processes & Associated Equipment

Inlet channel to re-use plant



Rapid gravity sand filters





Raw water feed line to sand filers

CIP tanks

Product Water

A4: BEAUFORT WEST WATER RECLAMATION PLANT

Unit Processes & Associated Equipment

Inlet valve for raw water

RO trains

UF membranes

A5: GOREANGAB WATER RECLAMATION PLANT
Unit Processes & Associated Equipment

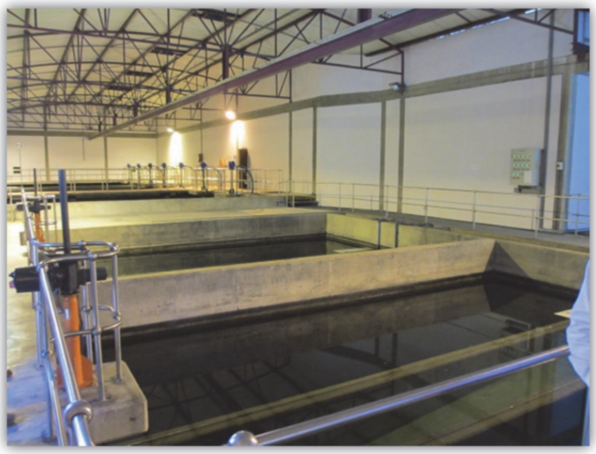
UF membranes

A5: GOREANGAB WATER RECLAMATION PLANT
Unit Processes & Associated Equipment

Product water pumps

A5: GOREANGAB WATER RECLAMATION PLANT
Unit Processes & Associated Equipment

BAC / GAC



GAC

Stabilisation

Backwash reservoir, water for cleaning the GAC, PAC and sand-filters

Ferric Chloride: day- and bulk tanks

A5: GOREANGAB WATER RECLAMATION PLANT
Unit Processes & Associated Equipment

1 of 2 inlet valves

Plant inlet: Intake of 850 m³/h

Pre-ozonation – Vent ozone destructor

1 of 2 Hydraulic jump: Ozonation foaming

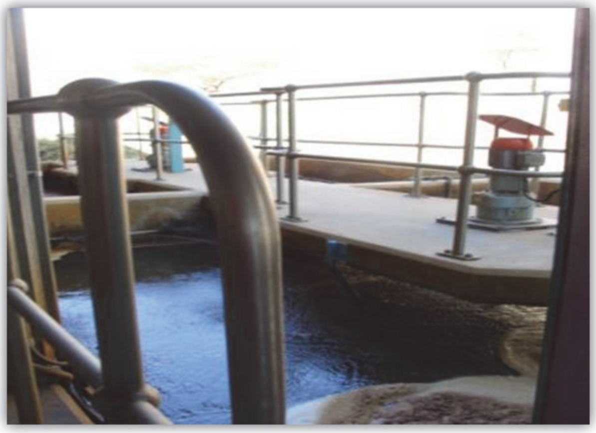
Polymer dosing

A5: GOREANGAB WATER RECLAMATION PLANT

Unit Processes & Associated Equipment

2x $FeCl_3$ day tanks (1 operational and 1 standby)

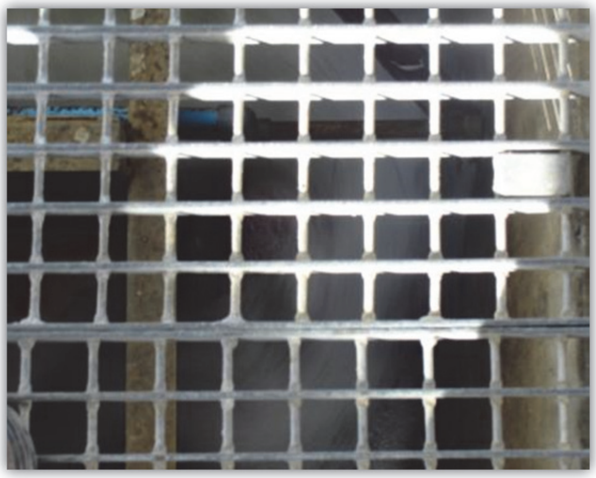
4x Flocculation and coagulation tanks



4x Dissolved air flotation (DAF) tanks

1 of 4 DAF tanks showing clear well channel

Potassium permanganate dosing to remove Fe, Mn

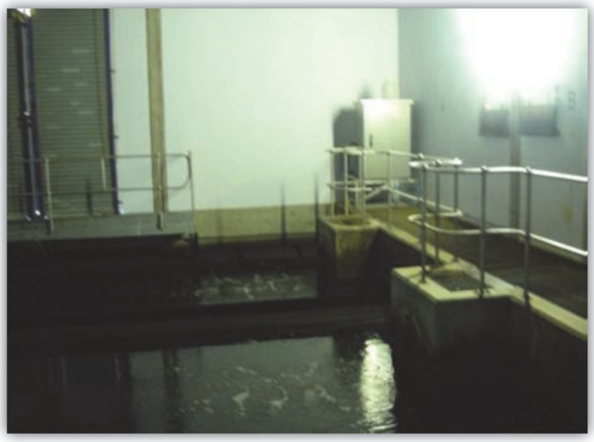


A5: GOREANGAB WATER RECLAMATION PLANT
Unit Processes & Associated Equipment

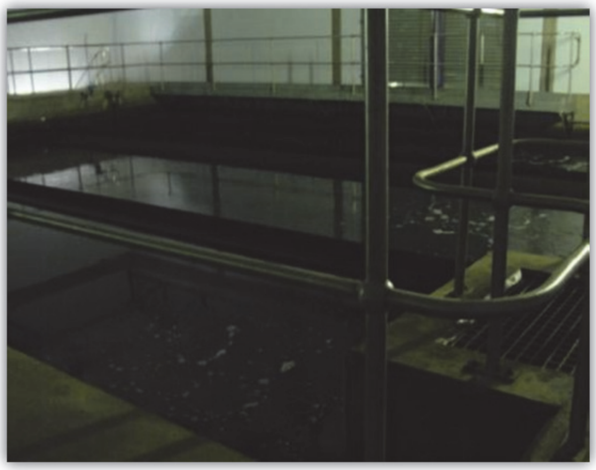
Valve between DAF and sand-filters:
Dosing of caustic soda to raise pH to 8.24 to decrease corrosion and to neutralise Fe and Mn

Pipe to sand-filters

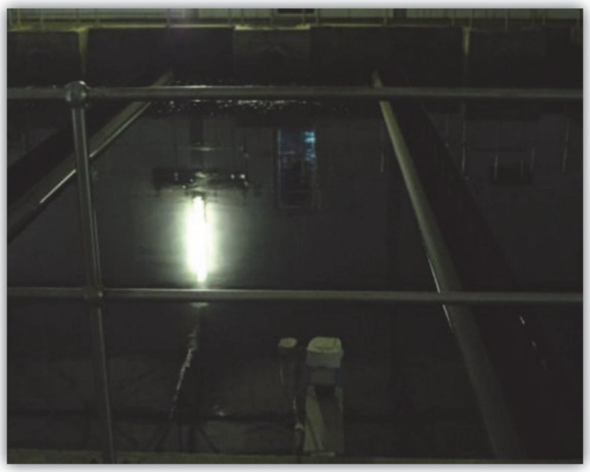
5x sand-filters: Dual media (hydroanthrocite and fine sand) and DAF composite sampler



Low light to prevent biomass growth



Sand-filter level sensor



Maintenance floor: Backwash pumps & compressors

A5: GOREANGAB WATER RECLAMATION PLANT
Unit Processes & Associated Equipment

Backwash pumps and compressors

Picture: Lahnsteiner, 2007

Picture: Norit

A6: GEORGE WASTEWATER RE-USE PLANT:
Unit Processes & Associated Equipment

Aerial view of UF Plant

UF feed pumps

UF membranes

Chemical dosing system: Sodium Hypochlorite

Chemical dosing system: Ferric Chloride

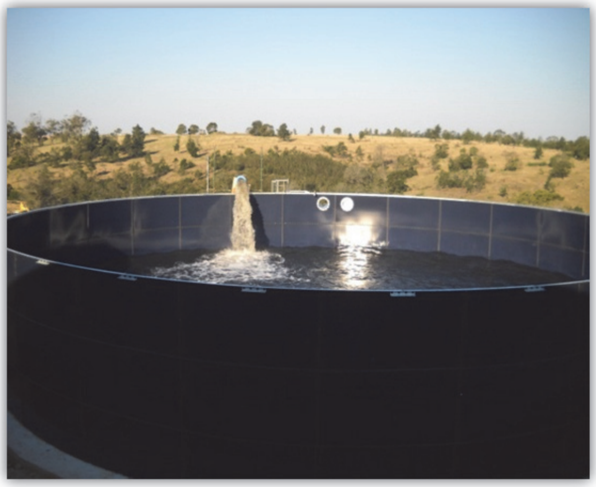
A6: GEORGE WASTEWATER RE-USE PLANT:
Unit Processes & Associated Equipment

Product water tank

Product water pumps

Treated Effluent Balancing Tanks

Membrane Filtrated Balancing Tank



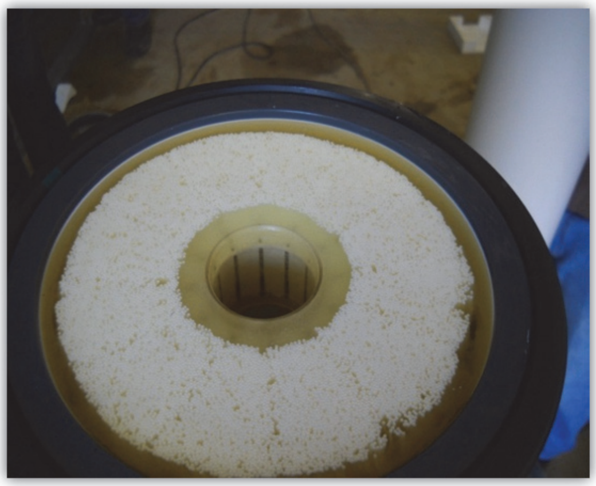
Screen Chamber
(Feed from Secondary Settling Tanks)

3 Pumps (2 duty and 1 standby) and
piping to feed UF trains

A6: GEORGE WASTEWATER RE-USE PLANT:
Unit Processes & Associated Equipment

6 UF Trains and Associated Piping

Membrane Detail



Chemical Dosing Tank Area

Ferric Chloride Dosing Station

MCC Room

MCC Room

A6: GEORGE WASTEWATER RE-USE PLANT:
Unit Processes & Associated Equipment

Backwash Recovery Tank and Pump Station

Filtrated Water Feed Pump Station
(3 Pumps, 2 on duty and 1 on standby)

A7: MOSSEL BAY WASTEWATER RE-USE PLANT
Unit Processes & Associated Equipment

CIP tank

UF membranes

RO trains

RO trains

Mossel Bay Wastewater Treatment Works

Mossel Bay WWTW Office Block

A7: MOSSEL BAY WASTEWATER RE-USE PLANT
Unit Processes & Associated Equipment

Maturation Pond with 24 hour retention

Maturation Pond with 24 hour retention

Two uptake pipes from 2 submersible pumps

Uptake pipe work valves

Uptake pipe work to coagulant unit process

Coagulant dosing

A7: MOSSEL BAY WASTEWATER RE-USE PLANT
Unit Processes & Associated Equipment

Impeller motor

Mixer blades for coagulation and flocculation

Disc Filters with Sprays: Screen up to 10 microns

Disc Filters with Sprays

Disc filters

Filtered water channel

A7: MOSSEL BAY WASTEWATER RE-USE PLANT
Unit Processes & Associated Equipment

Disc filters Housing unit

Disc filters Housing unit

Dosing storage drums

3000 l H2SO4

1000 ℓ anti-scalant storage tank

5000 ℓ coagulant storage tank

A7: MOSSEL BAY WASTEWATER RE-USE PLANT
Unit Processes & Associated Equipment

Automated backwash pumps

1 of 2 basket strainer housing units upfront the ultrafiltration units (UF)

Basket strainer

A7: MOSSEL BAY WASTEWATER RE-USE PLANT
Unit Processes & Associated Equipment

Basket strainer

Basket strainer

Ultrafiltration (UF) inlet and backwash pipework

1 of 2 UF units

UF product water to reverse osmosis (RO) unit 1

CIP filter unit

A7: MOSSEL BAY WASTEWATER RE-USE PLANT
Unit Processes & Associated Equipment

Dosing equipment for SMBS to neutralise hypochlorite

Second dosing equipment for dosing SMBS to neutralise biocide

CIP unit for both UF and RO

A7: MOSSEL BAY WASTEWATER RE-USE PLANT
Unit Processes & Associated Equipment

1st stage RO unit

Blending equipment: 2 pumps (1 duty/1 standby). Depending on conductivity, pumps are operated using actuating. Blending to prevent corrosion of metal pipe work

2 stage RO

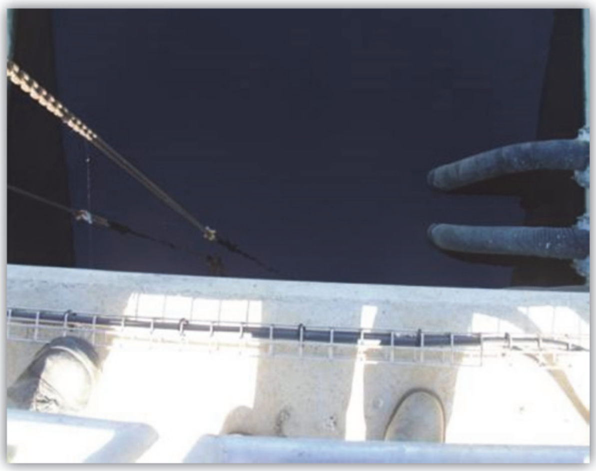
A7: MOSSEL BAY WASTEWATER RE-USE PLANT
Unit Processes & Associated Equipment

2 RO pumps (multi-stage). Max pressure of 12 bar each 128m³/h. Pressure maintained < 3 during CIP

1 of 2 high pressure lift pumps: Pumping to PetroSA

I beam

A7: MOSSEL BAY WASTEWATER RE-USE PLANT
Unit Processes & Associated Equipment



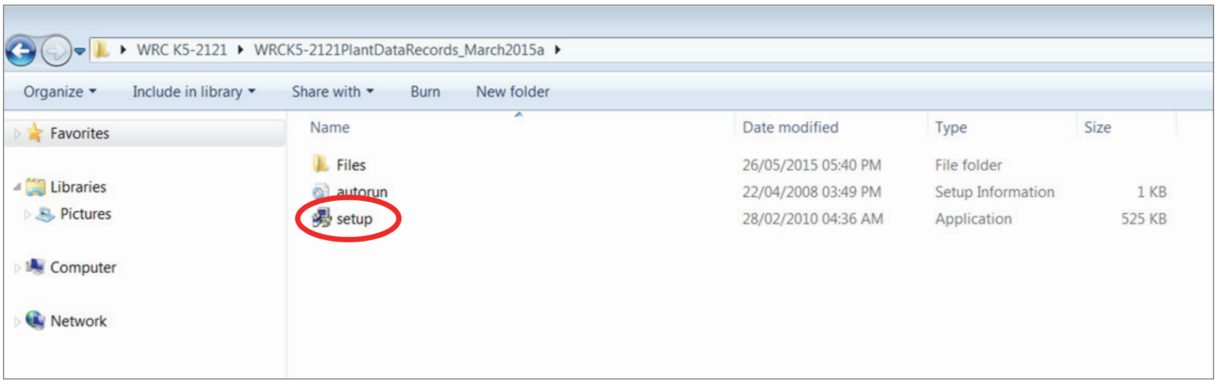
APPENDIX B: DATABASE FEATURES

The database was created in Microsoft Access 2010, however Access is not included in all Microsoft Office versions and the database was thus created to run independent from any Microsoft Office installation.

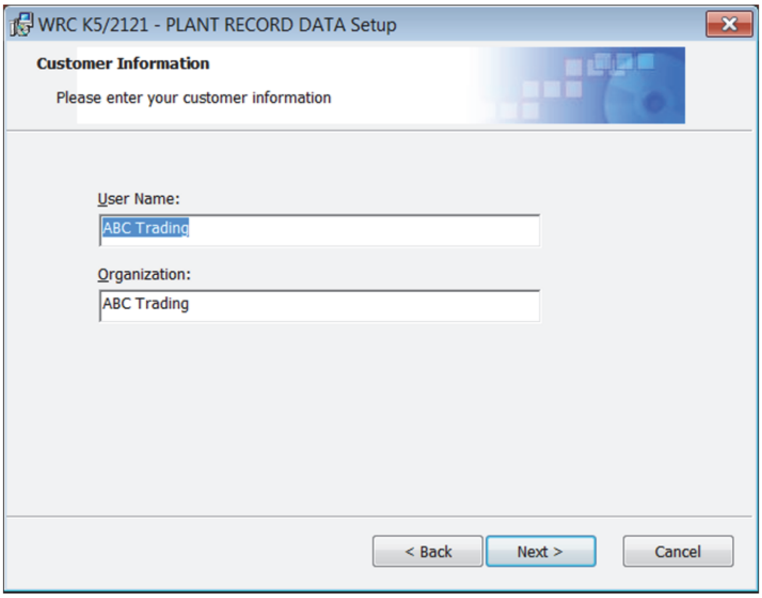
Please note that the installation of this database application may require Administrator rights to continue.

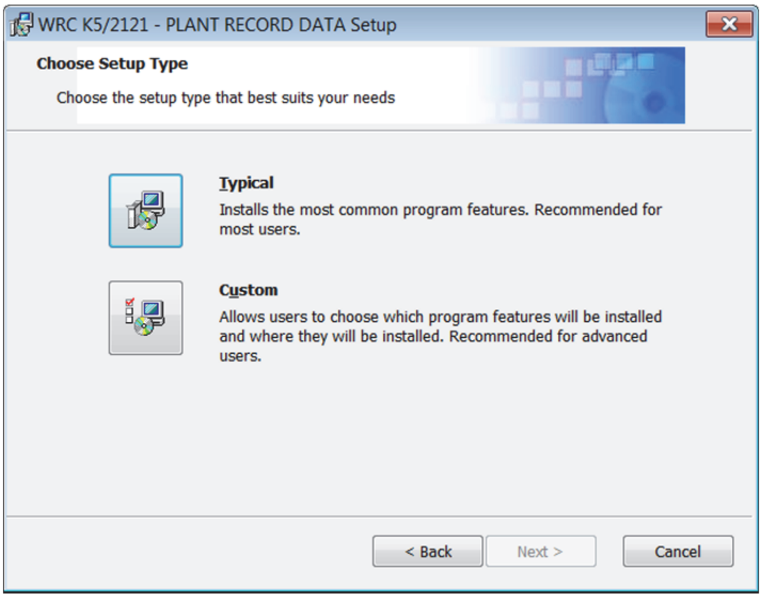
1 INSTALLATION OF DATABASE APPLICATION

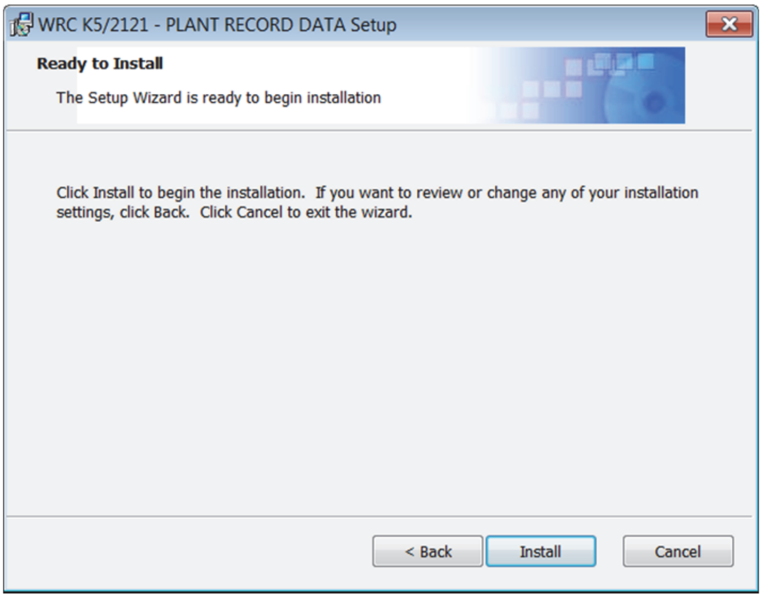
On the installation disk, double click on the `Setup` file and follow the instructions as shown below:

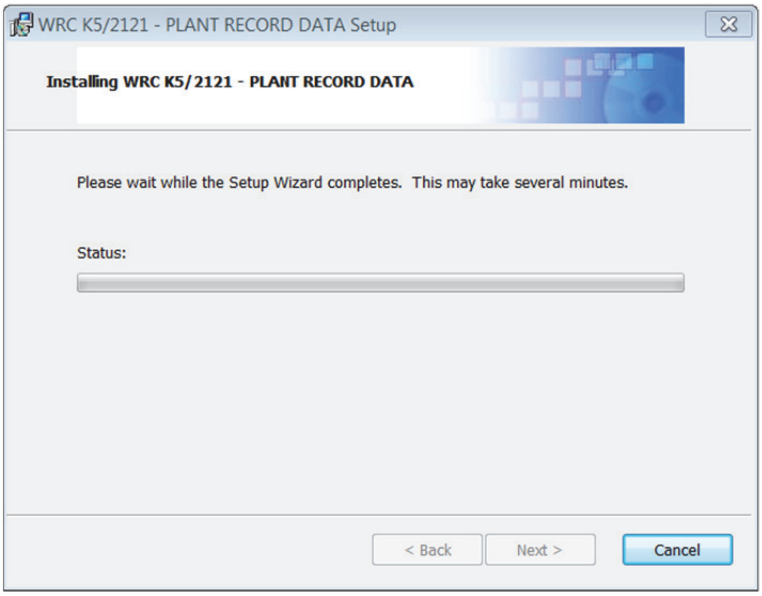



WRC K5/2121 - PLANT RECORD DATA License Agreement
End-User License Agreement
Please read the following license agreement carefully
End User License Agreement (EULA)
This software is provided "as is" without any guarantees or warranty. In connection with the software, the developer makes no warranties of any kind, either express or implied, including but not limited to warranties of merchantability, fitness for a particular purpose, of title, or of non-infringement of third party rights. Use of the software by a user is at the user's risk and is deemed acceptance of these terms.
I accept the terms in the License Agreement
I do not accept the terms in the License Agreement
< Back
Next >
Cancel


WRC K5/2121 - PLANT RECORD DATA Setup
Customer Information
Please enter your customer information
User Name:
ABC Trading
Organization:
ABC Trading
< Back
Next >
Cancel

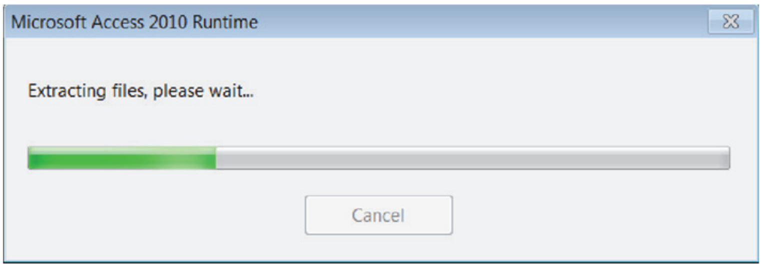

WRC K5/2121 - PLANT RECORD DATA Setup
Choose Setup Type
Choose the setup type that best suits your needs
Typical
Installs the most common program features. Recommended for most users.
Custom
Allows users to choose which program features will be installed and where they will be installed. Recommended for advanced users.
< Back
Next >
Cancel

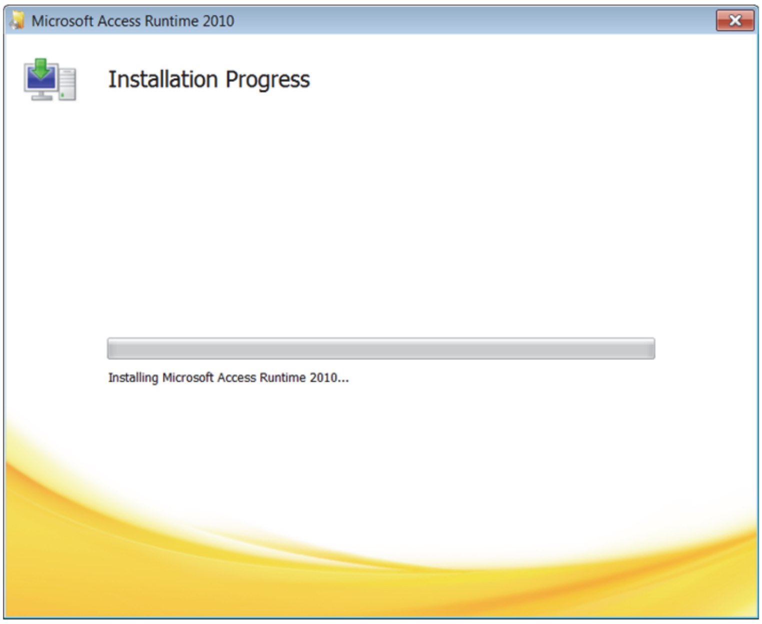


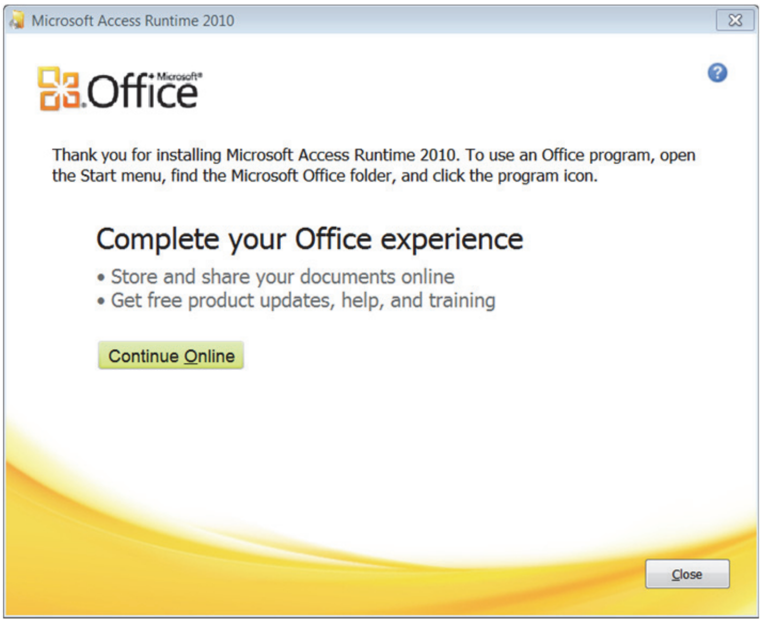


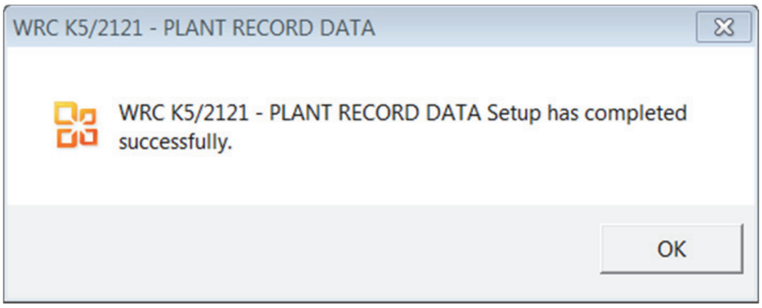
These steps concluded the installation of the database and, in the event that Microsoft Access is already installed, the Microsoft Access 2010 Runtime installation (as shown below can be cancelled and the setup will complete. However, in the absence of a Microsoft Access installation on your local computer, please run the Microsoft Access 2010 Runtime installation. This will allow the database application to run on your computer without having any Microsoft Office products installed on your computer.

Follow the instructions as shown below:









On completion of the installation, you will find a Desktop icon to access the database:

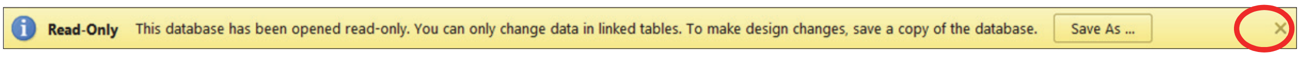
2 DATABASE FUNCTIONALITY

2.1 Database start up

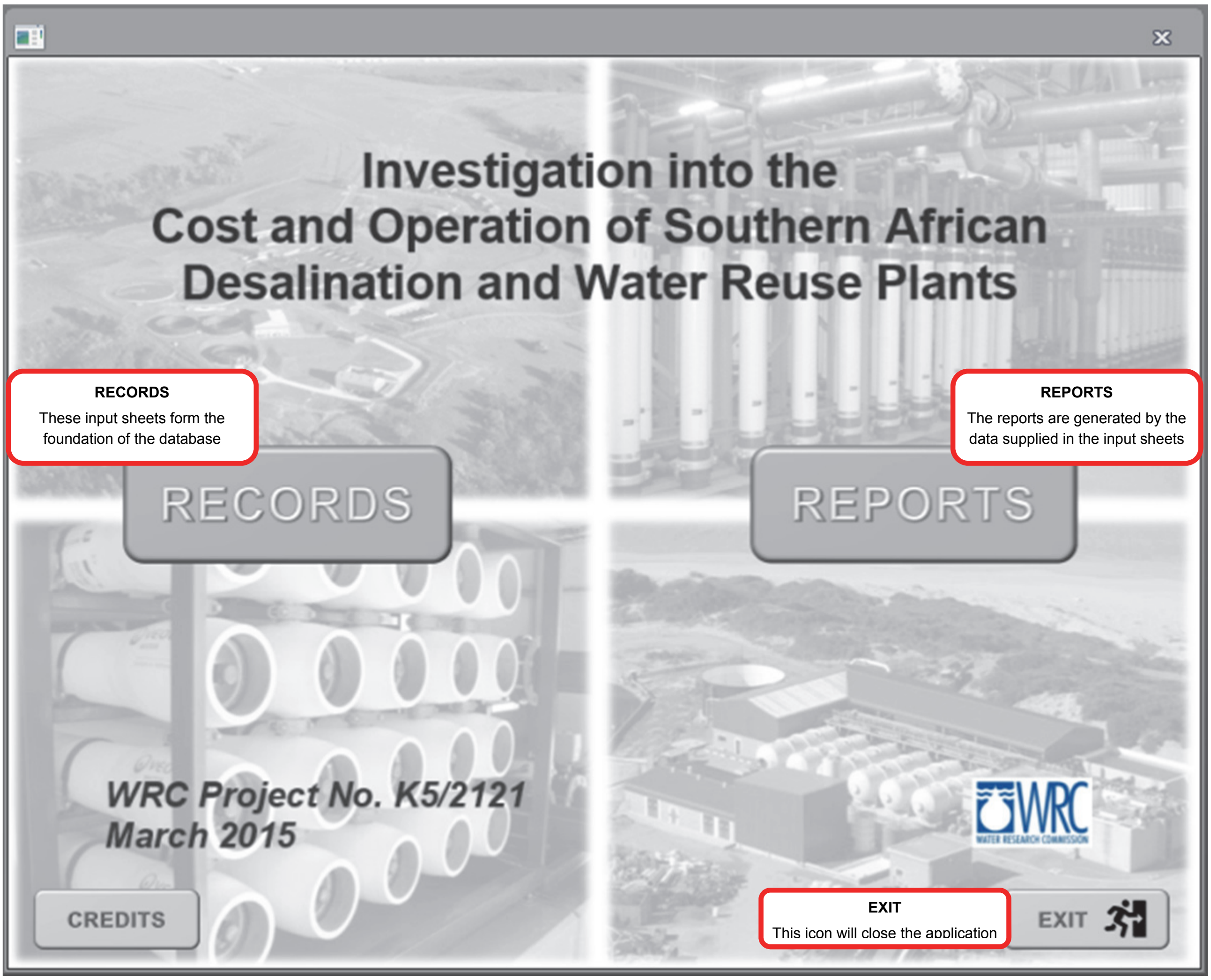
On opening of the database, the initial screen will provide a warning of a potential security threat, as the database includes macros. Please ignore the warning and click `Open`.

As stated on page 6 (section 2.2 of this volume), the data records of the seven plants will be made available for review only, therefore functionality is restricted to read only. Should you see the yellow bar at the top, please close the message `(X)` and continue to database content.

The `Save As` functionality has been disabled.

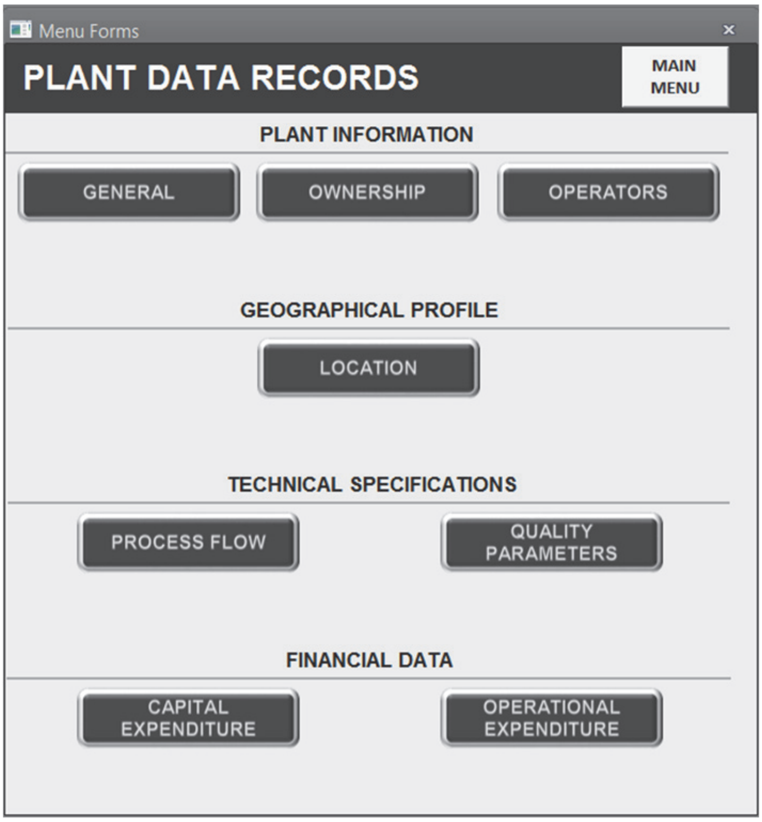


The Main Menu functionality is explained below:



2.2 Input sheets

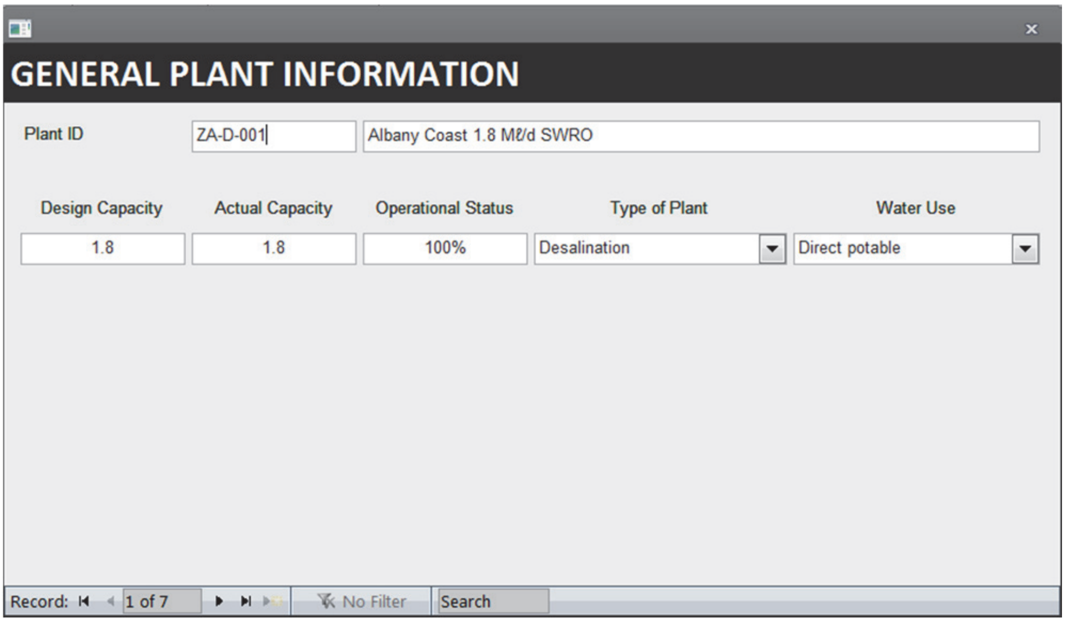
Once the user clicks on **RECORDS**, a sub-menu pop-up with links to the input sheets will open. To return to the Main Menu (a) at any time, please click on the **MAIN MENU** button.



The record input sheets are grouped into four sections, namely *Plant Information*, *Geographical Profile*, *Technical Specifications* and *Financial Data*.

2.2.1 Plant information

2.2.1.1 General plant information



2.2.1.2 *Plant Ownership*

PLANT OWNERSHIP

Plant	Albany Coast 1.8 Mℓ/d SWRO		
Plant Owner	Amatola Water	Main Landline	(043) 707 3700
Physical Address	6 Lancaster Road Vincent East London	Postal Address	Private Bag X3 Vincent East London

CONTACT INFORMATION

Name	Chris Nair	Phone No.	(082) 874 0173
E-mail	CNair@amatolawater.co.za		
Name	Sokunene George	Phone No.	(071) 869 5301
E-mail	sgeorge@amatolawater.co.za		

Record: 1 of 7 No Filter Search

2.2.1.3 *Plant Operators*

PLANT OPERATORS

Plant	Albany Coast 1.8 Mℓ/d SWRO		
Plant Operator	Amatola Water	Main Landline	(043) 707 3700
Physical Address	6 Lancaster Road Vincent East London	Postal Address	Private Bag X3 Vincent East London

CONTACT INFORMATION

Name	Andre Dyer	Phone No.	(083) 320 5261
E-mail	ADyer@amatolawater.co.za		
Name		Phone No.	
E-mail			

Record: 1 of 7 No Filter Search

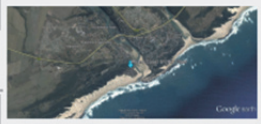
2.2.2 Geographical Profile

GEOGRAPHICAL PROFILE

Plant Name: Albany Coast 1.8 Mℓ/d SWRO

Town	Province	Country
Kenton-on-Sea	EC	South Africa
Latitude	**Longitude**	**Elevation (m)**
33° 41'27,65" S	26° 39'35,81" E	10.0

Add image



Record: 1 of 7 No Filter Search

2.2.3 Technical Specifications

2.2.3.1 Process Flow

PROCESS FLOW

Plant: Albany Coast 1.8 Mℓ/d SWRO

Description of process steps

PROCESS OVERVIEW
The Albany Coast water supply system, including the SWRO plant and nearby well fields, has a capacity of approximately 1.8 Mℓ/d RO and 1.2 Mℓ/d dune wells. The SWRO plant uses two feedwater sources: beach wells and brackish water abstracted from boreholes. The Diaz Cross Aquifer water is blended with the desalinated permeate, achieving the desired re-mineralisation naturally. The RO_{12} train features a higher throughput capacity and lower energy requirements, utilising a pressure exchanger and a turbine-based energy recovery system.
Other upgrades included the integration of micro filters (using 5 micron filter bags) for pre-treatment, chemical dosing systems and a clean-in-place system for the RO membranes.

SOURCE
Seawater is abstracted from beach wells located at the Bushman's River Estuary. Seawater is naturally filtered as it passes through the sand. Only water from the beach wells is treated by reverse osmosis. Brackish water is also abstracted from 7 wells in the sand dunes above the Diaz Cross Aquifer and pumped to the reservoir at Albany Seawater Treatment Plant where it is blended with desalinated seawater.

PRE-TREATMENT
The feedwater is pumped from the beach wells directly to a set of sand-filters and filtered for a second time before entering the RO plant. Raw water from the boreholes flows through a series of vertical chambers with filter bags and then into a 20 000 ℓ storage tank. The pre-filtered water then undergoes sand filtration, using a battery of horizontal sand filters for the new plant and a battery of vertical sand filters previously used for the older RO_1 plant. After sand filtration the water flows into a filtered water reservoir and is pumped via three (3) pumps through a final microfiltration step. Anti-scalant is dosed into the filtered water prior to entering the RO plant to prevent chemical scaling and lowered trans-membrane flux.

REVERSE OSMOSIS (RO)
The plant consists of two RO units with a capacity to produce up to 1.8 Mℓ/d. The equipment comprising the RO units consists of:
• Feedwater pumps and pipework;
• High pressure pump;

Record: 1 of 7 No Filter Search

2.2.3.2 Quality Parameters

QUALITY PARAMETERS

Plant: Albany Coast 1.8 Mℓ/d SWRO

	INTAKE WATER	TREATED WATER
pH	7.1	6.2
Total Phosphorus (mg P/ℓ)		
Potassium (mg/ℓ)		
Silica (mg/ℓ)		
Sodium (mg/ℓ)		
Strontium (mg/ℓ)		
Sulphate (mg/ℓ)		
TDS (mg/ℓ)	2 670	136
Temperature	19.3	22
Total Organic Carbon (mg/ℓ)		
TSS (mg/ℓ)		
Turbidity (NTU)	1.4	0.15

Record: 1 of 7 No Filter Search

2.2.4 *Financial Data*

2.2.4.1 *Capital Expenditure*

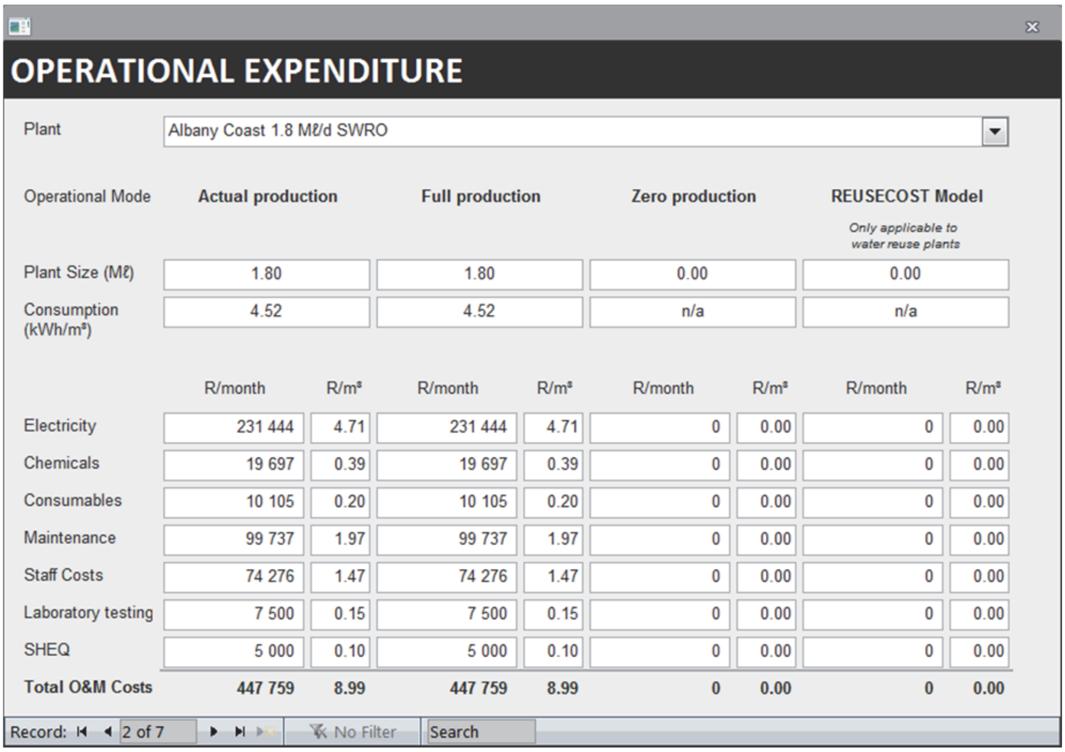
CAPITAL EXPENDITURE

Plant: Albany Coast 1.8 Mℓ/d SWRO

	Cost at time of construction	Cost at 2014/15 rates	Unit cost at 2014/15 rates (Rm/Mℓ/d)
PROJECT			
Professional fees	4 191 176	5 391 807	3.25
Environmental & specialist studies	0	0	0.00
Civil building & structures	1 955 882	2 516 177	1.52
Mechanical	0	0	0.00
Electrical, control & instrumentation	1 676 471	2 156 723	1.30
Bulk electricity	1 397 059	1 797 269	1.08
Monitoring & equipment testing	0	0	0.00
O&M Manual, training, etc.	0	0	0.00
INTAKE			
Intake	1 676 471	2 156 723	1.30
TREATMENT PLANT (PROCESS SPECIFIC)			
Pre-treatment	1 397 059	1 797 269	1.08
Membranes (UF/RO)	0	0	0.00
Dissolved Air Flotation (DAF)	0	0	0.00
RG Sand Filters	0	0	0.00
Ozone	0	0	0.00
Biological Activated Carbon (BAC)	0	0	0.00
Granular Activated Carbon (GAC)	0	0	0.00
UltraFiltration (UF)	0	0	0.00
Treatment plant (UF/RO)	13 132 353	16 894 330	10.18
DISCHARGE			
Outfall	1 397 059	1 797 269	1.08
Post-treatment	558 824	718 908	0.43
Waste treatment	0	0	0.00
Product pumpstation & pipelines	558 823	718 908	0.43
Product storage & pipework	0	0	0.00
Total Capital Expense	**27 941 176**	**35 945 383**	**21.65**

Record: 1 of 7 No Filter Search

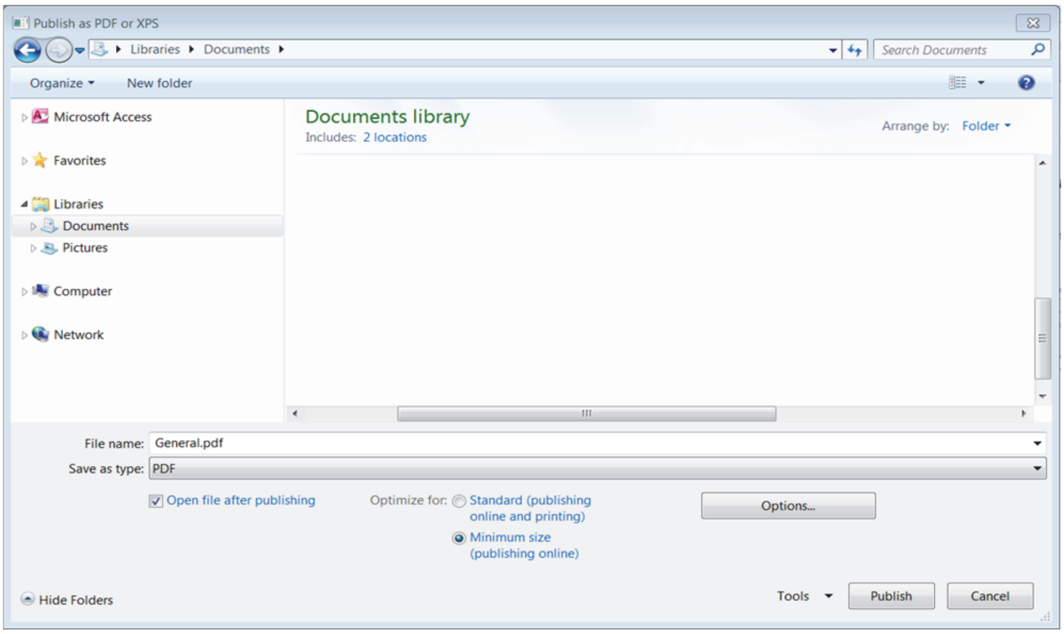
2.2.4.2 *Operational Expenditure*



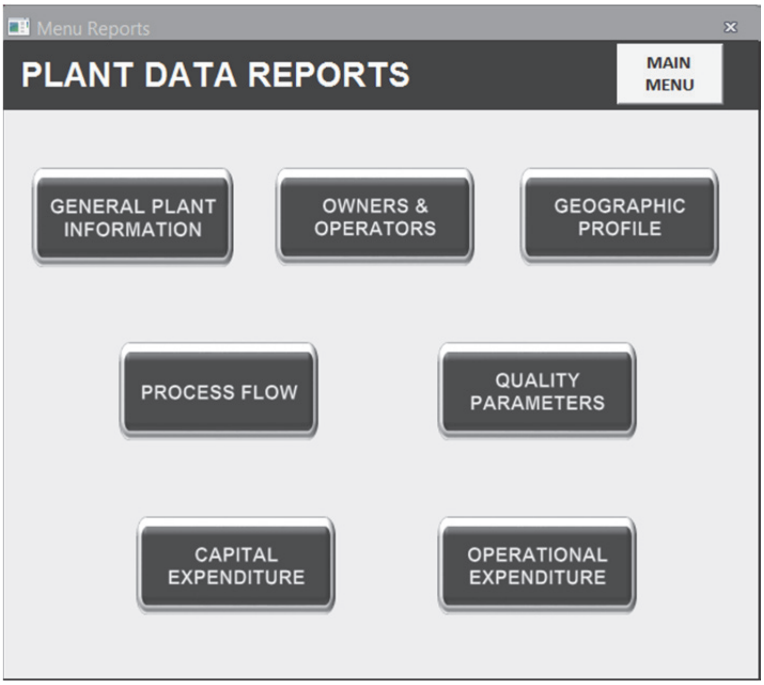
2.3 Reporting

Once the user clicks on **REPORTS**, a sub-menu pop-up with links to the reports will open. To return to the Main Menu (a) at any time, please click on the **MAIN MENU** button.

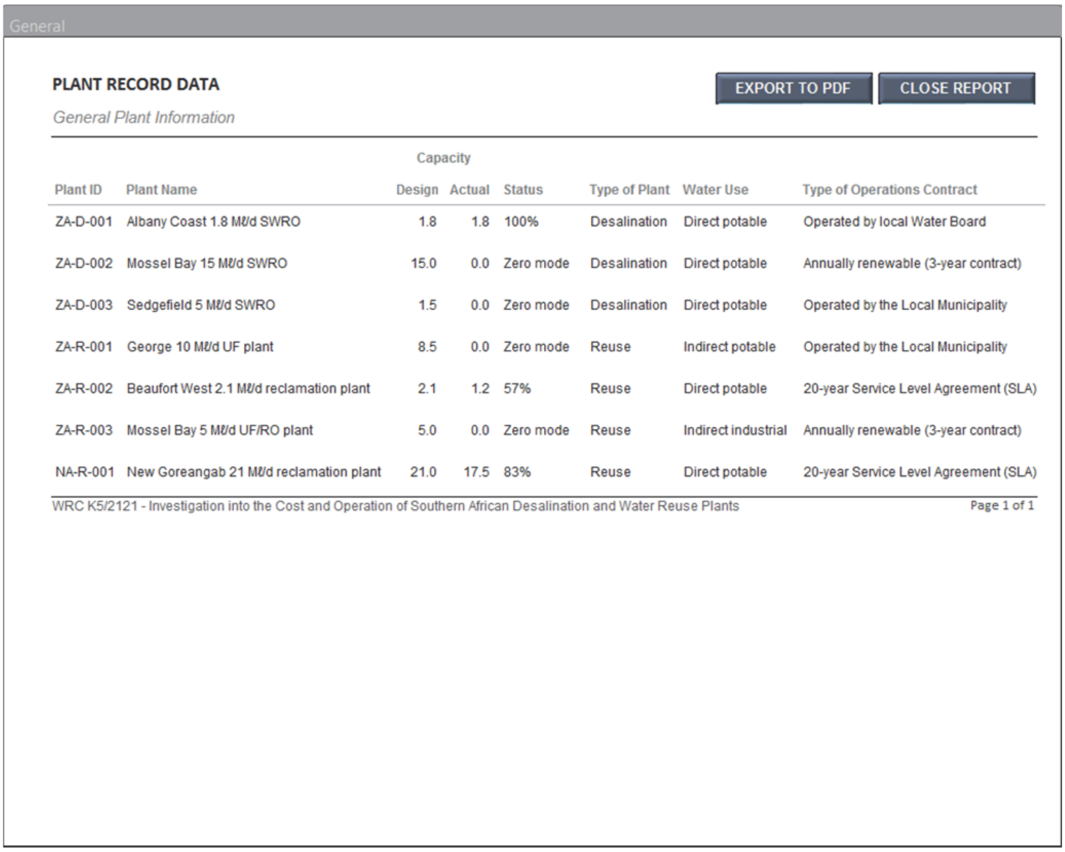
All the reports will be displayed on screen, with two buttons on the top right, providing the user with the option to **EXPORT TO PDF** or **CLOSE REPORT**. While these buttons are displayed during viewing mode, it will not be exported into the PDF file. When the **EXPORT TO PDF** option is selected, the following dialog box will open, with the default location in My Documents:



The reporting functionality is split in the same manner as the input sheets, with the relevant sub-menu popup linking to the reports.



2.3.1 General plant information



General

PLANT RECORD DATA

General Plant Information

EXPORT TO PDF CLOSE REPORT

		Capacity					
Plant ID	Plant Name	Design	Actual	Status	Type of Plant	Water Use	Type of Operations Contract
ZA-D-001	Albany Coast 1.8 Mℓ/d SWRO	1.8	1.8	100%	Desalination	Direct potable	Operated by local Water Board
ZA-D-002	Mossel Bay 15 Mℓ/d SWRO	15.0	0.0	Zero mode	Desalination	Direct potable	Annually renewable (3-year contract)
ZA-D-003	Sedgefield 5 Mℓ/d SWRO	1.5	0.0	Zero mode	Desalination	Direct potable	Operated by the Local Municipality
ZA-R-001	George 10 Mℓ/d UF plant	8.5	0.0	Zero mode	Reuse	Indirect potable	Operated by the Local Municipality
ZA-R-002	Beaufort West 2.1 Mℓ/d reclamation plant	2.1	1.2	57%	Reuse	Direct potable	20-year Service Level Agreement (SLA)
ZA-R-003	Mossel Bay 5 Mℓ/d UF/RO plant	5.0	0.0	Zero mode	Reuse	Indirect industrial	Annually renewable (3-year contract)
NA-R-001	New Goreangab 21 Mℓ/d reclamation plant	21.0	17.5	83%	Reuse	Direct potable	20-year Service Level Agreement (SLA)

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2.3.2 Plant owners and operators

OwnOp

PLANT RECORD DATA

EXPORT TO PDF CLOSE REPORT

Owners and Operators

Plant ID	Plant Name	Role	Owner	Main Landline	Contact 1	Phone No.	E-mail
ZA-D-001	Albany Coast 1.8 Mℓ/d SWRO	Owner	Amatola Water	(043) 707 3700	Chris Nair	(082) 874 0173	CNair@amatolawater.co.za
		Operator	Amatola Water	(043) 707 3700	Andre Dyer	(083) 320 5261	ADyer@amatolawater.co.za
ZA-D-002	Mossel Bay 15 Mℓ/d SWRO	Owner	Mosselbay Municipality	(044) 606 5000	Hendrik Schoeman	(044) 606 5274	hschoeman@mosselbay.gov.za
		Operator	VWS (Veolia)	(021) 871 1877	David Brown	(021) 871 1877	david.brown@veoliawater.com
ZA-D-003	Sedgefield 5 Mℓ/d SWRO	Owner	Knysna Municipality	(044) 302 6300	Rhoydon Parry	(044) 302 6332	rparry@knysna.gov.za
		Operator	Knysna Municipality	(044) 302 6300	Rhoydon Parry	(044) 302 6332	rparry@knysna.gov.za
ZA-R-001	George 10 Mℓ/d UF plant	Owner	George Municipality	(044) 801 9111	David Sauls	(044) 801 9393	david@george.org.za
		Operator	George Municipality	(044) 801 9111	David Sauls	(072) 875 0727	
ZA-R-002	Beaufort West 2.1 Mℓ/d reclamation plant	Owner	Beaufort West Municipality	(023) 414 8020	Louw Smit	(023) 414 8102	louw@beaufortwestmun.co.za
		Operator	Water & Wastewater Engineering	(021) 880 1829	Pierre Marais	(082) 870 1988	pierre@wastewater.co.za
ZA-R-003	Mossel Bay 5 Mℓ/d UF/RO plant	Owner	Mosselbay Municipality	(044) 606 5000	Hendrik Schoeman	(044) 606 5274	hschoeman@mosselbay.gov.za
		Operator	VWS (Veolia)	(021) 871 1877	David Brown	(021) 871 1877	david.brown@veoliawater.com
NA-R-001	New Goreangab 21 Mℓ/d reclamation plant	Owner	Windhoek Municipality	(061) 290 2690	Kosmas Nikodemus	(061) 290 3469	Kosmas.Nikodemus@windhoekcc.org.na
		Operator	Wingoc	(061) 272 138	John Esterhuizen	(061) 272 138	John@wingoc.com.na

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2.3.3 Geographical Profile

GeoProfile

PLANT RECORD DATA

EXPORT TO PDF CLOSE REPORT

Geographic Profile

Plant ID	Plant Name	Town	Province	Country	Latitude	Longitude	Elevation (m)
ZA-D-001	Albany Coast 1.8 Mℓ/d SWRO	Kenton-on-Sea	EC	South Africa	33° 41'27,65" S	26° 39'35,81" E	10.0
ZA-D-002	Mossel Bay 15 Mℓ/d SWRO	Mossel Bay	WC	South Africa	34° 09'01,31" S	22° 06'33,33" E	14.0
ZA-D-003	Sedgefield 5 Mℓ/d SWRO	Sedgefield	WC	South Africa	34° 01'58,62" S	22° 48'03,68" E	17.0
ZA-R-001	George 10 Mℓ/d UF plant	George	WC	South Africa	34° 00'23,57" S	22° 27'51,00" E	188.0
ZA-R-002	Beaufort West 2.1 Mℓ/d reclamation plant	Beaufort West	WC	South Africa	32° 22'46,22" S	22° 35'16,04" E	830.0
ZA-R-003	Mossel Bay 5 Mℓ/d UF/RO plant	Mosselbay	WC	South Africa	34° 06'36,49" S	22° 05'59,60" E	9.0
NA-R-001	New Goreangab 21 Mℓ/d reclamation plant	Windhoek	MP	Namibia	22° 31'54,22" S	17° 01'46,89" E	1 601.0

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2.3.4 Process Flow

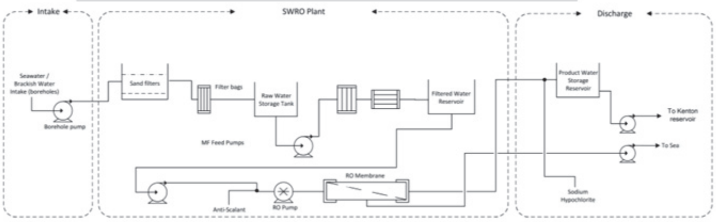
Process

PROJECT DATA RECORDS

Process Flow

EXPORT TO PDF CLOSE REPORT

Albany Coast 1.8 Mℓ/d SWRO



PROCESS OVERVIEW

The Albany Coast water supply system, including the SWRO plant and nearby well fields, has a capacity of approximately 1.8 Mℓ/d RO and 1.2 Mℓ/d dune wells. The SWRO plant uses two feedwater sources: beach wells and brackish water abstracted from boreholes. The Diaz Cross Aquifer water is blended with the desalinated permeate, achieving the desired re-mineralisation naturally. The $RO_{1,2}$ train features a higher throughput capacity and lower energy requirements, utilising a pressure exchanger and a turbine-based energy recovery system.
Other upgrades included the integration of micro filters (using 5 micron filter bags) for pre-treatment, chemical dosing systems and a clean-in-place system for the RO membranes.

SOURCE

Seawater is abstracted from beach wells located at the Bushman's River Estuary. Seawater is naturally filtered as it passes through the sand. Only water from the beach wells is treated by reverse osmosis. Brackish water is also abstracted from 7 wells in the sand dunes above the Diaz Cross Aquifer and pumped to the reservoir at Albany Seawater Treatment Plant where it is blended with desalinated seawater.

PRE-TREATMENT

The feedwater is pumped from the beach wells directly to a set of sand-filters and filtered for a second time before entering the RO plant. Raw water from the boreholes flows through a series of vertical chambers with filter bags and then into a 20 000 ℓ storage tank. The pre-filtered water then undergoes sand filtration, using a battery of horizontal sand filters for the new plant and a battery of vertical sand filters previously used for the older RO_1 plant. After sand filtration the water flows into a filtered water reservoir and is pumped via three (3) pumps through a final microfiltration step. Anti-scalant is dosed into the filtered water prior to entering the RO plant to prevent chemical scaling and lowered trans-membrane flux.

REVERSE OSMOSIS (RO)

The plant consists of two RO units with a capacity to produce up to 1.8 Mℓ/d. The equipment comprising the RO units consists of:
• Feedwater pumps and pipework;
• High pressure pump;
• Energy recovery system (installed by Veolia) for $RO_{1,2}$ and RO_3;
• RO pressure vessels with membrane units and high pressure pipework;

2.3.5 Quality Parameters

Parameters

PLANT DATA RECORDS

Quality Parameters

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Albany Coast 1.8 Mℓ/d SWRO

PARAMETER	INTAKE WATER	TREATED WATER
Specifications		
Alkalinity (mg/ℓ)		
Aluminium (mg/ℓ)		
Ammonia (mg/ℓ)		
Barium (mg/ℓ)		
Boron (mg/ℓ)		
Cadmium (mg/ℓ)		
Calcium (mg/ℓ)		
Chloride (mg/ℓ)		
Chlorine (ppm)		0.53
Chromium (mg/ℓ)		
COD (mg/ℓ) - dichromate		
Colour (mg/ℓ Pt)		
Conductivity (mS/m)	41 300	160
Copper (mg/ℓ)		
Cryptosporidium (per 100 mℓ)		
DOC (mg/ℓ)		
E Coli (per 100 ml)		
Faecal Coliforms (per 100 mℓ)		
Fluoride (mg/ℓ)		
Giardia (per 100 mℓ)		
Iron (mg/ℓ)		

2.3.6 Capital Expenditure

Capex

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Capital Expenditure

	Albany Coast 1.8 Mℓ/d SWRO		
	Base Cost (at time of construction)	Estimated Current Cost 2014/15 Rates	Est. Unit Cost (Rm/Mℓ/day) 2014/15 Rates
PROJECT			
Professional Fees	4 191 176.47	5 391 807.00	3.25
Environmental and Specialist Studies	0.00	0.00	0.00
Civil building and structures	1 955 882.30	2 516 177.00	1.52
Mechanical	0.00	0.00	0.00
Electrical, Control and Istrumentation	1 676 470.59	2 156 723.00	1.30
Bulk Electricity	1 397 058.80	1 797 269.00	1.08
Monitoring and equipment testing	0.00	0.00	0.00
O&M Manual, training, etc.	0.00	0.00	0.00
INTAKE			
Intake	1 676 470.59	2 156 723.00	1.30
TREATMENT PLANT			
Pre-treatment	1 397 058.80	1 797 269.00	1.08
Membranes	0.00	0.00	0.00
Dissolved Air Flotation (DAF)	0.00	0.00	0.00
RG Sand Filters	0.00	0.00	0.00
Ozone	0.00	0.00	0.00
Biological Activated Carbon (BAC)	0.00	0.00	0.00

2.3.7 Operational Expenditure

Opex

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Operational Expenditure

Albany Coast 1.8 Mℓ/d SWRO

Operational Mode	Actual Production		Full Production		Zero Production		REUSECOST Model	
Size (Mℓ)	1.80		1.80		0.00		0.00	
Energy Consumption (kWh/m³)	4.52		4.52		n/a		n/a	
	R/month	R/m³	R/month	R/m³	R/month	R/m³	R/month	R/m³
Electricity	231 444	4.71	231 444	4.71	0	0.00	0	0.00
Chemicals	19 697	0.39	19 697	0.39	0	0.00	0	0.00
Consumables	10 105	0.20	10 105	0.20	0	0.00	0	0.00
Maintenance	99 737	1.97	99 737	1.97	0	0.00	0	0.00
Staff Costs	74 276	1.47	74 276	1.47	0	0.00	0	0.00
Lab Analysis	7 500	0.15	7 500	0.15	0	0.00	0	0.00
SHEQ	5 000	0.10	5 000	0.10	0	0.00	0	0.00
MONTHLY COST	447 759	8.99	447 759	8.99	0	0.00	0	0.00

Mossel Bay 15 Mℓ/d SWRO

Operational Mode	Actual Production		Full Production		Zero Production		REUSECOST Model	
Size (Mℓ)	0.00		15.00		0.00		0.00	
Energy Consumption (kWh/m³)	n/a		4.39		n/a		n/a	
	R/month	R/m³	R/month	R/m³	R/month	R/m³	R/month	R/m³
Electricity	100 000	0.00	1 539 311	3.37	100 000	0.00	0	0.00
Chemicals	20 000	0.00	492 966	1.08	20 000	0.00	0	0.00

APPENDIX C: DATABASE

AVAILABLE ON ENCLOSED CD