Decision-Support Model for the Selection and Costing of Direct Potable Reuse Systems from Municipal Wastewater

Report to the
Water Research Commission

by

CD Swartz[1], CJ Coomans[1], HP Müller[2], JA du Plessis[2], W Kamish[2]
[1]Chris Swartz Water Utilization Engineers
[2]Stellenbosch University

WRC Report No. 2119/1/14
ISBN 978-1-4312-0543-1

April 2014

Obtainable from

Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

This report contains a CD at the back with the following:

- A REUSECOST Costing Model
- A REUSEDSM model

EXECUTIVE SUMMARY

Numerous options are available when Water Supply Authorities (WSAs), the Department of Water Affairs (DWA), planners and funders (such as the Development Bank of Southern Africa (DBSA)) consider water reuse to improve water source surety (and sustainability) or make provision for water-scarce periods. Sufficient information on the options is often not readily available to those wishing to make an informed selection of the best options for their specific situation. This difficult to obtain information comprises technical, costing, energy and environmental data. Even if the information is eventually obtained, comparison of the best options is mostly not feasible or effective, because of the differences in priorities assigned to the multitude of factors making up the selection criteria. There was therefore a need for a decision-support model (DSM) for municipalities and water boards to identify, evaluate, compare, and select appropriate water reclamation and reuse options which can produce sufficient quantities of safe drinking water from available secondary treated wastewater sources.

Because the cost of reuse schemes forms one of the main selection criteria, there was also a need for more comprehensive reuse costs to inform the development of the DSM. The guide therefore included the development of a reuse costing model, REUSECOST.

The aims of the DSM are to collate existing expertise and information for planning and implementation of potable water supply and direct potable reuse projects, and to provide a decision-support system in the form of a spreadsheet-based, multi-criteria decision support model (named REUSEDSM).

The project focussed on direct potable reuse as a water supply option to augment conventional water sources in water scarce areas. While many of the selection criteria considered in developing the REUSEDSM decision support model could equally apply and be used for evaluating indirect potable reuse options, the indirect reuse schemes were not considered due to the additional drivers and considerations that are involved, such as receiving water quality management (dam, river or aquifer), environmental and institutional aspects, to name but a few. This was beyond the scope of this project.

In developing the decision support and costing models, the raw water feed to the water reclamation plants was limited to secondary treated effluent from municipal domestic wastewater treatment plants. In terms of feed water quality, mine effluent and industrial effluents were therefore excluded. [It should be noted that although industrial effluent *per se* as a feed source to a water reclamation plant is excluded in this report, municipal wastewater treatment plant effluents may contain complex industrial components which will have a significant effect on the selection of water reclamation treatment processes].

The REUSEDSM was presented to the South African water sector at two technology transfer workshops in Pretoria and Stellenbosch during January 2014.

ACKNOWLEDGEMENTS

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

Reference Group	Affiliation
Dr N Kalebaila	Water Research Commission (Chairperson)
Dr A van Niekerk	Golder and Associates
Ms M Krüger	Midvaal Water
Mr C van der Walt	CSV Consulting Engineers
Mr P Thompson	Umgeni Water
Ms P Maduray	Umgeni Water
Prof F Schutte	Consultant
Dr G Offringa	GO Water Management
Mr R Brown	Drakenstein Municipality
Prof C Buckley	University of KwaZulu-Natal
Prof SJ van Vuuren	University of Pretoria
Mr S Victor	Ikusasa Water

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 co-operation of a number of individuals and institutions. The authors therefore wish to record their sincere thanks to the following:

- Ms Lauren Kidgell and Mr Wesley Cullum, students from the Civil Engineering Department of the Stellenbosch University, for their valuable research on costing and selection of water reuse schemes as part of their scripts for the Department
- Mr Jürgen Menge (then from the City of Windhoek) for arranging a workshop and meetings at the Gammams Wastewater Treatment Plant and New Goreangab Water Reclamation Plant in Windhoek, Namibia
- Mr Aldu Cornelissen from the department of Knowledge Management and Decision-Making of the Stellenbosch University for guidance and support in the learning and application of the Parmenides Eidos programme
- Planning and operational personnel of the various water boards in the country for operational costing data
- Engineers from Consulting Engineering companies for their valuable information and costing data.

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ACRONYMS & ABBREVIATIONS

AOP	Advanced oxidation processes
ASR	Aquifer storage and recovery
AWT	Advanced water treatment
BDS	Blue Drop system
COD	Chemical oxygen demand
DAF	Dissolved air flotation
DBP	Disinfection by-product
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DPR	Direct potable reuse
DWA	Department of Water Affairs
EDC	Endocrine disrupting compounds
EPA	U.S. Environmental Protection Agency
ESB	Engineered storage buffer
GAC	Granular activated carbon
GWRP	Goreangab water reclamation plant
GWRS	Groundwater replenishment system
IPR	Indirect potable reuse
NWRS	National water resources strategy
PPCP	Pharmaceuticals and personal care product
QA	Quality assurance
QC	Quality control
RO	Reverse osmosis
TSS	Total suspended solids
UF	Ultrafiltration
WHO	World health organisation
WRC	Water service provider
WSA	Water supply authority
WSP	Water Research Commission

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

Water Service Authorities (WSAs) in South Africa currently face a challenge with sustainable supply of sufficient quantities of good quality potable water to the population, due to the highly variable availability of raw water. This is mainly due to changing weather patterns, resulting in increased droughts (spatially and temporally) and flooding events. To address the raw water shortages, WSAs are increasingly investigating alternative raw water resources, of which reclamation and reuse (from treated wastewater) and desalination (both brackish and seawater) are the most important.

In 2008, DWA commenced with a nationwide programme to develop water reconciliation strategies for all towns across the country. The overall objective of the studies was to provide first-order water availability and water requirement reconciliation strategies for all towns and villages in South Africa (DWA, 2009b). The studies were undertaken from a water-resource perspective that took into consideration the overall scarcity of water in South Africa and the high cost of water transfer. The recommendations provide a list of the suitable interventions to address any current or future water supply shortfalls. In most instances water conservation and water demand management and the development of local surface and groundwater resources were the most feasible options to meet any current or projected future water supply shortfalls. However, the studies also indicate the need and potential for reuse of secondary treated wastewater for potable purposes, which is valuable for undertaking strategic planning on a national and regional basis for future drinking water supply.

The possibility for reuse of water is compromised by the poor state of most wastewater treatment works (WWTWs), and although water reuse needs to be considered for future water supply, the reality in most municipalities is that the WWTWs cannot produce the required water quality standard at a reliable level of confidence. Hence, upgrading of the existing infrastructure together with the introduction of proper O&M measures and management oversight are required to ensure a sustainable and safe water supply.

1.2 PROJECT OBJECTIVE AND AIMS

The overall objective of this project is to provide decision-makers with tools to compare options for water reuse schemes. The tools are based on a number of drivers, such as technical, water quality, costing, environmental, social and cultural aspects. More specifically, the aims of the model are to collate existing expertise and information for planning and implementation of potable water supply and direct potable reuse projects, and to provide decision-support guidelines and methodologies in the form of a spreadsheet-based, multi-criteria decision support model. This will enable municipalities to identify, evaluate, compare, and select appropriate options for water reclamation and reuse. The aims of the project are as follows:

1. Establish what the current status of drinking water supply in South Africa
2. Draw up a guidelines document on the costing and selection of water reclamation (from secondary treated wastewater) technologies to assist water supply authorities when considering or planning water reclamation or wastewater reuse plants.
3. Extend the water costing model, WATCOST, which is currently being developed for water treatment plants, to also include water reclamation plants.
4. Develop a decision-support model for the selection and costing of water reclamation technologies
5. Produce a final report that provides details on the methodology that was used in developing the decision support model, and in particular on the application of a decision support model.

1.3 SCOPE AND LIMITATIONS

The project focussed on direct potable reuse as a water supply option to augment conventional water sources in water scarce areas. While many of the selection criteria considered in developing the water reuse decision support model (REUSEDSM) could equally apply and be used for evaluating indirect potable reuse options, the indirect reuse schemes were not considered due to the additional drivers and considerations that are involved, such as receiving water quality management (dam, river or aquifer), environmental and institutional aspects, to name but a few. This was beyond the scope of this project.

In addition, in developing the decision support and costing models, the raw water feed to the water reclamation plants were limited to secondary treated effluent from municipal domestic wastewater treatment plants. In terms of feed water quality, mine effluent and industrial effluents were therefore excluded.

1.4 LAY-OUT OF THE REPORT

The scope and lay-out of the report is summarised in the table below.

BACKGROUND, INTRODUCTION AND OBJECTIVES	The background presents the need for guidelines on costing and selection of water reclamation systems. This is preceded by a section on definitions of reuse concepts and terminology that are used, and the specific objectives of the guidebook.	Chapter 1
WATER QUALITY ASPECTS	The feed water quality and its important role in the selection and performance of reuse treatment processes are described in this section. Final water quality considerations are also presented in some detail.	Chapter 2 SECTION 2.2
OVERVIEW OF WATER RECLAMATION TECHNOLOGIES AND PROCESS CONFIGURATIONS	This section provides an overview of treatment processes and technologies that are used in water reclamation, as well as process configurations that have been applied at a number of reclamation schemes internationally.	Chapter 2 SECTION 2.3
ENVIRONMENTAL CONSIDERATIONS AND RESIDUALS MANAGEMENT	The very important aspects of environmental impact of water reclamation and reuse projects and environmental legislation are discussed. Information is also provided on the treatment and disposal of plant residuals, and in particular the disposal of brine streams.	Chapter 2 SECTION 2.3
OPERATION AND MAINTENANCE ASPECTS	Operations and maintenance aspects of water reuse plants are presented, with specific emphasis on operational and compliance monitoring.	Chapter 2 SECTION 2.5
SOCIAL AND INSTITUTIONAL ASPECTS	This section summarises important aspects relating to the social perspective of water reuse projects, in particular with respect to public acceptance. It also reviews the relevant institutional aspects in water reuse.	Chapter 2 SECTION 2.6
COSTING CONSIDERATIONS	In this section a number of cost influencing factors are described, together with costing elements and criteria. Cost comparisons with desalination plants and conventional treatment plants are also provided.	Chapter 2 SECTION 2.7
COSTING OF WATER RECLAMATION TECHNOLOGIES	As one of the focus points of this report, a model for estimating costs of water reuse schemes was developed. The REUSECOST model is presented in this section in a step-by-step sequence.	Chapter 3
DECISION SUPPORT MODEL FOR SELECTION OF WATER REUSE SYSTEMS	Together with the section on costing, the selection of water reclamation and reuse technologies and alternatives forms the main focus of this report. This section describes and demonstrates the REUSEDSM decision-support model.	Chapter 4
FURTHER DEVELOPMENT AND IMPLEMENTATION OF DECISION SUPPORT MODELS FOR WATER REUSE PROJECTS	The guide concludes with a chapter in which the most important guidelines and best practices are summarised, and where a flow diagram is presented for steps to be followed when undertaking a water reclamation project.	Chapter 5

1.5 WATER SUPPLY OPTIONS IN SOUTH AFRICA

The following water sources are used for potable water supply in South Africa:

1.5.1 Surface water supplemented by water reuse and desalination

Surface water is currently the predominant water source in the country. In the long-term, however, DWA expects surface water to contribute proportionately less with proportionately significant increases in return flows through the treatment of urban (domestic and industrial) wastewater, and mining effluent and desalination (DWA, 2011).

1.5.2 Desalination

With the sea being an unlimited source of water, desalination of seawater is the ultimate option for supplying coastal cities. In recent years, the technology in this field has improved significantly and the associated energy use and costs have decreased to the extent that it has become a more feasible option. The possible impacts of climate change on the availability of surface and groundwater put another important perspective on the desalination of seawater, especially in the Western Cape (DWA, 2011).

The benefits of desalination include its proximity to demand, reduced infrastructure costs, reduced water losses, and favourable upgrading and replacement costs. Desalination plants can be operated when needed and can be upscaled with far shorter lead times than dams for example. Examples of where this is the case are the desalination plants in Plettenberg Bay (Bitou Municipality), Knysna and Sedgefield (Knysna Municipality) and Mossel Bay (Mossel Bay Municipality).

1.5.3 Water reuse

Water reuse can be done in a number of ways, *viz*.:

- Industrial reuse
- Agricultural reuse
- Dual pipe system
- Direct and indirect potable reuse

Each of these options has substantially different costs, quantities and value to the end user. Considerable work is currently being done in South Africa to promote water reuse in its various forms and the different water cycle sectors.

1.5.4 Groundwater use and treatment

Groundwater offers a significant volume of additional water to agriculture, the mining sector and towns. It is often the only available and affordable supply of water for many towns and rural communities to ensure future growth and development. In South Africa, groundwater is in many instances accessible, yet it is often not recognised as a resource, or overlooked as inferior to surface water, both by planners and consumers (DWA, 2011). With the current water shortages experienced in many parts of the country, studies and investigations aimed at utilising the vast potential of groundwater sources are increasingly being commissioned.

Note! Water losses should be addressed as first priority before even starting to consider other options such as desalination or reuse.

1.5.5 Recommendations for future drinking water supply

Some of the pointers in the DWA resource strategy document are highlighted below, together with comments where appropriate:

- Options for water supply must be considered beyond the traditional river storage options, *i.e.* building of dams. In order to assess the requirements of water supply, it is important to look at all options on the demand and supply-side. Dams nevertheless still forms a sustainable water source provider, but should always be considered as part of the national water balance.
- Cost analysis should be undertaken on the cost of infrastructure, cost of distribution to system or place of demand both in terms of CAPEX and OPEX. This has been addressed by DWA in their Cost Benchmark studies (DWA, 2009).
- Environmental costs should be part of the evaluation and decision-making. The costs of plant residuals disposal, and especially brine disposal, is currently receiving attention at a high level.
- The use of treated effluent should be investigated to a feasibility level as a matter of urgency, and pilot plants should be constructed to test implementation. When the feasibility and benefits of the use of treated effluent is proven, the implementation will be handed over to the local authority. It is, however, important to ensure that by that time, the municipality will have the capacity, ability and political will to operate and maintain the reuse plants, otherwise the schemes will not be sustainable.
- Towns, villages, communities, mines and other users with insufficient surface water, particularly those located distant from surface water schemes, must accept and adopt groundwater as a primary resource if they are to get the water they need to grow.
- Guidelines and rules for exploration of new water sources that are in place need to be disseminated and enforced, which requires regulatory and support capacity.

The shortage of available water in the region is leading to large-scale interest in and application of water reclamation and reuse of wastewater as alternative water supply sources to sustain development and economic growth in the region. Water reclamation plants have been constructed and are in operation in Beaufort West (direct potable reuse), George (indirect potable reuse) and Mossel Bay (reuse for industrial purposes), while direct potable reuse in Durban (eThekwini Municipality) and Hermanus are at an advanced planning stage. Before considering the various selection and costing criteria for water reuse options, it is necessary to provide a background to water reclamation and reuse systems and treatment plants.

1.6 REVIEW OF WATER RECLAMATION AND REUSE

1.6.1 Water reclamation and reuse definitions and terminology

For the successful application and sustainability of water reclamation and reuse as a water source to alleviate water scarcity situations, it is critically important that there is a common understanding of the concepts and terminology used in planning and implementation of water reuse schemes. It is also important that the definitions and terminology be updated on a regular basis as development of reuse planning and implementation processes develop, which is currently in an accelerated stage. New approaches and concepts should be taken up in the international and local literature and clearly explained, not only to the water reuse stakeholders and role-players, but also the public at large. One such new concept in water reuse is the “fit-to-purpose” approach (Lazarova *et al*, 2013), which entails the production of reuse water of such a quality that it meets the needs of end-users.

Many new water reuse projects have also adopted new terminology to improve the image of these projects with the public, notably names such as new water (or NEWater), processed water, purified water and eco- water. At both the IWA World Water Congress in Busan, Korea in 2012, and the IWA Water Reuse Specialist Group Conference in Windhoek, Namibia in 2013, considerable time was devoted to discussions on this important topic.

For purposes of this document, the following terminology and definitions are provided, which is derived from current consensus in the local and international water reuse sector.

Wastewater

Wastewater is any water that is derived from a variety of possible uses of the water, and typically contains residual pollutants associated with the use of the water.

Return flows

Return flows are treated or untreated wastewater that is discharged to a natural surface water or groundwater body after use.

Water reuse

Water reuse comprises the utilisation of wastewater or effluent from a variety of sources (e.g. domestic wastewater, industrial effluent, mine effluent) for a new or different beneficial application, such as for drinking purposes, industrial use or irrigation.

Potable reuse

Potable reuse involves the reuse of wastewater for drinking purposes after it has been extensively treated by a number of treatment processes to produce water that is safe for human consumption and human use.

Non-potable reuse

Non-potable reuse is the reuse of treated or untreated wastewater for purposes other than for drinking water or potable purposes, such as industrial purposes or irrigation.

Direct reuse

Direct reuse involves the reuse of treated or untreated wastewater or effluent by direct transfer from the site where it was produced, to the site of the new or different beneficial application.

Indirect reuse

Indirect reuse comprises the reuse of treated or untreated wastewater from a surface water or groundwater body where it was discharged to with the intention of reuse, before being abstracted for reuse at a new or different site of beneficial application.

Planned reuse (intentional reuse)

Planned reuse is the reuse of treated or untreated wastewater as part of a planned project, and is therefore always performed intentionally and consciously for a specific application(s).

Unplanned reuse (incidental reuse or *de facto* reuse)

Unplanned reuse is the reuse of treated or untreated wastewater after it has been discharged as return flow into a surface water or groundwater body without the intention of reuse, and from which it is then abstracted for a variety of applications.

Reclaimed water

Reclaimed water (also popularly referred to as new water) is any wastewater that has been treated to a level that is suitable for sustainable and safe reuse for the application that it is intended for.

Recycled water

Recycled water is any water recovered by treatment of wastewater, effluent, grey-water or storm-water runoff to a quality that makes it suitable for beneficial use. It is therefore considered to be a synonym for reclaimed water.

The definitions of water reuse terms and components were compiled into a single schematic diagram to illustrate the different types of reuse (Figure 1.1).

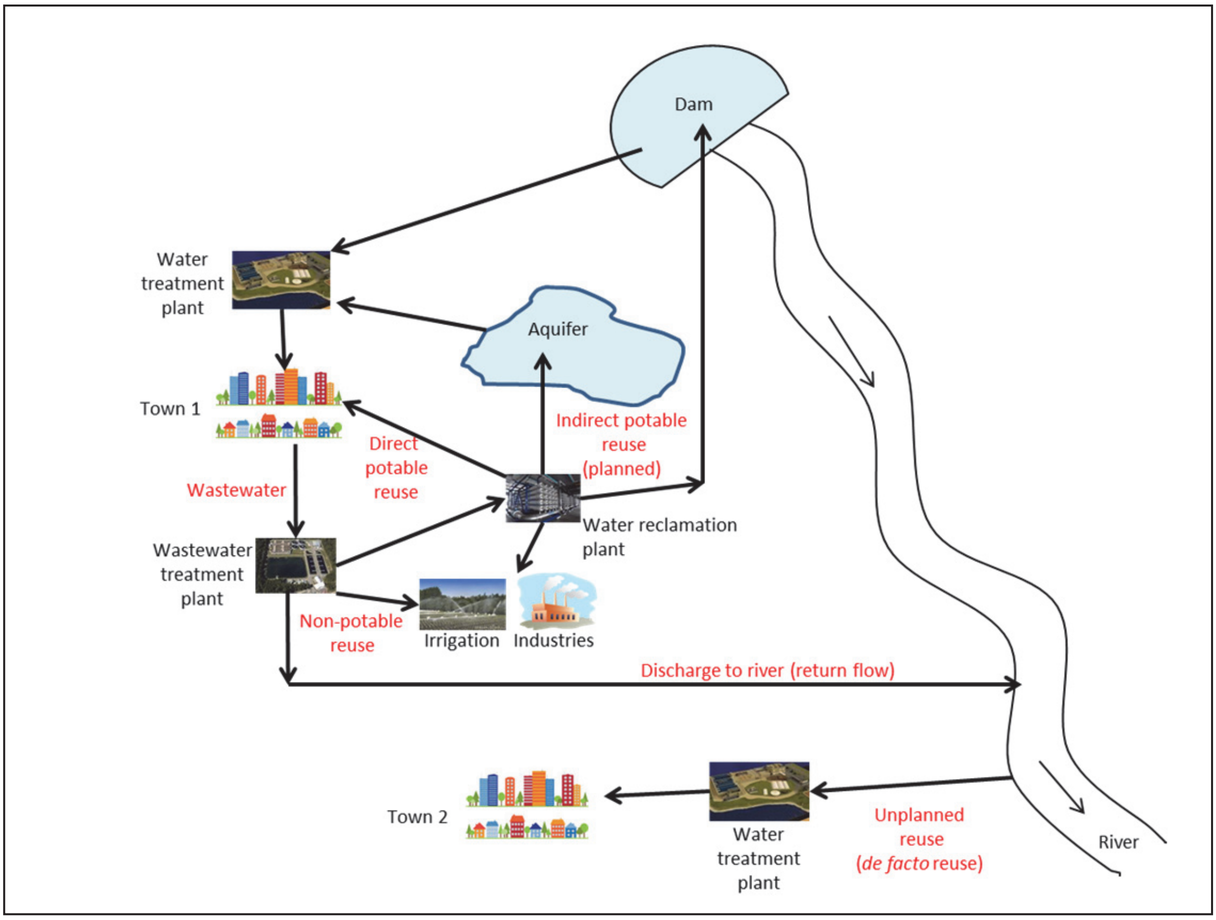


Figure 1-1: Schematic diagram illustrating the different types of water reuse

1.6.2 Water reuse applications world-wide

Water reuse is widely practiced throughout the world, both in developed, developing and emerging countries. Almost all these reuse systems are indirect potable reuse or non-potable reuse schemes. The only real direct potable reuse schemes are in Windhoek, Namibia, Beaufort West, South Africa, Big Springs, Texas, USA and Cloudcroft, New Mexico, USA. The two southern African reuse schemes constitute one of the main reasons for the current studies and research in South Africa to develop monitoring programs based on health-based targets for a wide range of chemicals of emerging concern and disinfection by-products, as well as public acceptance studies (social and institutional research projects).

1.6.2.1 International

United States

In the USA, the reuse schemes that are often cited in research studies are the reclamation plants at Orange County Water District, California, Big Springs, Texas, and Cloudcroft in New Mexico. The Big Springs and Cloudcroft Schemes are direct potable reuse schemes, while the Orange County project is an indirect potable reuse scheme. The latter is, however, also included below to highlight some if its features for comparison with the direct potable reuse schemes.

Orange County Water District (GWRS, 2008) (indirect potable reuse)

The Orange County in the USA often experiences water shortages. After excessive pumping of the groundwater basin in the 1940s it became vulnerable to seawater intrusion where, according to the Groundwater Replenishment System (GWRS, 2008), traces of salt were detected as far as 5 miles (8 km) inland. The Orange County Water District (OCWD) constructed Factory 21 in 1976. It is one of the country's largest advanced wastewater treatment facilities to replenish the groundwater system with potable reclaimed water and prevent seawater intrusion (GWRS, 2008). The treated water (including reverse osmosis) is injected into 23 multi-casing injection wells into the groundwater basin along the Talbert Gap to create a hydraulic barrier to seawater intrusion. Wastewater is treated at the Orange County Sanitation District by a process that includes bar screens, grit chambers, trickling filters, activated sludge, clarifiers and disinfection processes. The treated wastewater then flows to the GWRS where it undergoes microfiltration, reverse osmosis, UV radiation and addition of hydrogen peroxide.

Big Springs, Texas

The Big Springs Water Reclamation Plant in Texas is owned and managed by the Colorado River Municipal Water District (CRMWD). The feedwater source is secondary treated wastewater from the Big Springs WWTW, and the treated water is supplied to the City of Big Springs distribution network. The plant has been in operation since 2011. The plant capacity is 7.6 ML/d. It uses a multi-barrier treatment process combination with reverse osmosis and advanced oxidation as the main treatment processes. A high concentrate license had to be obtained to discharge the residuals into the Beals

Creek. Public education campaigns were used to educate and inform the public. The motivation for the design and construction of this reuse scheme was prolonged drought periods that were experienced.

Cloudcroft, New Mexico

The Village of Cloudcroft in New Mexico further treats secondary treated wastewater from the Cloudcroft WWTW to potable standard for distribution to the village. It also employs reverse osmosis and advanced oxidation as main treatment processes. The plant is relatively small, with a treated water output of around 0.38 ML/d. Water quality requires compliance with the EPA and New Mexico Environment Department (NMED) guidelines for drinking water. The scheme was commissioned in 1999.

Europe

Europe has experienced growing water stress in the last two decades in terms of both water scarcity and water quality degradation, and about half of the countries have water stress issues at the present time. Countries exhibiting high water stress include Cyprus, Malta, Belgium, Spain, Germany, and Italy [Hochstrat *et al.*, 2005]. Countries in Northern Europe generally have low water stress, although some regions currently use almost 100% of their available water resources.

Advanced wastewater treatment including membranes, typically MF or UF preceding RO, is used in some recharge projects and at least one indirect potable reuse project. Disinfection is accomplished almost exclusively either by chlorine or UV, with a current trend toward UV. Several research projects and demonstration studies are underway that are funded by the EU addressing treatment technologies, water quality, and integrated water management.

Currently there are no standardized water reuse standards for the entire European community, and water reuse criteria and guidelines differ from country to country in those countries that have developed standards or guidelines. Different approaches and philosophies have resulted in widely differing regulations. Some countries (or regions of countries) have imposed restrictive standards similar to those in Australia and the U.S., while others base their standards on the WHO guidelines for wastewater use in agriculture and aquaculture [World Health Organization, 1989].

Middle East and North Africa

The drivers for water reuse in developing countries in the Middle East vary but are mainly related to population growth, climate, limited water resources, and socio-economic conditions. Agricultural irrigation is the leading use of reclaimed water in the Middle East. In some Muslim countries, the use of wastewater for irrigation has been opposed on religious grounds (*i.e.*, that the water originated from wastewater and is therefore contaminated).

Many developing countries in the Middle East consider water reuse criteria in industrialized countries to be overly restrictive and too expensive to implement. WHO has developed guidelines aimed at systems that are low cost, easy to operate, and have minimal water quality requirements and, thus, is embraced by many countries in the region.

Latin-America and South America

More than 80% of the 700 million people in Latin America live in urban areas, making large quantities of treated and untreated wastewater available for reuse, mainly for agricultural irrigation. Drivers for water reuse include wastewater availability, seasonal variations in water availability and use, low or no cost of wastewater to farmers, high salinity of many natural waters, and soil and crop benefits associated with organic matter and nutrients in wastewater used for irrigation.

Australia

The Western Corridor Recycled Water Project is one of the largest recycled water projects in the world, increasing and diversifying South East Queensland's water sources. Three advanced water treatment plants, located at Bundamba, Gibson Island and Luggage Point, are the backbone of the Western Corridor Recycled Water Project. At these plants treated wastewater supplied from six existing wastewater treatment plants located throughout Brisbane and Ipswich is further treated using world best-practice technologies to create purified recycled water.

There have been no exceedences resulting from a failed exclusion of contaminants of concern by the microfiltration, reverse osmosis or advanced oxidation processes. Since normal operations commenced at the end of August 2008, all results have met the required standards. Western Corridor Recycled Water Pty Ltd considers that the water quality results for the purified recycled water confirm that the treatment process barriers are able to control any water quality hazards and produce purified recycled water suitable to augment a drinking water supply.

Singapore

Singapore has a daily water consumption of 1.36 million m^3, about 50% of which is for industrial, commercial and other non-potable use and the remainder for domestic use. There is an extensive planned indirect potable reuse (IPR) system in Singapore to help sustain the increasingly diminishing water sources. The water sources in Singapore include imported water from Johor in Malaysia, local catchment water, desalinated water and NEWater. NEWater is the outcome of the abovementioned planned IPR (PUB, 2012). To ensure that NEWater is of acceptable quality for IPR, a multi safety barrier approach has been adopted. The safety barriers include: source control, greater than 85% domestic sources, comprehensive secondary wastewater treatment, microfiltration, reverse osmosis and ultraviolet disinfection, natural attenuation in surface reservoirs, conventional water treatment, comprehensive water quality monitoring program, and a strict operating philosophy (Seah *et al.,*2008). These processes are shown in Figure 1.2.

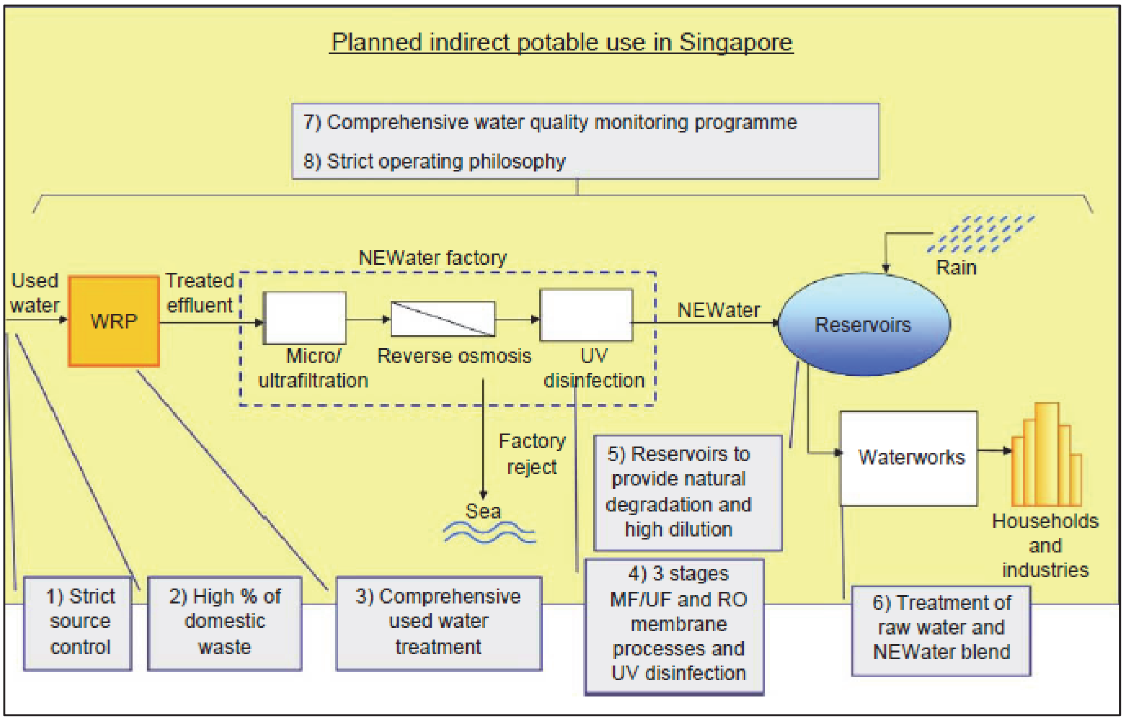


Figure 1-2: Multiple safety barrier approach at the NEWater plant in Singapore (Seah, 2008)

1.6.2.2 Southern Africa

Table 1.1 shows a listing of the main water reuse projects in Southern Africa (DWA, 2011). The first direct potable reuse plant in the world, the New Goreangab Water Reclamation Plant in Windhoek is located in southern Africa, while the first water reclamation plant in South Africa itself was commissioned in the town of Beaufort West in 2010. In South Africa, water reuse accounts for approximately 14% of total water use, and return flows account for a large part of water available for use from some of the important river systems. This constitutes unplanned indirect potable reuse. South Africa has limited fresh water resources and has been defined as water stressed by International standards. A number of reconciliation strategy studies have been conducted in major centers in South Africa, and the reuse of water has been identified as an important consideration in avoiding water shortages, particularly in coastal areas. Reuse of water is also becoming increasingly cost competitive in South Africa, but does have the negative characteristic of being relatively energy intensive, although considerably less energy intensive than seawater desalination.

Where water reuse is more cost-effective compared to other alternatives (such as reducing water requirements, securing a fresh water supply or desalinating sea water), then water reuse becomes an attractive choice provided that the quality of water can meet the necessary requirements and there are not any important cultural or social objections to the use of this water.

Table 1-1: Selected water reuse projects in Southern Africa (adapted from DWA, 2011)

Source of Reclaimed Water			Reclaimed Water User		Type or Reuse	
Water Authority	**Facility**	**Level of treatment**	**Institution/ Organization**	**Category of use**	**Planned or unplanned**	**Direct or Indirect**
City of Windhoek	Gammams WWTW and Goreangab Dam	Water reclamation, with advanced treatment processes	City of Windhoek	Drinking water	Planned	Direct potable reuse
Beaufort West	Beaufort West WWTW	Water reclamation, with advanced treatment processes	Town of Beaufort West	Drinking water	Planned	Direct potable reuse
City of Cape Town	Potsdam WWTP	Secondary, tertiary	Chevron Refinery	Industrial, process water	Planned	Direct
Saldanha	Urban Stormwater	Storage, infiltration		Recharge of aquifer	Planned	Direct
City of Johannesburg	-	Secondary, disinfection	Kelvin Power Station	Industrial, cooling water	Planned	Direct
Rustenburg	Rustenburg WWTP	Secondary, disinfection	Platinum Mines	Metallurgical process and mining process water	Planned	Direct
City of Tshwane Metropolitan Municipality	Rooiwal WWT	Secondary, disinfection	Rooiwal Power station	Industrial, cooling water	Planned	Direct
eThekwini Municipality	Southern WWTP	Secondary, tertiary	Mondi Paper Company/SAPREF	Industrial, cooling water	Planned	Direct
Sasol, Sasolburg Municipal WWTP	Sasol 1 WWTP	Secondary trickling filtration	Sasol, Sasolburg	Industrial Process water	Planned	Direct
Anglo American Thermal Coal	Emalahleni Water Reclamation Plant	Advanced, disinfection	Emalahleni Municipality	Drinking and municipal water	Planned	Direct
Optimum Coal Holdings	Optimum Water Reclamation Plant	Advanced, disinfection	Steve Tshwete Municipality	Drinking and municipal water	Planned	Direct
Steve Tshwete Local Municipality	Boskrans Wastewater Treatment Plant	Secondary, disinfection	Kanhym Feed Lots	Agro industry use	Planned	Direct

Source of Reclaimed Water			Reclaimed Water User		Type or Reuse	
Water Authority	**Facility**	**Level of treatment**	**Institution/ Organization**	**Category of use**	**Planned or unplanned**	**Direct or Indirect**
Anglo American Thermal Coal, Vaal Colliery	Lethabo Water reclamation Plant	Advanced membrane treatment	Lethabo Power Station	Industrial, cooling water	Planned	Direct
Polokwane Municipality	Pietersburg Wastewater Treatment Plant	Secondary, disinfection	Platinum Mines	Mining and metallurgical process water	Planned	Direct
City of Johannesburg	Southern Wastewater Treatment Works	Secondary, disinfection	Water users along Middle Vaal River	Full Spectrum	Planned	Indirect
City of Johannesburg	Northern Wastewater Treatment Works	Secondary, disinfection	Water users along Crocodile West River	Full spectrum	Planned	Indirect
City of Tshwane	Zeekoegat Wastewater Treatment Works	Tertiary, disinfection	City of Tshwane via Wallmansthal Plant	Potable	Planned	Indirect
Msunduzi Local Municipality	Darvill Wastewater Plant	Secondary, disinfection	Umgeni Water	Potable from Inanda Dam	Planned	Indirect
Emalahleni Local Municipality	Wastewater Treatment Works	Secondary, disinfection	Loskop Dam water users	Mainly irrigation, but full spectrum	Planned	Indirect

1.6.3 Research needs in water reclamation and reuse

The following topics were identified as priority areas for further research to be done (personal notes, WISA 2012):

- Cost: benefit studies
- Social acceptance
- Risk-based guidelines for processes and systems
- Guidelines for operations and maintenance
- Reducing cost of analytical methods
- Survey of towns with reuse potential
- EDC and other CEC test methods
- Guidelines for design of processes
- Improve efficiency of processes for priority chemicals removal
- Improved disinfection

Tchobanoglous *et al* (2011) identified the following research topics as high priorities for direct potable reuse in the US:

- Design considerations for sizing engineered storage buffers
- Enhanced monitoring techniques and methods for direct potable reuse
- Develop standard terminology, messaging, and communication materials for planning and implementation of DPR
- Treatment train reliability: Impacts of treatment train and process operation modifications to enhance the performance and reliability of secondary, tertiary, and advanced treatment systems
- Evaluation of blending requirements for purified water
- Enhanced monitoring techniques and methods
- Equivalent advanced treatment trains
- Communication resources for DPR
- Acceptance of direct potable reuse

1.7 NEED FOR GUIDELINES ON COSTING AND SELECTION OF WATER RECLAMATION TECHNOLOGIES

Numerous options are available when WSAs, DWA, planners and funders (such as the Development Bank of Southern Africa (DBSA)) considers water reuse to improve water source surety (and sustainability) or make provision for water scarce periods. Sufficient information on the options is often not readily available to those wishing to make an informed selection of the best options for their specific situation. This difficult to obtain information comprises technical, costing, energy and environmental data. Even if the information is eventually obtained, comparison of the best options is mostly not feasible or effective, because of the differences in priorities assigned to the multitude of factors making up the selection criteria. There was thus a need for a decision-support model (DSM) for municipalities and water boards to identify, evaluate, compare, and select appropriate water reclamation and reuse options which can produce sufficient quantities of safe drinking water from available water sources.

Because the cost of reuse schemes forms one of the main selection criteria, there was also a need for more comprehensive reuse costs to inform the development of the DSM. Presenting the costing criteria and data in the form of a guide document was therefore included as an objective of this Water Research Commission project. Apart from forming an integral part of the DSM, it is also of value as a stand-alone guide on costing of water reuse projects. The guide therefore included the development of a reuse costing model, REUSECOST, which is included in this report.

CHAPTER 2: KEY FACTORS AFFECTING SELECTION OF WATER RECLAMATION TECHNOLOGIES

2.1 INTRODUCTION

The National Strategy for Water Reuse (DWA, 2011) lists five key considerations related to water reuse as an option for water supply and augmentation, namely: water quality aspects, water treatment technology, cost relative to other water supply alternatives, social and cultural perceptions, and environmental considerations. Another important consideration to be added is operation and maintenance of direct potable reuse plants.

2.2 WATER QUALITY ASPECTS

Both the quality of the raw water source and the required final water quality strongly affect the cost of reuse systems, as it determines the treatment requirements of the plant. Reuse of water becomes attractive when the water quality requirements are relatively low (for example for irrigation or secondary industrial use). For direct potable reuse, however, the required water quality relates to public health, and should never be compromised in an attempt to reduce the capital or operating costs of a treatment system needed to achieve the required health-related water quality targets. Furthermore, while the costs for direct potable reuse may be higher than other alternatives, the security (reliability) of supply may also make reuse more attractive.

2.2.1 Water quality and security of supply

Changes in weather patterns during recent years, whether as a result of carbon-emissions or long-term cycles, have led to severe droughts in some areas and intermittent flooding in other areas. This has resulted in variable reliability of supply on the conventional drinking water sources of surface water (dams, rivers) and groundwater (boreholes, springs), and a new look at desalination (seawater and brackish groundwater) and water reclamation and reuse. Recent droughts in the Southern Cape have resulted in the emergency construction of seawater desalination plants in Mossel Bay, Sedgefield, Knysna and Plettenberg Bay. Water reuse plants were constructed in Beaufort West (direct potable reuse – the first in South Africa), Mossel Bay (non-potable reuse supplying process water to a large industry) and George (indirect potable reuse).

2.2.2 Feed water (wastewater) constituents and risks

The feed water for water reuse is in most instances secondary treated wastewater from municipal wastewater treatment plants. This can be made up entirely from domestic sewage, but often also contain industrial effluent, which may result in the presence of a number of undesirable pollutants in the water (most of the urban wastewater treatment plants also receive industrial effluent). These pollutants may consist of

- Pharmaceuticals
- Health care products
- Pesticides
- Heavy metals
- Industrial chemicals

They may be difficult to treat or can require costly treatment processes to reduce the pollutant concentrations to acceptable levels. There is also concern about risks in terms of ability to design, operate and maintain these more sophisticated treatment processes satisfactorily; and, importantly, risks related to predicting the public health impacts of water reuse for drinking purposes.

2.2.3 Public health considerations

Cain (2011) reports that few epidemiologic and toxicological potable reuse health effects studies have been conducted over the past 30 years to investigate the public health impact of IPR and DPR. The Windhoek, Namibia DPR project utilized epidemiological and toxicological studies to find no relationship observed between drinking water source and diarrheal disease cases. The Denver, Colorado potable water reuse demonstration project published the only other DPR study. A two year toxicological health effects project used *in vivo* studies for chronic and reproductive effects, and found that there were no adverse health effects when the subjects were exposed to reclaimed water supplies. All other health effects studies to date have evaluated IPR with toxicological studies, the most recent being the 2007 IPR Singapore Water Reclamation Study which did not show any health effects in fish or mice. Although these studies revealed no obvious health effects, design shortcomings, age of studies, and technology's rapid advancement over the past decade are factors worthy of important consideration in interpretation and extrapolation.

2.2.4 Reviewing water quality standards

The following water quality standards exist in South Africa:

- South African Water Quality Guidelines for a number of different water user sectors (DWAF, 1996);
- Drinking water quality standards (SANS 241, 2005, Edition 6 [currently being revised]), and the
- General and Special Standards pertaining to the discharge of treated wastewater to the water resource.

These standards and guidelines were not specifically developed to address the issues associated with water reuse. Worldwide research into water reuse is producing new information, which needs to be considered in guiding and regulating water reuse projects. The Department will review and/or develop standards and guidelines for water reuse in the near future. Water quality targets for physical, chemical and microbiological determinands are provided in ***Appendix A***.

2.2.5 Endocrine disrupting compounds (EDCs) and chemicals of emerging concern (CECs)

Sophisticated analytical instrumentation makes it possible to identify and quantify extremely low levels of individual inorganic and organic constituents in water. Examples of these instruments include gas chromatography/tandem mass spectrometry (GC/MS/MS) and high-performance liquid chromatography/mass spectrometry (HPLC/MS). These analyses are costly and may require extensive and difficult sample preparation, particularly for non-volatile organics. With further analytical advancements, nearly any chemicals will be detectable in environmental waters, wastewater, reclaimed water, and drinking water in the future, but the human and environmental health relevance of detection of diminishingly low concentrations remains a greater challenge to evaluate. Table 2.1 provides categories of compounds which may be detectable in reclaimed water.

Table 2-1: Categories of trace chemical constituents (natural and synthetic) potentially detectable in reclaimed water and illustrative example chemicals (NRC, 2012)

End use Category	Examples
Industrial chemicals	1.4-Dioxane, perfluorooctanoic acid, methyl tertiary butyl ether, tetrachloethane
Pesticides, biocides, and herbicides	Altrazine, lindane, diuron, fipronil
Natural chemicals	Hormones (178-estradiol), phytoestrogens, geosmin, 2-methylisoborneol
Pharmaceuticals and metabolites	Antibacterials (sulfamethoxazole), analgesics (acetaminophen, ibuprofen), beta-blockers (atenolol), anti-epileptics(phenytoin, carbamazapine), veterinary and human antibiotics (azithromycin) oral contraceptives (ethinyl estradiol)
Personal care products (PCPs)	Triclosan, sunscreen ingredients, fragrances, pigments
Household chemicals and food additives	Sucralose, bisphenol A (BPA), dibutyl phthalate, alkylphenol polyethoxylates, flame retardants (perfluorooctanoic acid, perfluorooctane sulfonate)
Transformation products	NDMA, HAA’S, and THM’S

Although trace chemical constituents are "pollutants" when they are found in the environment at concentrations above background levels, they are not necessarily "contaminants" (that is, found in the environment at levels high enough to induce ecological and/or human health effects). The target levels for selected EDCs and CECs of the EPA, WHO and others appear are shown in ***Appendix B***. Cain (2011) compared the removal efficiencies of various advanced water treatment unit processes for EDCs, residual pharmaceutical active compounds (PHACs) and PCPs (Table 2.2).

Table 2-2: Percentage removal of EDCs, PHACs and PCPs by AWT unit treatment processes (Cain, 2011)

Group	Classification	Reverse Osmosis	BAC	Activated Carbon	Nanofiltration	Biodegradation	Advanced Oxidation	Photodegradation	Activated Sludge	UV	Cl2/CLO2	Softening	Coaf/Floc
EDCs	Pesticides	E	E	E	G	v	L-E	E	v	E	v	G	P
	Industrial Chemicals	E	E	E	E	G-E	G-G	v	v	E	P	P-L	P-L
	Steroids	E	E	E	G	L-E	E	v	v	E	E	P-L	P
	Metal	E	G	G	G	P	P	v	E	P	P	F-G	F-G
	Inorganics	E	F	P-L	G	P-L	P	P-L	P-L	P	P	G	P
	Organometallics	E	G-E	G-E	G-E	L-E	L-E	L-E	L-E	F-G	P-F	P-L	P-L
PHACs	Antibiotics	E	E	F-G	E	E	L-E	G-E	v	F-G	P-G	P-L	P-L
	Anti-depressants	E	G-E	G-E	G-E	G-E	L-E	G-E	G-E	F-G	P-F	P-L	P-L
	Anti-inflammatory	E	G-E	E	G-E	E	E	v	v	E	P-F	P-L	P
	Lipid regulators	E	E	E	G-E	P	E	v	v	F-G	P-F	P-L	P
	X-ray contrast media	E	G-E	G-E	G-E	E	L-E	E	v	F-G	P-F	P-L	P-L
	Phsychiatric control	E	G-E	G-E	G-E	G-E	L-E	G-E	G-E	F-G	P-F	P-L	P-L
PCPs	Synthetic musks	E	G-E	G-E	G-E	E	L-E	v	v	E	P-F	P-L	P-L
	Sunscreens	E	G-E	G-E	G-E	G-E	L-E	G-E	G-E	F-G	P-F	P-L	P-L
	Antimicrobials	E	G-E	G-E	G-E	v	L-E	F	v	F-G	P-F	P-L	P-L
	Detergents	E	E	E	E	L-E	F-G	v	v	F-G	P	P-L	P-L

E = excellent (>90%); G = good (70-90%); F = fair (40-70%); L = low (20-40%); P = poor (<20%) v – variable

While there are no specific regulations for CECs in reclaimed water as of 2012, further investigation is necessary before any final decisions can be made on the subject. While the application of reclaimed water for urban and landscape irrigation (i.e., lawns, golf courses, parks, non-food gardens, etc.) is thought to pose very low risk to humans in contact with the various plants/surfaces irrigated, recent research by Knapp *et al.* (2010) indicates that there may be indirect health effects resulting from use of reclaimed water in agricultural applications.

2.3 WATER RECLAMATION TECHNOLOGIES AND PROCESS CONFIGURATIONS

2.3.1 Water reclamation technologies

Locally, conventional as well as advanced treatment technologies for water reclamation have in most instances already been tested and proven for South African conditions. Water reclamation has already been studied in South Africa since the 1960's when the concept arose at the CSIR in Pretoria and research and development work, followed by pilot plant studies at the Daspoort Wastewater Treatment Works commenced. There is therefore a local knowledge base on water reclamation to plan, design, construct, operate and maintain a wide range of treatment technologies. More recently, a number of more sophisticated technologies such as advanced oxidation and membrane treatment have also been applied to a number of local projects (cf Durban Reuse Plant and the Beaufort West Water Reclamation Plant). The South African water industry has the foundation for confidently developing and applying the more advanced water reuse technologies (DWA, 2011). A specialist technical division, the WISA Water Reuse Division, has also recently been established within the Water Institute of Southern Africa, to further improve communication, capacity building and information sharing.

A summary of treatment technologies used in water reclamation appears in Table 2.3. The selection and implementation of the appropriate treatment technology are key to the successful implementation of water reuse projects. It is strategically important to achieve this objective by:

- Selecting capable agencies/organisations with knowledgeable and competent staff to implement and operate reuse projects;
- Planning and executing the procurement of technology with the appropriate emphasis on functionality and proven performance;
- Ensuring that local knowledge of and support for the technology are available; and
- Providing technology guidance and training to reuse project implementing agencies/organisations.

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.

Table 2-3: Applicable water treatment technologies for water reuse (DWA, 2011)

Category of Pollutants	Applicable Technologies
Macro-organics, COD and BOD_5	• Biological treatment (activated sludge, trickling filtration, fixed film reactors, membrane bioreactors) • Chemical coagulation/flocculation and clarification
Particulate and suspended solids	• Chemical coagulation/flocculation and clarification • Granular media filtration • Membrane filtration
Nutrients – Nitrogen	• Biological nitrogen removal (nitrification/ denitrification) • Air stripping (ammonia) • Chemical coagulation/flocculation and solids separation
Nutrients – Phosphorus	• Biological phosphorous removal (enhanced biological phosphorus uptake) • Chemical precipitation (typically metal salt addition)
Microbiological Agents: Bacteria Viruses Parasites	• Membrane filtration • Chemical disinfection (chlorine, bromine compounds etc.) • Ultra Violet (UV) radiation
Salinity, inorganic salts	• Precipitation • Ion exchange • Membrane desalination (nanofiltration /reverse osmosis)
Metals	• Precipitation • Chemical adsorption • Membrane separation
Micro-organics: Volatile Organics Pesticides Pharmaceuticals Endocrine Disruptors	• Advanced oxidation (H_2O_2/UV) • Adsorption by activated carbon (granular/powder) • Membrane separation (nanofiltration /reverse osmosis) • Biologically enhanced adsorption (BAC)
Disinfection byproducts	• Modify disinfection agent in upstream processes • Advanced oxidation • Adsorption by activated carbon (PAC/GAC) • Membrane separation (nanofiltration /reverse osmosis)

2.3.2 Process configurations used in water reclamation

A number of different process configurations are possible in which the water reuse treatment technologies listed in Table 2.3 can be applied, and are shown in Figure 2.1 (Cain, 2011). The flow diagrams in Figure 2.1 show the five configurations that have mostly been used.

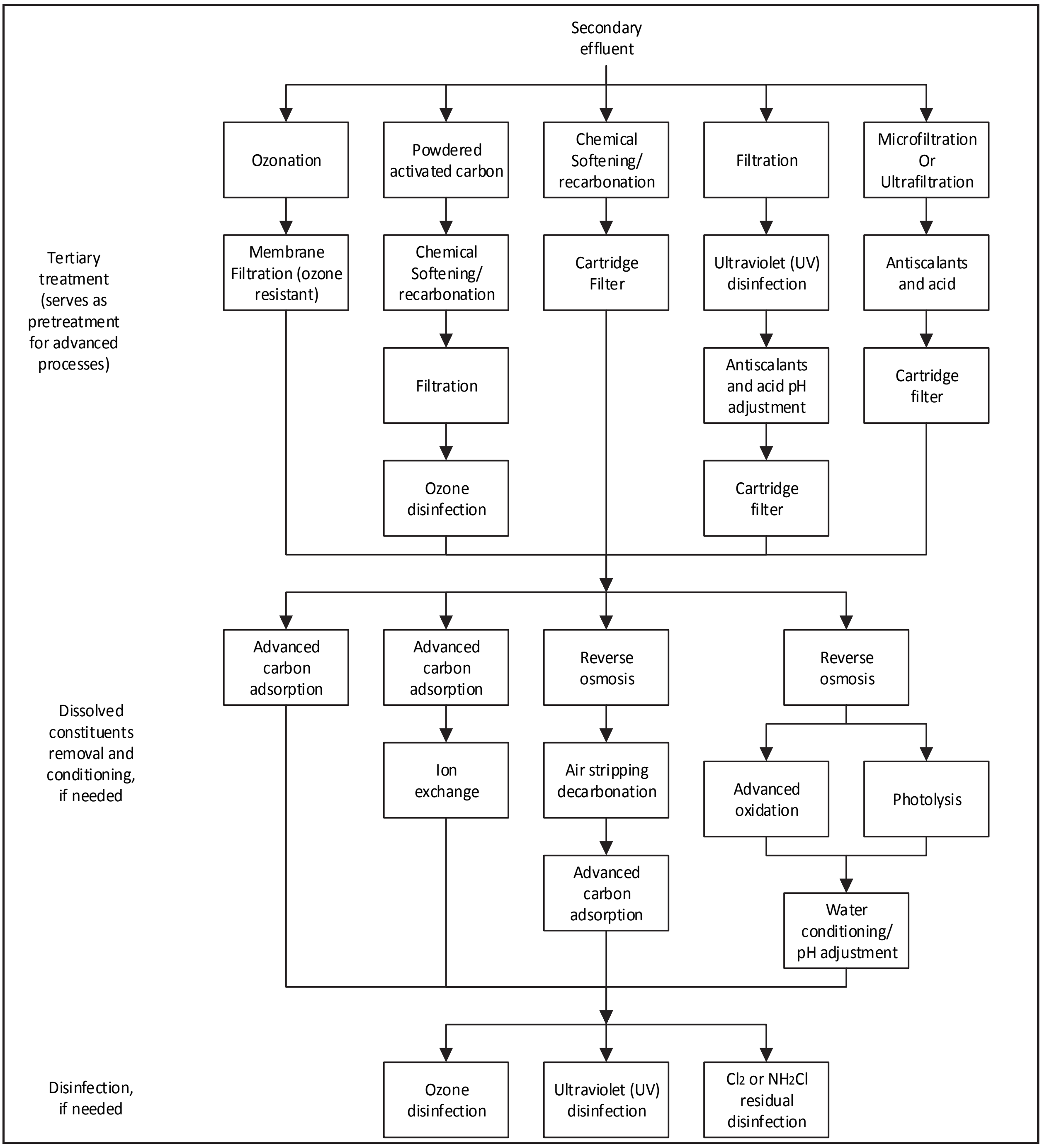


Figure 2-1: Possible water reuse treatment configurations (Cain, 2011)

2.3.2.1 Example 1 – Old Goreangab Water Reclamation Plant

Chemical treatment – Phase separation – filtration – disinfection

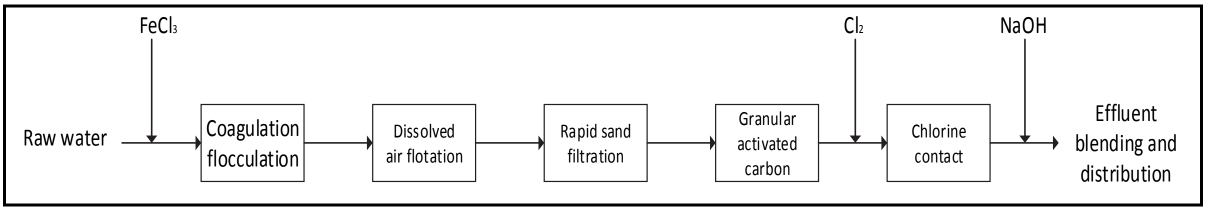


Figure 2-2: Configuration of the Old Goreangab Water Reclamation Plant

2.3.2.2 Example 2 – New Goreangab Water Reclamation Plant (NGWRP)

Chemical treatment – Phase separation – filtration – membrane filtration – disinfection

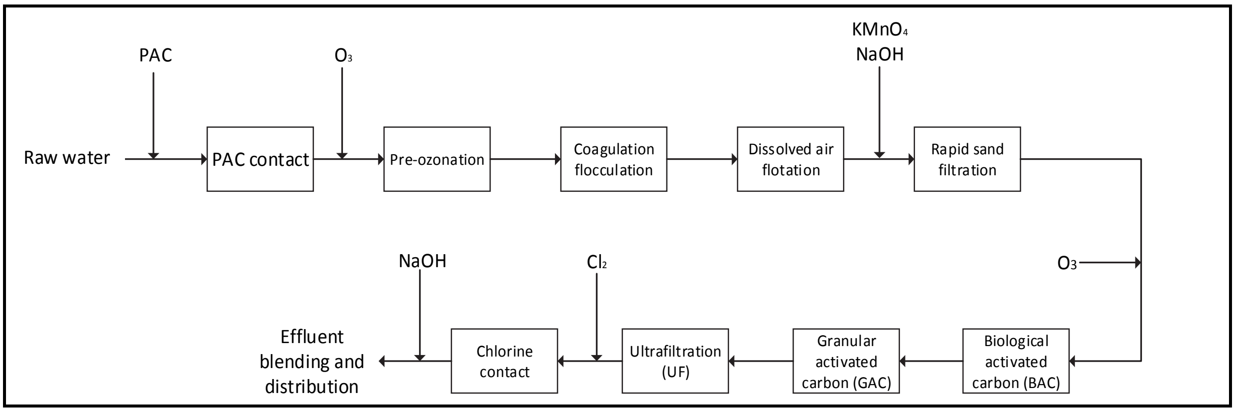


Figure 2-3: Configuration of the New Goreangab Water Reclamation Plant (NGWRP)

2.3.2.3 Example 3 – Cloudcroft, New Mexico

Reverse Osmosis – Advanced Oxidation – Blending – Membrane filtration – UV disinfection – Activated Carbon – Disinfection

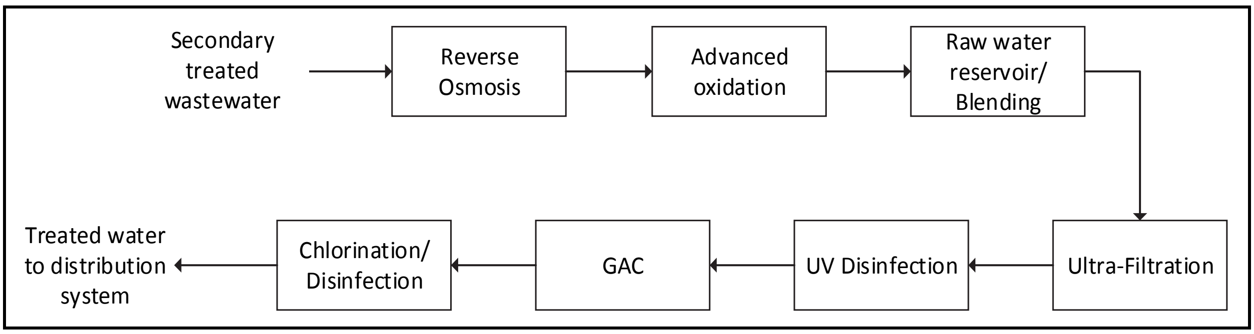


Figure 2-4: Configuration of the Cloudcroft Water Reclamation Plant

2.3.2.4 Example 4 – Big Springs, Texas

Membrane filtration – Reverse Osmosis – Advanced Oxidation – Blending – Flocculation – Sedimentation – Filtration – Disinfection

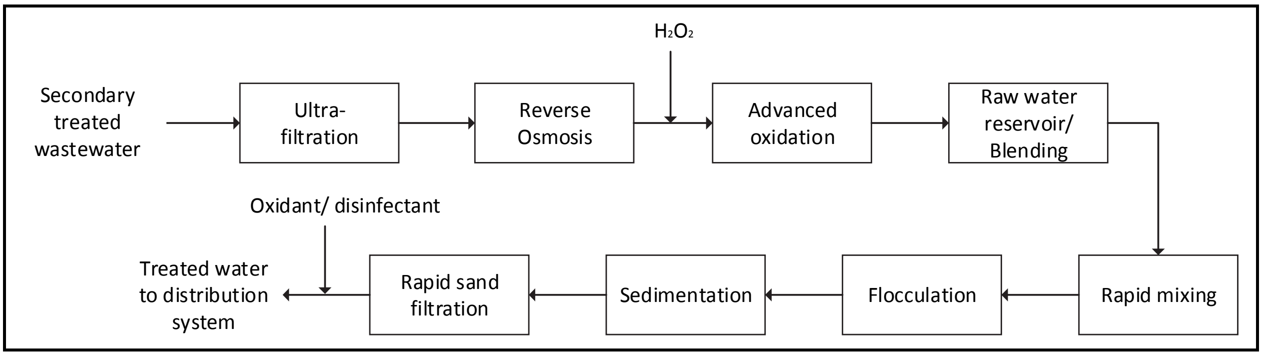


Figure 2-5: Configuration of the Big Springs Water Reclamation Plant

2.3.2.5 Example 5 – Beaufort West, South Africa

Rapid sand filtration – Membrane filtration – Reverse Osmosis – Advanced Oxidation – Disinfection

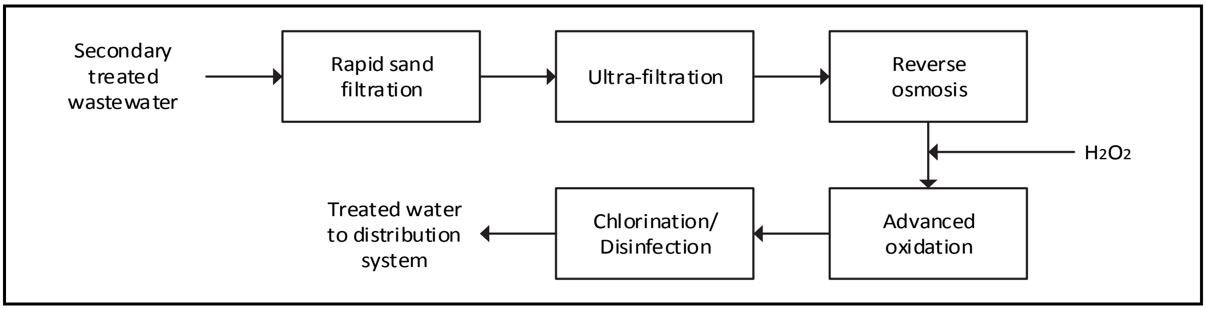


Figure 2-6: Configuration of the Beaufort West Water Reclamation Plant

2.3.3 Examples from existing direct potable reuse schemes

A consideration of the treatment processes and process configurations in the Windhoek and Beaufort West Water Reclamation Plants provides a broader understanding of how these processes operate and interact in practice.

2.3.3.1 The New Goreangab Water Reclamation Plant

The Goreangab water reclamation plant in Windhoek, Namibia is a world-renowned pioneer in direct water reclamation. A noteworthy aspect of the Goreangab water reclamation plant was that industrial and domestic effluent are separated and only the domestic effluent was treated at Gammams wastewater treatment plant, while all the major industrial effluent streams were diverted to another treatment plant. The initial capacity of the Goreangab reclamation plant was 4300 m^3/day. During a drought in 1992 the plant was upgraded to a capacity on 14000 m^3/day (Haarhoff, 1991).

During another severe drought in 1997 it was decided to build a new water reclamation plant adjacent to the existing Goreangab plant, and the New Goreangab Water Reclamation Plant (NGWRP) was commissioned in 2002(Menge, 2006). The final treatment train of the NGWRP is shown in Figure 2.7.

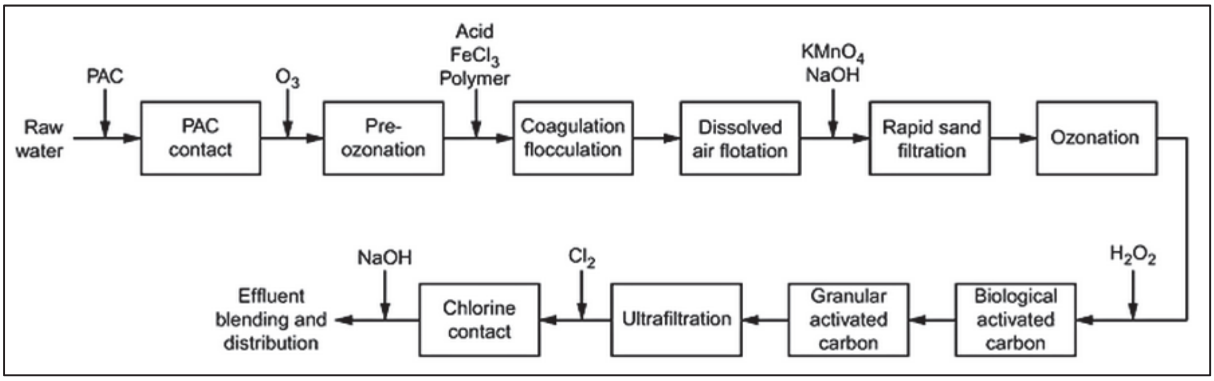


Figure 2-7: Treatment process train of the NGWRP (adapted from du Pisani 2006; Lahnsteiner and Lempert, 2007:441)

The NGWRP process, with a capacity of 21 ML/d, consists of (Menge *et al*, 2009):

- Raw water is supplied either from the Goreangab Dam or from secondary treated effluent from the maturation pond effluent after the Gammams WWTP. Both sources can be mixed at any ratio or only one source used at a time. (However, the quality of the water in the Goreangab Dam has deteriorated to such an extent that this source is not used anymore at present).
- **Powdered activated carbon** can be added as a back-up for adsorption, should the ozone process fail, or for taste and odour treatment.
- **Pre-ozonation**: The raw water mix is treated with the off gas and excess ozone.
- **Chemical dosing and coagulation**: Ferric chloride is added as primary coagulant to achieve enhanced coagulation for maximum organic removal in the first solids separation step. When needed, hydrochloric acid can be added for pH control or a polymer to aid the flocculation.
- **Dissolved air flotation (DAF)** is used for suspended solids and organics separation.
- **Chemical dosing**: Caustic soda (NaOH) and permanganate (MnO_4) are added to raise the pH and accelerate the precipitation of iron and manganese on the sand filters.
- **Rapid sand filtration**: Dual media filters with anthracite and graded sand are used. The filters are equipped with filter-to-waste facility for maximum cyst/oocyst removal.
- **Ozone contact**: Oxygen is produced on-site with a Pressure Swing Adsorption (PSA) plant. Ozone is dosed at three dosage points.
- **Chemical dosing**: Hydrogen peroxide (H_2O_2) is dosed to neutralize any ozone residuals to protect the biological activity in the next step.
- **Biological activated carbon (BAC) filters** remove the biodegradable matter.
- **Granular activated carbon filters (GAC)** to remove organic molecules from the water.

- **Ultrafiltration (UF):** Water is filtered through UF membrane modules to remove bacteria, protozoa and viruses.
- **Breakpoint chlorination**.
- **Stabilisation** by adding caustic soda to raise the pH.
- Blending: At the New Western Pump Station (NWPS) the reclaimed water is blended with surface water from the Von Bach scheme at a ratio of 1:3 and introduces it into the distribution system.

The plant is operated and maintained by the Windhoek Goreangab Operating Company Ltd. (WINGOC) through a 20 year contract with the City of Windhoek. WINGOC is made up of three major international water treatment contractors: 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*, 2012). A risk assessment (RA) was also carried out to describe and evaluate the risks associated with wastewater reuse, and to identify any potential weaknesses in the treatment train.

2.3.3.2 Beaufort West Water Reclamation Plant

Beaufort West's reclamation system is the first direct potable reuse plant producing drinking water in South Africa. The plant was initially intended to be constructed as a public-private partnership (PPP), *i.e.* financed and operated by an external contractor. However, the municipality of Beaufort West was assigned a governmental grant from the drought relief fund, which allowed the municipality to use these funds for construction of the reclamation plant. A tender document specified requirements for the project and the plant was built according to the design and build approach. The contractor based the design of the plant on the multi-barrier concept, which is also used in the Windhoek New Goreangab reclamation plant, but used RO membrane/advanced oxidation treatment configuration. The following processes are used in Beaufort West: ferric-chloride dosing at inlet to the secondary settling of the WWTP, pre-chlorination, sedimentation basin, post-chlorination, rapid sand filtration, ultrafiltration (UF), reverse osmosis (RO), UV-hydrogen peroxide and final chlorination. The contractor is also responsible for operating the plant for 20 years.

The reclamation system in Beaufort West uses wastewater, mostly domestic sewage, as its only raw water source to produce drinking water. The system consists of the existing WWTP with activated sludge treatment followed by the membrane-based Beaufort West Wastewater Reclamation Plant (BWWRP). The system is a direct reclamation system (direct potable reuse). The sewage system is separated, meaning that no storm water is supposed to enter the sewage system; further no industrial effluent is diverted to the Beaufort West WWTP. However, storm water invariably finds its way to the inflow to the works.

The reclamation plant in Beaufort West uses fewer barriers compared to the WRP in Windhoek. The treatment process is therefore easier to operate since it mainly relies on two membrane filtration barriers, ultrafiltration and reverse osmosis, which are fully automated. Production rate started at a minimum of 1 ML per day, with an increase of 10% per year over a period of ten years. This means that after the first ten years of operation, when reaching design capacity, the plant needs to produce water for 20 hours per day. The contractor has a mandate to change operation or demand additional barriers in the WWTP if considered necessary with regard to the reclamation process. The WWTP is both owned and operated by the municipality.

Very few changes have been made to the WWTP after the introduction of the BWWRP. On initiative of the contractor for the WRP, ferric chloride is added after the activated sludge process to increase settling to allow more efficient removal of phosphates. This has shown to be a big improvement for the reclamation system. The reclamation system used in Beaufort West (Figure 2.8) can roughly be divided into three parts: pre-treatment, main treatment and post treatment or polishing. Pre-treatment, which consists of pre-chlorination, sedimentation basin (also referred to as maturation river), intermediate-chlorination and rapid sand filtration, is mainly used to reduce the loading on the membranes to prevent fouling. Thereby the life-length of the membranes is extended, which an important costing item due to the high cost of membrane replacement. The main treatment is the membrane system (UF plus RO) where the majority of the pathogens and particles are removed.

Skepticism against direct water reclamation is high, which is why communication of treatment efficiency and final water quality is important for public acceptance. Therefore, extensive monitoring, beside efficient barriers, is necessary. Monitoring is usually associated with high costs. Further, monitoring is even more important in the beginning of a project when the treatment plant is new and uncertainties about the treatment process and corresponding performance are larger.

The monitoring of the WWTP is performed by the municipality and follows suggestions from the Green Drop programme. No additional monitoring has been added after the construction of the Reclamation Plant. The laboratory in Beaufort West is not an accredited laboratory, resulting in only a yearly sample being sent to an external laboratory for analysis to fulfil the Green Drop programme requirements. More general monitoring is conducted twice a week by the WWTP manager. Phosphates and E-coli analysis cannot be performed in the existing laboratory and is therefore analyzed at an external laboratory on a monthly basis.

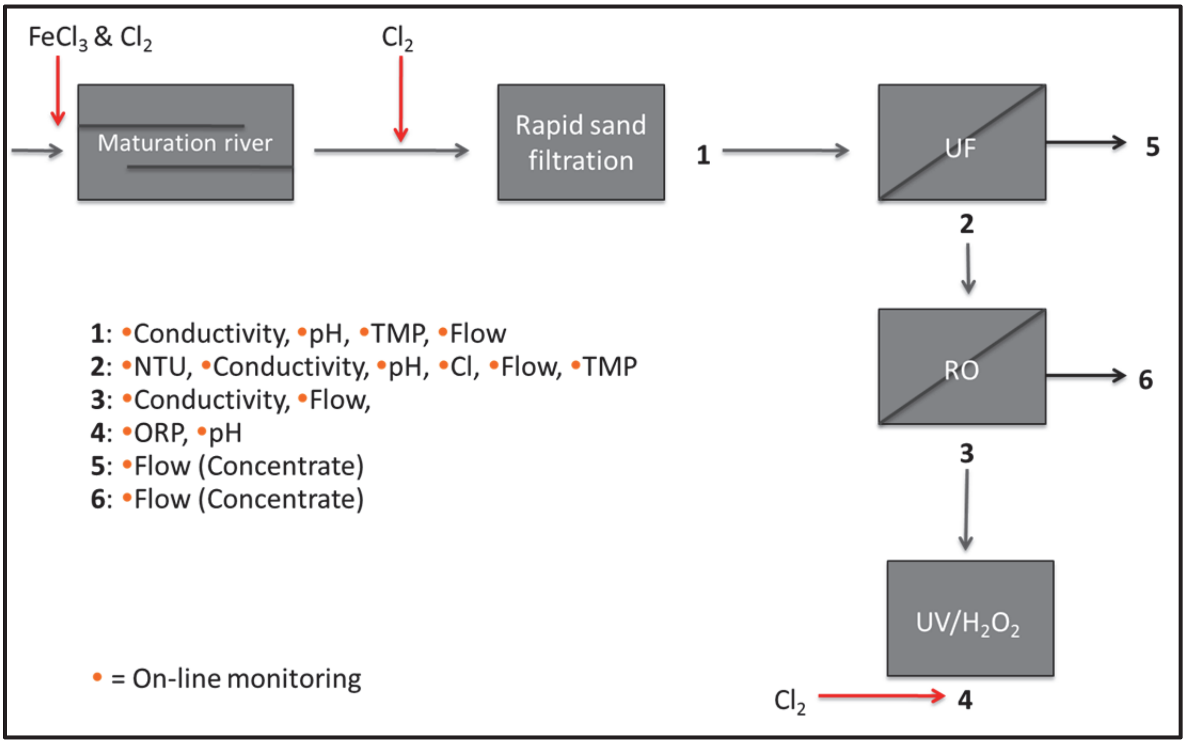


Figure 2-8: Flow diagram of Beaufort West WRP with on-line monitoring points.

2.3.4 Monitoring Wastewater Reclamation Plant (WRP)

Specifications for the plant required that the final product water at the WRP must meet the requirements of SANS: 241 2006, Class I, *i.e*. the quality of the drinking water must be acceptable for a lifetime of consumption. The national standard (SANS: 241, 2005) specifies the quality of produced drinking water in terms of: microbiological, physical, organoleptic and chemical parameters. Depending on what is measured they are recommended to be monitored either daily, weekly, monthly, quarterly or on an annually. The compliance for class 1 is evaluated on an annual basis, where 95% must fulfil the specified requirement (excluding aesthetic parameters). Due to increased costs connected to sampling and evaluation it is suggested in the SANS: 241, 2005 that a graded monitoring system should be implemented. That system takes into consideration the site specific conditions, e.g. raw water quality, population served, industrial activities and treatments barriers.

The municipality and the contractor together decide which parameters need to be monitored in the BWWRP. The monitoring program is a compromise between cost and safety through increased monitoring. Monthly samples are done both by the municipality and the contractor, and the contractor is carrying the cost for the sampling and monitoring process. All on-line monitored parameters are connected to automatic alarms that will trigger and alert the operator if any parameter deviates from specification. The plan includes which parameters should be measured and at what frequency. The plan is also designed to be dynamic, which is important for a new system. Further a suggestion of analysis equipment is presented. The monitoring plan is based on knowledge and experience, gathered over 50 years, at the New Goreangab reclamation system in Windhoek. There are, however, important differences between the two systems. New Goreangab, beside its larger capacity, also includes research projects that aim at gathering knowledge and information regarding wastewater reclamation. Therefore, NGWRP has a more extensive budget for monitoring compared to the reclamation system in Beaufort West.

The alarms at Beaufort West WRP are very important to secure a sufficient quality, but especially to protect the membranes. The process is constantly monitored and uses the same equipment that is used for on-line monitoring. If any of the on-line monitored values go out of specification, the plant automatically shuts down. Consequently, the alarms decrease the probability of low quality water leaving the system or permanently damage the membranes. All alarms that are triggered are also monitored by the supplier of the membranes to see if the operator is following manuals and taking correct actions.

2.4 ENVIRONMENTAL CONSIDERATIONS

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 reuse projects may have an environmental footprint and energy usage depending on the water reclamation technologies used.

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. Water reuse must therefore be evaluated in the context of other water supply and water augmentation options with consideration of environmental impacts, carbon footprint, ecological footprint and energy usage.

According to Stanford (2012), water scarcity and water supply shortages are not the only drivers for water reuse. Other reasons why certain regions in the USA where there are no water shortages are also implementing water reuse projects include the provision of ways to reduce the discharge of nutrients to rivers or dams, by rather using the water for irrigation of golf courses or public areas, and the provision of storage (surface reservoirs or underground aquifers) to retain the water for later use.

2.4.1 Environmental Considerations in South Africa

While South Africa is facing serious problems with the delivery of adequate services to its citizens as required by the Constitution, the same Constitution also put an obligation on different organs of state to ensure that the environment needs to be protected to the benefit of mankind. Section 24 in Chapter 2 of the Constitution of South Africa (Act 108, 1996) stated that:

"Everyone has the right: (a) to an environment that is not harmful to their health or well-being; and (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that: (i) prevent pollution and ecological degradation; (ii) promote conservation; (iii) secure ecological sustainable development and use of natural resources while promoting justifiable economic development."

The Constitution, in Section 152 of Chapter 7, further states that: (1) The objectives of local government are: (c) to promote social and economic development; (d) to promote a safe and healthy environment…".

From this fundamental piece of legislation 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. The Environmental Impact Assessment (EIA) procedure provided for a systematic approach towards finding the balance between developments and the protection of the environment.

Based on the obligation provided in the Constitution, various pieces of legislation have been developed to enable the implementation of these requirements. The following legislation is applicable:

2.4.1.1 The National Environmental Management Act (NEMA) (Act 107 of 1998)

The EIA procedures were originally governed by the Environmental Conservation Act (Act 73 of 1989) which provide for specific steps to be followed and regulations were promulgated to list the activities that need to adhere to these procedures. On 18 June 2010 a new and more comprehensive set of regulations were promulgated under Section 24 of the NEMA; Regulation 543, governing the reporting process to be followed and Regulation 544, 545 and 546 (also refer to as listing notices 1, 2 and 3 respectively), providing the list of activities that need to be subjected to the EIA process, with 544 and 546 providing the list of activities that needs to be subjected to a Basic Assessment procedure and 545 providing the list of activities that need to be subjected to the Scoping procedure.

Regulation 544 provides for, among others:

- Activity 15/44 – The construction of facilities for the desalination of sea water with a design capacity to produce more than 100 cubic metres of treated water per day or the expansion of an existing facility with more than 100 m^3/day.
- Activity 12/40 – The construction of: (i) canals; (ii) channels; (iv) dams; (x) buildings exceeding 50 square metres in size or the expansion thereof with more than 50 m^2; or (xi) infrastructure or structures covering 50 square metres or more of the expansion thereof with more than 50 m^2 where such construction occurs within a watercourse or within 32 metres of a watercourse, measured from the edge of a watercourse, excluding where such construction will occur behind the development setback line.

2.4.1.2 The National Environmental Management: Waste Act (NEM: Waste Act) (Act 59 of 2008)

Section 19 makes provision for the promulgation of regulations to manage waste activities. The associated regulation 718 was promulgated on 3 July 2009 and makes provision for two sets of activities i.e. Category A and Category B activities. Category A activities listed those activities that need to be subjected to the Basic Assessment procedures, while Category B activities need to adhere to the Scoping procedures. These procedures are as stipulated in Regulation 543 under the NEMA, previously discussed.

Category A activities include, among others:
(II) The treatment of effluent, wastewater or sewage with an annual throughput capacity of more than 2 000 m^3 but less than 15 000 m^3.
(18) The construction of facilities for activities listed in Category A of this Schedule (not in isolation to associated activity).
(19) The expansion of facilities or changes to existing facilities for any process or activity, which requires an amendment of an existing permit or license or a new permit or license in terms of legislation governing the release of pollution, effluent or waste.
(20) The decommissioning of activities listed in this Schedule.

Category B activities include, among others:
(7) The treatment of effluent, wastewater or sewage with an annual throughput capacity of 15 000 m^3 or more.
(11) The construction of facilities for activities listed in Category B of this Schedule (not in isolation to associated activity).

2.4.1.3 The National Water Act (NWA) (Act 36 of 1998)

The NWA listed a number of actions as "water uses" for which a license is required, unless an authorisation has been granted in terms of the relevant published general authorisations. These water uses include, among others:
(e) engaging in a controlled activity identified as such in section 37(1) or declared under section 38(1); [Section 37 (1) – The following are controlled activities: (a) irrigation of any land with waste or water containing waste generated through any industrial activity or by a water work. Section 38 allows the Minister to declare any activity as a controlled activity.]
(f) discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
(g) disposing of waste in a manner which may detrimentally impact on a water resource;
(h) disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;

The general authorisation (GA) refers to above has been published on 26 March 2004 in Government Gazette 26187 and is referred to as GA 399. GA 399 is applicable to all the water uses listed above [(e), (f), (g) and (h)], and its validity was extended till 1 April 2012 with Government Notice No 417 (16 May 2011). Although this technically means that none of the water uses as listed above can be executed under a general authorisation and that a license is required, it is believed that the Department of Water Affairs still consider the GA as applicable and that these water uses therefore can be implemented without a license.

For all of the abovementioned water uses a license is required and according to NEMA, an EIA process needs to be followed if a license is required by any organ of state.

2.4.1.4 National Heritage Resource Act (NHRA) (Act No. 25 of 1999)

The NHRA requires in Section 38 a heritage resource authority (South African National Heritage Resources Agency (SAHRA)) to asses for a number of development categories, whether such a development might have an negative impact on the heritage resources and if there is a possibility of such an impact, an EIA process need to be followed. The developer of such a category of development needs to inform SAHRA of his intent to proceed with such a development, where after an assessment needs to be done. These development options include the following in Section 38:
(a) the construction of a road, wall, powerline, pipeline, canal or other similar form of linear development or barrier exceeding 300m in length;
(c) any development or other activity which will change the character of a site—

(i) exceeding 5 000 m^2 in extent; or

(ii) involving three or more existing even or subdivisions thereof; or

(iii) involving three or more erven or divisions thereof which have been consolidated within the past five years; or

(iv) the costs of which will exceed a sum set in terms of regulations by SAHRA or a provincial heritage resources authority;

(c) any other category of development provided for in regulations by SAHRA or a provincial heritage resources authority,

In all cases where the so called Specific Environmental Management Acts (SEMA's) requires that an EIA procedure be followed, that procedure needs to be according to the NEMA regulations as discussed above. The main purpose of the requirements through various Acts, as discussed above, when considering the development or expansion of a water treatment facility, is to ensure that the impact such a project might have on the environment needs to be limited. In order to ensure sustainability the so called "precautionary principal" needs to be adhered to, despite the legislative requirements discussed above.

2.4.2 Residuals management

The proper disposal and treatment of concentrate and residuals will be needed if non-destructive processes are used. Therefore, the following actions are recommended:

- Identify the need for additional treatment (a regulatory framework is needed to manage concentrate).
- Define the proper disposal.
- Understand public health considerations.
- Consider heat recovery in wastewater.
- Consider cost issues.

Note that this issue pertains to all recycled water types (and not only direct potable reuse), and is related to source control efforts (residuals management starts at the source). Managing salinity is also important. The reader is also referred to WRC publications on "Guidelines for the Utilisation and Disposal of Wastewater Sludge", a series of five volumes (WRC Report No. TT 349/09, June 2009) for more information on residuals management and disposal.

2.4.3 Brine disposal options

A number of alternatives exist for the disposal of brine, and the choice of which to use is influenced by environmental considerations (legislation; permits by regulating authorities), location of the desalination plant, and cost. The most generally used treatment and disposal options are discussed below (Schutte, 2005).

2.4.3.1 Ocean Disposal

For seawater or brackish water desalination, brine disposal in off-shore turbulent zone (to ensure mixing) may be acceptable. The cost involved may be reasonable, and consists mainly of capital cost of the pipeline and diffusers, and pumping costs as operating expenditure. A permit from the relevant authorities will be required for this activity.

2.4.3.2 Surface water discharge

Disposal to a receiving body of surface water (*e.g.* river, ocean, lagoon) that will not be adversely affected by the concentrate. This activity will also require a permit.

2.4.3.3 Sewer discharge

Discharging plant residuals into the collection system of a wastewater treatment facility. This activity will require agreement with the municipality. Generally, this would only be an option where small volumes of brine is concerned (*e.g.* from small desalination plants).

2.4.3.4 Deep well injection

Injecting concentrate into an acceptable underground aquifer using a disposal well. This is practised widely in some overseas countries, notably the USA, but has not been applied in South Africa to date, presumably because of the potential pollution of groundwater.

2.4.3.5 Evaporation ponds

Solar evaporation, generally limited to small flows and areas of arid climate (with high evaporation rates and low rainfall) and inexpensive land. Essentially a zero-liquid discharge process. Because of potential pollution of the groundwater, ponds must be lined, which has a significant cost implication. Evaporation ponds also require a permit or license from the relevant authorities.

2.4.3.6 Land application

Disposal to percolation ponds or use as irrigation water.

2.4.3.7 Livestock watering or irrigation

This may be feasible for low TDS brines (generated during desalination of brackish waters by low rejection membranes, and/or at low recovery rates). Irrigation may be feasible on salt-tolerant plants.

2.4.3.8 Co-disposal

Blending and disposal with wastewater treatment plant effluent or power plant cooling water, into ash dams or ashing systems for dust suppression. Potential pollution due to leaching may exist.

2.5 OPERATION AND MAINTENANCE ASPECTS

In considering which technologies are needed to treat a specific wastewater feed to the required health-based final water quality, the multi-barrier approach has been used successfully to minimise the risks of pathogens, micropollutants (chemicals of emerging concern) or treatment by-products to meet international norms and standards. An important consideration in the selection of appropriate technologies for water reclamation and reuse plants is the ability of the available technical workforce in a region to operate and maintain these technologies to produce the required water quality on a consistent basis. This is especially important in developing countries.

In water reclamation plants, monitoring of the unit processes, and in particular those preceding the treatment barriers, is of critical importance to ensure that the unit processes functions optimally and that all the barriers are maintained. The unit processes should be monitored for function, performance and cost-efficiency. The processes should include all pre-treatment processes, main treatment processes, post-treatment (disinfection, corrosion control and blending) and processes concerned with the treatment and disposal of plant residuals. Flow measurements, dosing rates, unit loadings, pressures, visual observations and water quality indicators are the important monitoring parameters that are applicable to each unit treatment operation. Recording the performance of any treatment plant should begin immediately during start-up and continue during operation. The frequency and type of monitoring in a water reclamation plant depend on the treatment objectives, location of the barriers and critical control-points, and availability of resources (although the minimum requirements should never be compromised because of the potential health impacts.

The following are important considerations when drawing up an operational monitoring program for a reclamation and reuse plant:

- Evaluate current wastewater treatment plant monitoring (important parameters are COD, pH, ammonia, nitrate, phosphate, suspended solids, total dissolved solids and faecal coliforms in the final effluent).
- Minimize the potential for fouling during advanced treatment. Here aspects such as the occurrence of algae in maturation ponds, increased organic loadings and ammonia is especially important.
- Develop a list of constituents to be measured for operational monitoring, including: total organic carbon, characterization of organics, and other parameters that may provide comparison of treatment effectiveness.
- 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).

- Evaluate the removal of EDCs and other CECs by membranes and advanced oxidation processes (AOPs).
- 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.
- Examine the use of sidestream treatment rather than returning the untreated waste stream to the head of the plant and recycling constituents.
- 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).

2.5.1 Real-Time online monitoring

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. This process may include:

- Determine which, if any, surrogate parameters should be monitored.
- Determine the monitoring needs for chemical constituents and microbial pathogens.
- Define performance standards for real-time online monitoring.
- Develop online monitoring regimes.
- Validate regimes on pilot- and full-scale installations.

2.5.2 Rapid feedback methodology

If neither of real-time online monitoring or engineered buffers are readily available, a methodology that provides very rapid feedback for parameters of interest, including microbiological parameters, CECs, and other chemicals should be used. These are methods that are normally accurate, reliable and capable of being readily integrated into Supervisory Control and Data Acquisition (SCADA) systems at water reclamation facilities.

2.5.3 Maintenance programs (preventative maintenance)

Maintenance is critically important at water reuse plants, particularly to ensure good performance of the treatment barriers. A detailed Operation and Maintenance Schedule should therefore be available for the reclamation plants, including any pre-treatment, post-treatment and residuals handling facilities. The maintenance of equipment and machinery at a works can be carried out in several ways. These can be classified as:

- routine preventative or planned maintenance
- breakdown maintenance
- equipment replacement.

Budgeting for maintenance will require that sufficient funding is available for the following:

- Preventative maintenance – operating budget
    - Labour (staff time, person hours)
    - Parts and supplies
    - Equipment
- Emergency maintenance – operations reserve account
    - Labour (overtime)
    - Materials
    - Replacement of equipment
    - Contractors
- Equipment replacement
    - Evaluation and design
    - Labour
    - Equipment cost

In South Africa, it is a quite common at water supply facilities that insufficient funds are budgeted for maintenance of the facilities. Moreover, if these funds are not properly ring-fenced it is often used for other purposes and then not available for the original intended maintenance. This should be addressed at a high level.

2.5.4 Staffing, training and scarce skills development

2.5.4.1 Operating

Operation of any treatment plant can be performed under contract, but it is preferable that the plant is operated by personnel of the water supply authority (municipality or water board). In South Africa, with limited water treatment operations skills, the tendency is currently towards using PPP agreements for management and operation of reclamation plants.

Operation of water reclamation plants may require skilled personnel, especially for membrane and advanced oxidation processes. Plant operators should have the skills necessary to perform daily operation of the plant and to report any deviations from normal operating parameters.

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. This would require some form of training in membrane treatment and oxidation processes, albeit short courses or as part of formal training. This personnel member would be either a technician, technologist or engineer.

2.5.4.2 Maintenance

Sufficient labour must be available and funded for preventative maintenance functions. A good preventative maintenance program will document the schedule and work plan for each maintenance function. This schedule serves as the basis for estimating the labour requirements for preventative maintenance.

To determine trade and person-hour requirements for each preventative maintenance function, the function should be broken down into tasks. The tasks can then be analysed further to determine person-hours required for the specific maintenance function and the specific trades needed. A general summary for the activities associated with each maintenance task is then provided.

It is important to emphasize the need for using trained and experienced individuals to perform maintenance functions. In larger systems, individuals who are specialised in each trade will in all likelihood be available to service necessary equipment, or to contract out for speciality maintenance work, such as electrical control panel repair or generator maintenance.

2.5.5 Operating manuals

A detailed operating manual is an essential part of any water treatment plant, and should be made available during the commissioning of the plant. The consulting engineer must ensure that a set of operating manuals are provided to the client prior to or during commissioning, and that the operating personnel receives training on how to read and use the manuals. The manuals for a reclamation plant should contain all information required for the trouble-free operation of the plant, which should include the following:

- overall description of the reclamation plant (with flow diagrams)
- treatment philosophy
- description of pre-treatment processes
- description of main processes in the reclamation plant
- description of post-treatment processes
- description of residuals management processes and procedures
- design criteria
- start-up procedures
- normal operating procedures (day-to-day)
- cleaning procedures (for separation processes, filters, membranes and the plant as a whole)
- shut-down procedures
- process control and quality control procedures (monitoring)(see 9.1 above)
- trouble-shooting

- summary of technical specifications
- drawings
- safety aspects
- glossary/index

2.6 SOCIAL AND INSTITUTIONAL ASPECTS

The importance of public acceptance of any water supply scheme is widely recognised. It is in particular a crucial consideration where potable reuse of wastewater is one of the alternative or supplemental supply options. This is also the case where treated municipal wastewater is used for irrigation of food crops. Public perceptions and cultural or religious taboos may create obstacles to certain water reuse applications. Water users attach religious, cultural and aesthetic values to water and any water reuse project must remain sensitive to these values.

2.6.1 Public perceptions and public involvement in decision-making

The following important aspects are critical to consider as part of public perception:

- Public participation
- Public engagement
- Public acceptance
- Subjective or perceived norms and values
- Social capital
- Economic implications
- Institutional aspects

2.6.2 Institutional aspects

Water reuse projects have many sophisticated technical, engineering, financial, operational and maintenance aspects. A key consideration to any such project is the fact that the water typically has to be treated to improve/upgrade its quality, before it is fit for reuse by a downstream user. The downstream user must be guaranteed an appropriate quality of water to protect designated use of the water. Reuse projects therefore require a high level of confidence in the implementation and operating agencies.

A public sector agency, such as a municipality or water board must have a minimum threshold of capacity and competency, (in terms of technical expertise, planning ability, project management capability, financial strength and rating), be a trusted water services deliverer and be accepted by the community and stakeholders as a reliable organization, before it can be considered as capable of implementing a water reuse project.

An agency/organisation must be able to demonstrate the capability to implement water reuse projects. It is therefore likely that the agencies and organisations with an acceptable capability and capacity profile to implement water reuse projects would be limited to metropolitan municipalities, water boards, some larger local municipalities, private companies specialised in the water sector and public private partnerships.

Private sector management, engineering and financing capacity related to water reuse, as demonstrated by several successful water reuse projects in mining and industry is well established in South Africa. International interest in local water reuse projects has been expressed. The substantial private sector capacity must be leveraged in the implementation of water reuse projects.

2.7 COST CONSIDERATIONS

Apart from water quality requirements and the source of supply, the costs of water supply schemes are also determined by the geographical location (topography, climate, distance from supply sources) and the water supply costs (raw water costs, abstraction costs and bulk transport costs (pumps and pipelines)). Where the costs of the raw water supply are becoming increasingly higher, the cost-efficiency of water reclamation schemes is making such schemes more competitive with other alternatives. DWA (2011) points out the important premise that the economic value/cost of water must always be seen in the broader context of affordability, reliability and responsible use of a limited resource.

2.7.1 Factors influencing the cost of reuse systems

A number of factors have an influence on the cost of technologies that may be used for water reclamation or reuse projects. The following are factors that influence the cost of technologies that are used in water reclamation projects:

2.7.1.1 Plant and technology costs

The actual cost of the equipment may vary significantly for different processes and manufacturers.

2.7.1.2 Energy sources

Because energy is one of the largest O&M cost components, water reclamation costs are also very sensitive to changing energy prices. Consideration of various energy sources is therefore important to reduce the overall cost of the water supply system.

2.7.1.3 Feed water intake

Large distances from the feed water source increase the capital costs of the reclamation plants.

2.7.1.4 Feed water quality

The composition of the feed water has a direct influence on the capital and operating cost, especially where pre-treatment is required. The poorer the feed water quality, the more advanced treatment technologies are required, resulting in higher capital and operating costs.

2.7.1.5 Disposal of waste streams

The disposal of waste streams (sedimentation residuals, filter backwash water, membrane backwash and brine streams) can have a significant impact on the total capital and operating cost of the reclamation system. New waste disposal legislation requires treatment and disposal facilities that are costly and greatly determines the feasibility of various options.

2.7.1.6 Plant life

The amortisation period, which is determined by the plant life, affects the capital costs and the unit treatment costs.

2.7.1.7 Interest rates

The interest rates affect the capital costs, performance ratio, total investment and selection of the preferred plant.

2.7.1.8 Site costs

Land costs are a major determinant of the location preference. An important factor is the cost of transporting the water to this location. Water transport over long distances will increase the unit cost of the treated water.

2.7.1.9 Product water quality requirement

This criterion determines the number of stages of the final treatment steps, but the cost implication is considerably less than for the feed water quality influence.

2.7.1.10 Pre-treatment

This relates to the quality of the feed water (see above) and can have a substantial effect on the overall cost of the process configuration.

2.7.1.11 Chemical costs

Chemicals may be required for pre-treatment, coagulation, cleaning of membranes and post-treatment, and can add to the operating costs of the technologies. The local availability and price are important considerations.

2.7.1.12 *Availability of skilled labour*

Skilled labour for operation and maintenance of the treatment technologies, and in particular for the more advanced technologies, is not always readily available. To source these skills and/or to provide specialized training will increase the O&M costs of the treatment plant.

2.7.1.13 *Storage and distribution of the final water*

This is not a part of the treatment system, but does influence the overall project cost.

2.7.2 Costing criteria

2.7.2.1 *Capital costs*

Swartz *et al* (2013) lists cost estimating and economic criteria that can be used in the development of water supply facilities and infrastructure. The capital costs of water supply projects consist of the following:

a. Construction Capital Cost

Construction cost is the total amount expected to be paid to a qualified contractor to build the required facilities at peak design capacity.

b. Non-construction Capital Cost

Non-construction capital cost is an allowance for the following elements associated with the constructed facilities:

- Facilities planning
- Engineering design
- Permitting
- Services during construction
- Administration

2.7.2.2 *Land Cost*

The market value of the land required to implement the water supply alternative.

2.7.2.3 *Land Acquisition Cost*

The estimated cost of acquiring the required land, exclusive of the land cost.

2.7.2.4 *Total Capital Cost*

Total capital cost is the sum of construction cost, non-construction capital cost, land cost, and land acquisition cost.

2.7.2.5 Equivalent Annual Cost

Total annual life cycle cost of the water supply alternative based on service life and time value of money criteria established herein. Equivalent Annual Cost accounts for:

- Total Capital Cost
- Operations and Maintenance (O&M) costs (with the facility operating at average day capacity)
- Time value of money (annual interest rate)
- Facilities service life

2.7.2.6 Unit Production Cost

Equivalent Annual Cost divided by total annual water production.

2.7.3 Treatment Facility Cost

Public perception and effluent quality standards in water reclamation projects demand advanced water reclamation facilities, and back-up systems to provide additional reliability. It should also include the cost of well-equipped laboratory facilities. A typical capital cost breakdown for water treatment plants are provided below (Figure 2.9) (Swartz *et al*, 2012). The ratios will be in the same order for water reclamation plants.

Civil **60%**	**Electrical** **12-15%** consisting of **Electric (80%)** **Electronic (20%)**	**Mechanical** **25-28%**

Figure 2-9: A typical capital cost breakdown for water treatment plants (Swartz *et al*, 2012)

2.7.4 Operating costs

Operating costs include the following:

- Human resources (personnel)
- Chemicals
- Energy
- Maintenance cost
- Management cost
- Safety
- Raw water cost
- Plant residuals disposal (including brine disposal)
- Monitoring (including Blue and Green Drop costs)
- Training costs

2.7.5 Distribution System Cost

The cost components of a reclaimed water distribution system are similar to that of a potable water supply system. The cost of a reclaimed water distribution system is project-specific, depending on the type of reuse. In general, indirect potable reuse is less expensive than the direct potable reuse applications due to additional system redundancies and treatment processes required for direct potable reuse. Non-potable reuse can be more expensive than indirect potable reuse because it requires a separate distribution system to convey the reclaimed water to the end users, and may also require the installation of irrigation systems and seasonal storage reservoirs.

2.8 SOUTH AFRICAN COST COMPARISON STUDY

This section introduces the costing data of nine plants that were analysed in this study. The procedures performed on the various components of the costing data of these plants are described and the final present value unit costs to produce potable water at each of these plants are presented. The percentage contributions of the components to the cost of each plant are displayed in graphical format to allow for ease of comparison in the discussion of results. A comparison was made of the capital and operating costs of a number of water reclamation plants. It includes a comparison with the costs of local desalination plants, as well as with the costing figures supplied by some of the large water boards in South Africa (as presented in Swartz *et al*, 2006).

2.8.1 Raw data collection

The general information of the data collected from the various plants analysed in this study is displayed in Table 2.4. Amatola Water and Umgeni Water do not have values for their capacity as it was never known how much treated water the costing data was accounting for. The colour-coding of Table 2.6 allows for simple general comparison of treatment procedures.

2.8.2 Data manipulation

This section describes the various manipulation procedures applied to the raw data obtained for the nine plants.

2.8.3 Consumer Price Index

The Consumer Price Index (CPI) is an indication of the changes in price level of goods and services purchased urban consumers. The CPI can be used as a measure of inflation for items such as the value of wages and for regulating the prices of general products. Therefore, in this study the CPI of South Africa has been used to project the costs of personnel at various plants where the data is outdated from the present value. The general costs incurred at plants have also been projected to present value using the CPI. Courtesy of (Statistics South Africa, 2012a), Table 2.5 shows the annual

South African CPI values that were used to calculate the new annual personnel and general costs of a plant each year, from the given year to 2012.

Table 2-4: General information of treatment plants analysed in this study

Plant Type	Plant name	Location	Capacity (ML/d)	Year of available data	Source of costing data
Conventional	**Rand Water**	Gauteng	5260	2004	(Swartz *et al.,*2006)
	Amatola Water	Eastern Cape	NA	2004	(Swartz *et al.,* 2006)
	Umgeni Water	KwaZulu-Natal	NA	2012	(Umgeni Water, 2010)
Desalination	**Bitterfontein**	Western Cape	0.288	2004	(Swartz *et al.,* 2006)
	Sedgefield	Western Cape	1.5	2010	(Civil designer, 2010)
Water reclamation	**NGWRP**	Windhoek, Namibia	21	2003	(du Pisani, 2006:79)
	Beaufort West	Western Cape	2	2012	(Marais and von Durckheim, 2012)

The formula used to perform this calculation is shown in equation 2.1:

$$P_{n+1} = P_n \times (1 + CPI) \qquad \text{[Equation 2.1]}$$

where:

P_{n+1} = personnel cost at year n+1
P_n = personnel cost at year n
CPI = annual increase of CPI as a percentage (%)

This formula is used consecutively until n+1 = year 2012. The value of P_{n+1} will then be equal to a good approximation of the cost of personnel in the year 2012.

Table 2-5: South African CPI annual average percentage increase (adapted from (Statistics South Africa, 2012a))

Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Average	5.8%	1.4%	3.4%	4.6%	7.2%	11.5%	7.1%	4.3%	5.0%	5.7%

Table 2-6: Treatment train and capacity of each advanced treatment plant analysed

PLANT	WATER RECLAMATION				DESALINATION	
	NGWRP	**NEWater**	**GWRS**	**Beaufort West**	**Sedgefield**	**Bitterfontein**
CAPACITY (ML/d)	21	273	265	2	1.5	0.288
TREATMENT TRAIN	PAC	Micro-filtration	Micro-filtration	Phosphate removal	Direct intake	
	Coagulation/ flocculation	Reverse osmosis	Reverse osmosis	Settling	Pre-disinfection	Reverse osmosis
	Dissolved air flotation	Advanced oxidation	Advanced oxidation	Rapid sand filtration	Reverse osmosis	
	Rapid sand filtration	Chlorination	Chlorination	Ultra-filtration	Chlorination	
	Ozonation			Reverse osmosis		
	BAC + GAC			Advanced oxidation		
	Ultra-filtration			Chlorination		
	Chlorination					

2.8.4 Energy tariff index

In order to project outdated energy cost fractions of a plant's annual cost it was necessary to obtain the energy tariff annual percentage changes from ESKOM, South Africa's leading electricity public utility. The values shown in Table 2.7 were used to project the Energy component of a plants cost to 2012 wherever applicable. The formula used to perform these projections is similar to Equation 2.1, however, the CPI percentage is replaced by the Eskom tariff increase percentage.

Table 2-7: Eskom energy tariff annual percentage increases (adapted from (Eskom, 2012))

Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Average (%)	8.4	2.5	4.1	5.1	5.9	27.5	31.3	24.8	25.8	16.0

2.8.5 Producer Price Index

The Producer Price Index (PPI) measures the average change in prices received by domestic producers for their output. As seen in the business plan of Umgeni Water for 2010/11-2014/15 (Umgeni Water, 2010) the South African PPI was used to project the chemical cost component and the maintenance cost component of each plant, wherever applicable. Table 4.5 contains the annual average South African PPI percentages that were used in this study. This index is applied in the same way that the CPI and Energy tariff index were applied. The formula used to perform the projection was again Equation 2.1 except the CPI percentage was replaced by the PPI percentage. Due to the negative value of the PPI percentage in the year 2009, the cost of chemicals and maintenance will drop slightly in the projection of the year 2009 in comparison to the year 2008.

Table 2-8: South African PPI annual average percentages (adapted from (Statistics South Africa, 2012b))

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Average	2.2%	2.3%	3.7%	7.7%	10.9%	14.2%	-0.1%	6.0%	8.4%	6.0%

2.8.6 Capital redemption

Most projects have a capital redemption plan set up in order to pay off the capital cost of the project. The capital redemption is broken into annual or monthly payments which make the total amount easier to comprehend and manipulate. As the capital of a water treatment plant is often included as a component of its annual cost (and as allowance has been made for it in this study) each plant analysed in this study requires the initial capital to be broken into annual components. In most cases the data obtained on plants already contained a component of annual capital cost/redemption. Where the capital cost of a plant was only available as a lump sum, assumptions had to be made. The assumption, which was observed in a Desalination Guide for South African Municipal Engineers (Swartz *et al.,* 2006) is that the capital redemption period runs for 25 years at an interest rate of 12%. To make sense of these values equation 2.2 has been presented below. The equation gives an annuity factor which can be multiplied to the total capital expenditure of a project to determine the annual cost of capital over those 25 years.

$$\alpha = \frac{i(1+i)^n}{(1+i)^n - 1} \qquad \text{[Equation 2.2]}$$

where:
α = annuity factor (0 < α <1)
i = annual interest rate (%)
n = number of compounding periods (years)

In this study, where i = 12% and n = 25 years, then α = 0.1249997

This annual capital cost, whether as a unit cost per kilolitre or as a total annual cost, will remain constant for every year of projection to present value as it has been calculated with an annuity factor which already incorporates an interest rate.

2.8.7 Prime interest rate

The prime interest rates for South Africa are used to project the true value of capital from a given year to a wanted year. Therefore, the total capital cost of a plant, or a process within a plant, was projected to 2012 using the prime interest rates for each year. This was done in order to compare whole costs of technologies, regardless of annual operating and maintenance (O&M) costs. This method is thus not used for the calculation of the capital cost component in a plant's annual cost. Equation 2.1 is again used to perform these projections however the CPI value is replaced by the prime interest rate percentage for each year. The prime interest rates from 2003 to 2012 of South Africa can be found in Table 2.9 below.

Table 2-9: South African prime annual average interest rates (adapted from (Viljoen, 2012))

Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Average(%)	13.4	11.0	10.5	15.67	13.75	15.17	12.5	9.5	9.0	8.5

2.8.8 Exchange rates

The plants from other countries that were analysed presented data which was of foreign currency to South Africa. It was therefore necessary to obtain the appropriate exchange rate between those currencies and the South African Rand at the correct period. Specifically, these countries were the USA and Singapore with the currencies of the US Dollar (USD) and Singapore Dollar (SGD) respectively. These currencies were necessary to manipulate the data of the GWRS in the Orange County of USA and the NEWater plants in Singapore. Table 2.10 shows the two average annual exchange rates that were necessary for this study and the year from which they were taken. The year for exchange was chosen according to the most recent year of which data could be obtained.

Table 2-10: Exchange rates used for the GWRS and NEWater plants (XE Corporation, 2012)

Exchange	**ZAR /USD**	**ZAR/SGD**
Year	2010	2007
Average annual rate (ZAR / currency)	7.54	4.70

After the foreign currency has been exchanged into ZAR terms, the remainder of the calculations for these two plants could continue in the same manner as the local plants, using the abovementioned indexes.

2.8.9 Final results

The steps and equations mentioned in the section above were applied to the available data wherever necessary. A spread sheet format was utilized to complete the calculations. Table 2.11 shows the typical calculations for the GWRS plant that were performed to arrive at a present value.

Table 2-11: Data calculations for GWRS to determine the present value of cost components

	USD annual total	ZAR annual total	R/kL (2010)	R/kL (2011)	R/kL (2012)
Personnel	$6,966,873.00	R 52,530,222.42	R 0.59	R 0.62	R 0.66
Energy	$6,347,318.00	R 47,858,777.72	R 0.54	R 0.68	R 0.78
Chemicals	$4,152,496.00	R 31,309,819.84	R 0.35	R 0.38	R 0.40
Maintenance	$3,540,947.00	R 26,698,740.38	R 0.30	R 0.33	R 0.34
Total O&M	$21,007,634.00	R 158,397,560.36	R 1.78	R 1.78	R 1.78
Capital	$19,666,513.00	R 148,285,508.02	R 1.67	R 1.67	R 1.67
General	$8,600,232.00	R 64,845,749.28	R 0.73	R 0.77	R 0.81
TOTAL	**$49,274,379.00**	**R 371,528,817.66**	**R 4.17**	**R 4.21**	**R 4.25**

In order to explain these results shown in Table 2.11, the manipulation of component of energy is explained below.

a. The annual total cost of energy in USD was multiplied with the exchange rate from the table to yield the total annual energy cost in ZAR:

$6,347,318.00 x 7.54 R/$ = R 47,858,777.72

b. The ZAR value was divided by the annual production of the plant in m^3/year to determine the unit cost of the plant :

R 47,858,777.72 ÷ 89000000m^3/y = R 0.54

c. This unit cost was then increase according to the index value of energy tariffs in Table 4.4, for the year 2011:

R 0.54 x (1+ 25.8%) = R 0.68

d. The 2011 unit cost is increased again using the index value of energy tariffs in Table 4.4, for the year 2012:

R 0.68 x (1+ 16%) = R 0.78

e. This value is then the final present value of the unit cost of energy use in the production of potable water at the GWRS in Orange County.

The present values of personnel, chemicals, maintenance and general cost components for this plant were determined in a similar manner to the energy component, except the appropriate indexes were used in steps 3 and 4 above. These indices were explained earlier. It must be noted that the capital value does not increase each year. This is because the interest has already been incorporated into the plant's annual capital cost so it will remain a constant value until the plant's redemption period is complete. The total unit cost of producing potable water at the GWRS plant is thus the sum of all the components mentioned. This value is R4.25/kL.

Table 2.12 displays the final unit costs (in Rand per kilolitre) that were determined for each conventional, desalination and water reclamation plant. Appendix C contains the full spread sheet of the calculations for each plant.

Table 2-12: Summary of present value unit costs (R/kL) for various water plants

	Rand water	Umgeni Water	Amatola Water	Sedgefield	Bitter-fontein	Goreanga b	Beaufort West
Capacity (ML/d)	5260			1.5	0.288	21	2
Cost components (R/kL)							
Personnel	0.67	0.71	1.31	0.44	5.10		2.88
Energy	0.85	0.23	0.74	2.77	3.39		1.88
Chemicals	0.17	0.08	0.24	2.18	1.10		3.06
Maintenance	0.40	0.26	0.50	0.46	1.64		2.61
Total O&M	2.09	1.28	2.80	5.86	11.22	6.44	10.43
Capital	0.11	0.25	0.39	3.73	1.50	1.84	4.43
General	0.22	2.15	0.45	0.00	0.93		1.39
TOTAL(R/kL)	**2.42**	**3.69**	**3.63**	**9.59**	**13.65**	**8.28**	**16.25**

In order to build up a form of comparison between the plants, a stacked column chart is presented to show the different plant unit costs and the proportion of each of the six components within each unit cost (Figure 2.10). For ease of comparison, pie charts showing the percentage of each of the six abovementioned cost components were created for each plant (Figures 2.11 and 2.12). Due to the nature of the NEWater data, it does not qualify to be displayed as a pie chart.

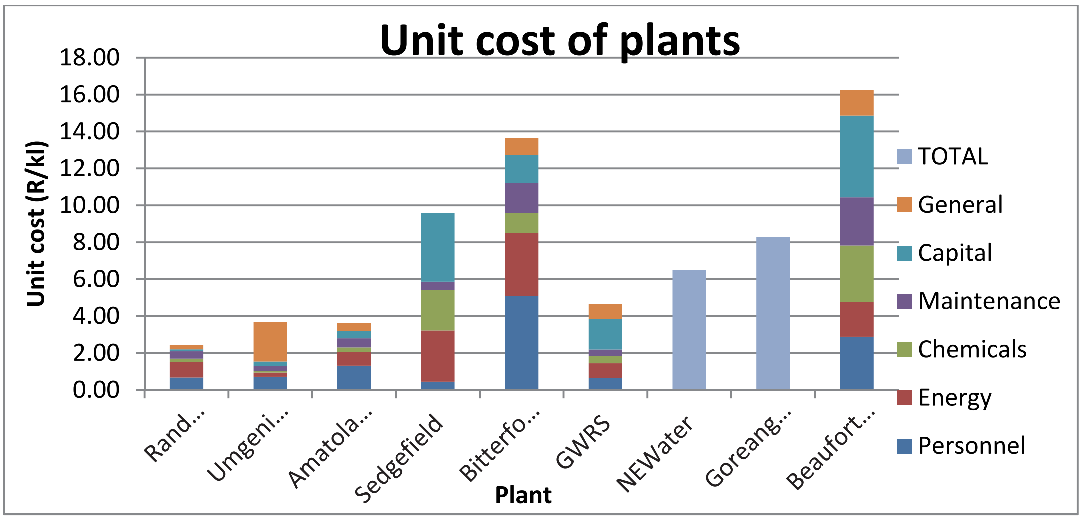


Figure 2-10: Stacked column chart of plant unit cost and component contribution

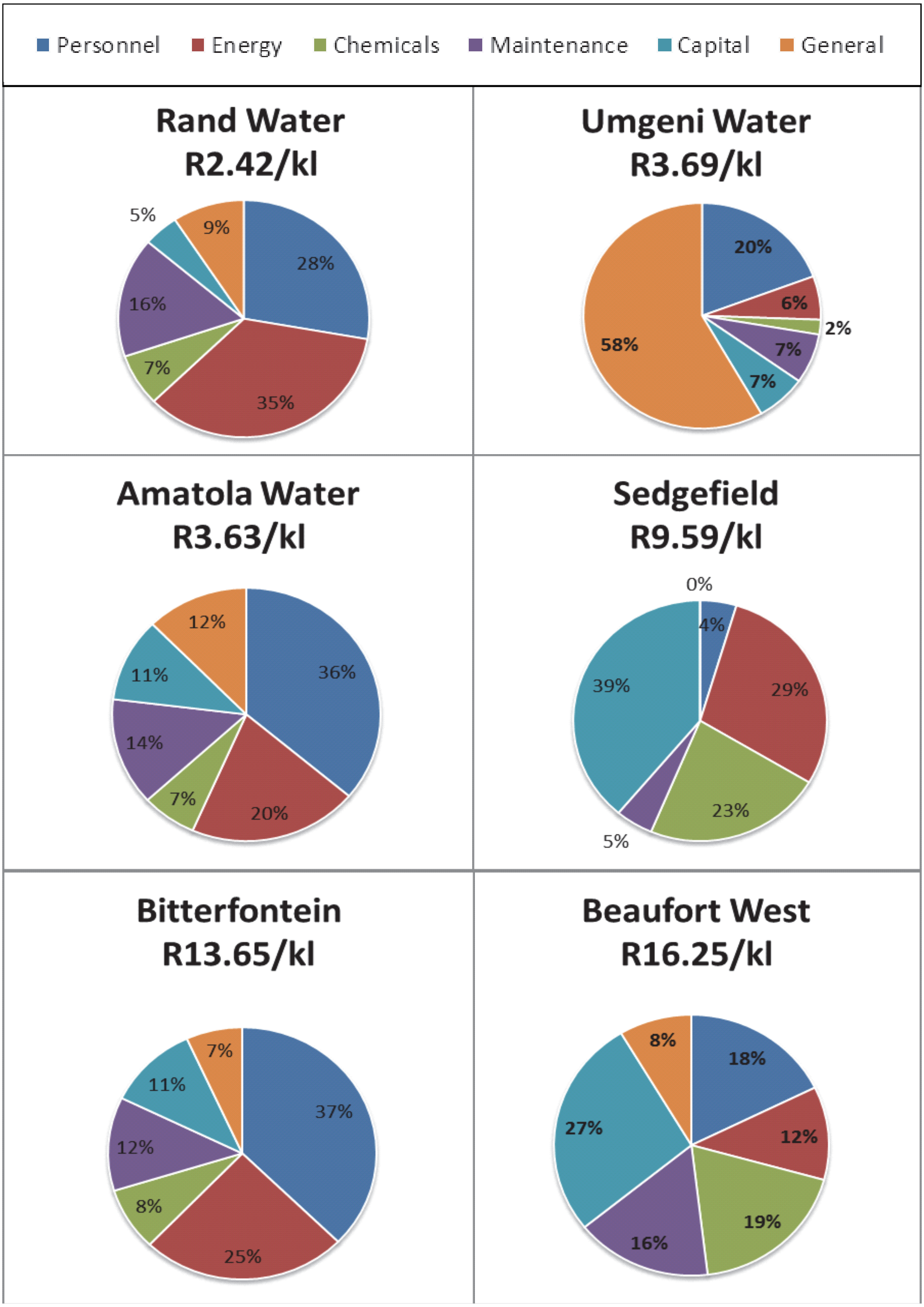
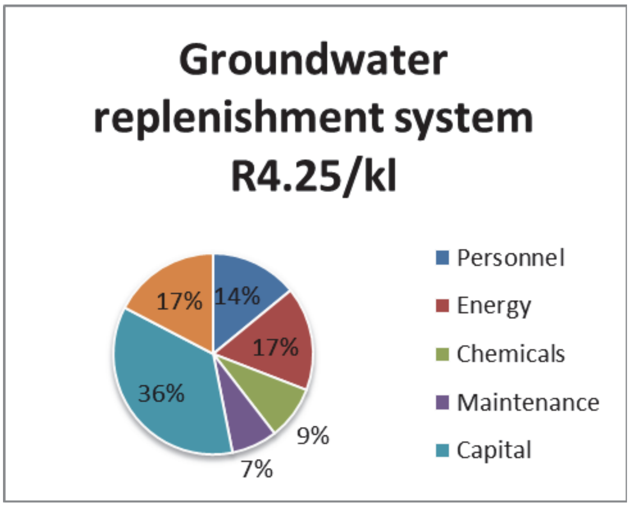


Figure 2-11: Pie charts of plant unit costs showing contribution of each component



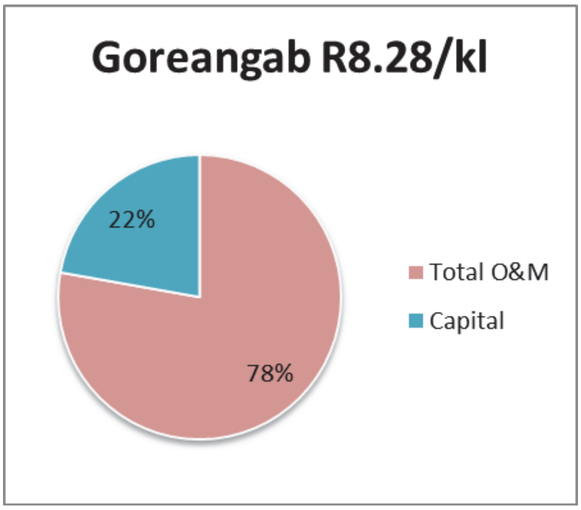


Figure 2-12: Pie charts of plant unit costs showing contribution of each component

A valuable graph of the relationship between the capacity of water reclamation plants and their unit cost is presented below (Figure 2.13). A logarithmic trend line shows the strong relationship between the variables. As the capacity of the plants increase, the unit cost decreases.

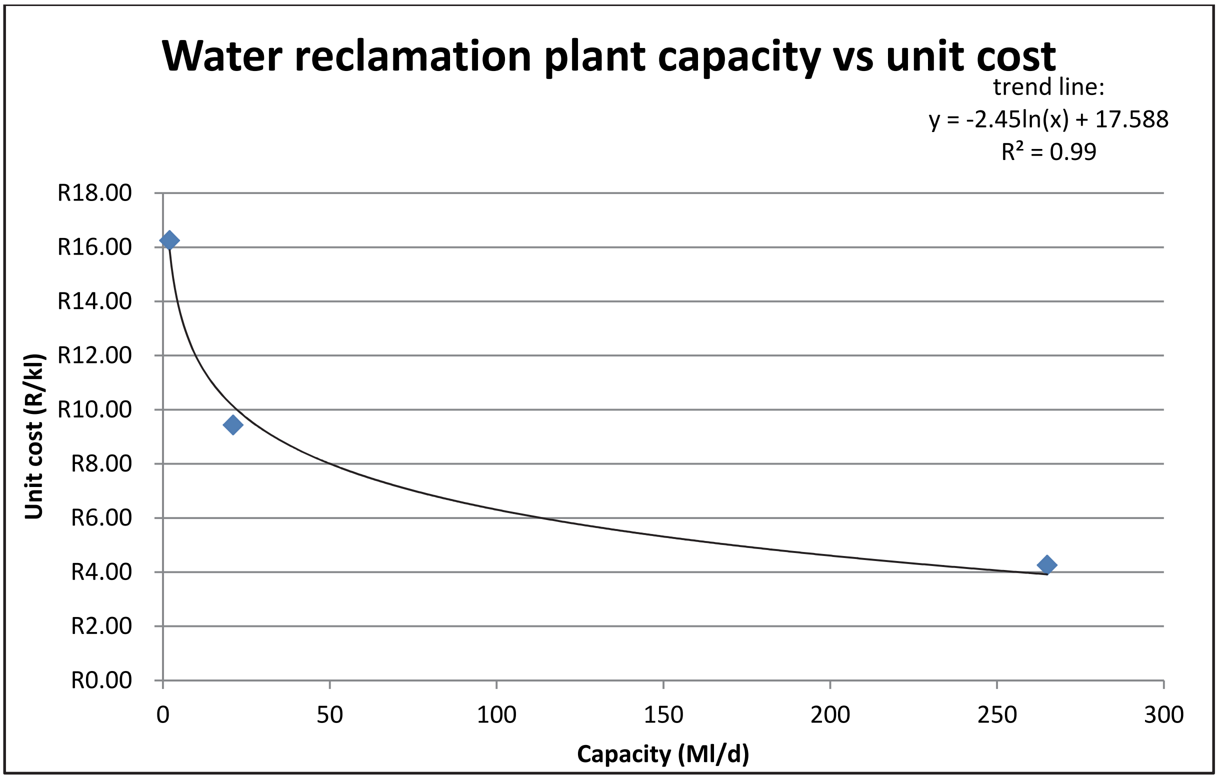


Figure 2-13: Water reclamation plant capacity and unit cost

CHAPTER 3: COSTING OF WATER RECLAMATION SCHEMES AND COMPARISON WITH CONVENTIONAL TREATMENT SCHEMES

3.1 INTRODUCTION

The WRC Water Reuse Costing Model (hereafter referred to as REUSECOST) that was compiled for this project is shown diagrammatically below. The model is an adaption from the WATCOST model that was developed in the WRC project TT 552/13 "*Development of a costing model to determine the cost-efficiency and energy efficiency of water treatment technologies and supply options*" (Swartz *et al*, 2013).

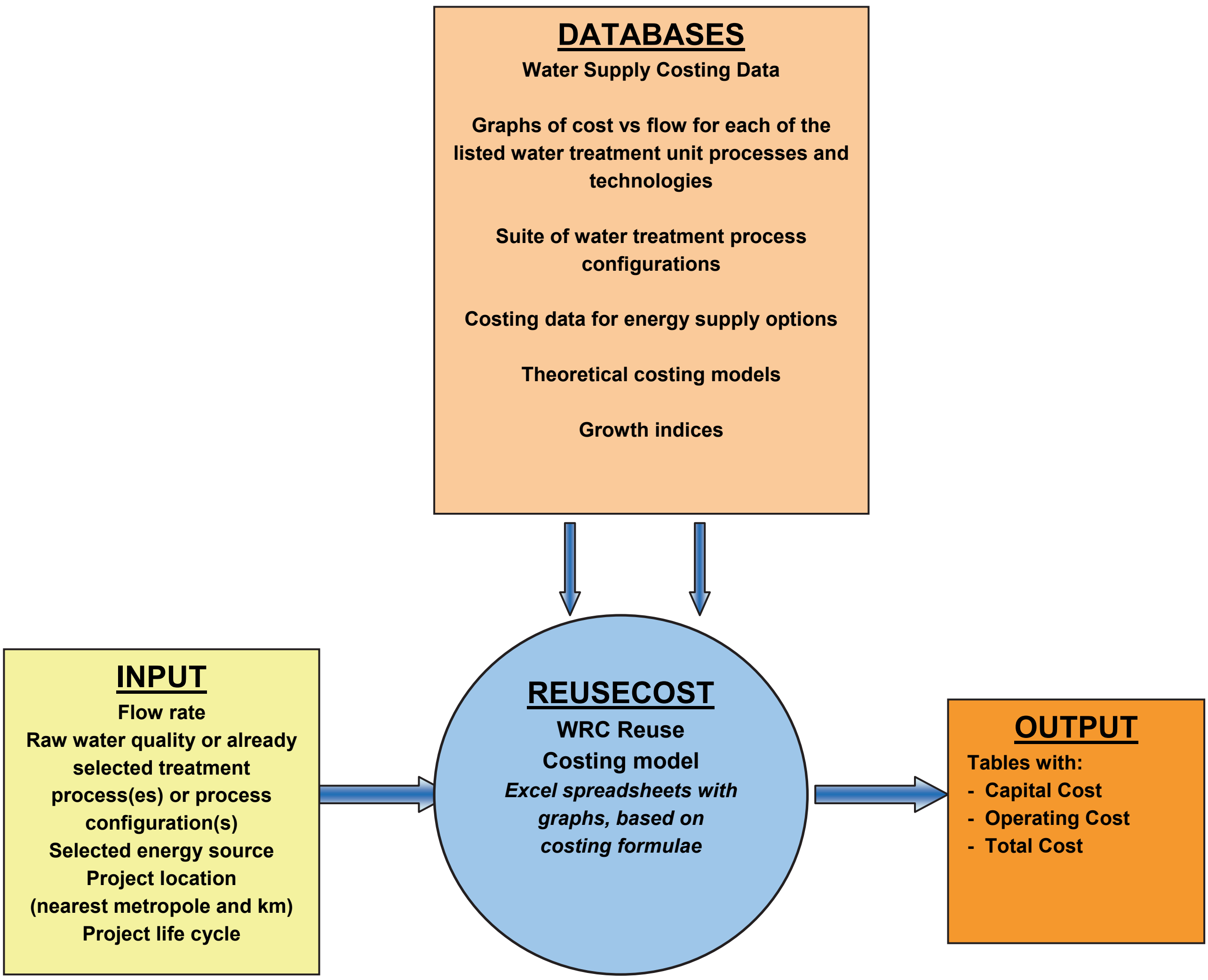


Figure 3-1: Schematic representation of the WRC Water Reuse Costing Model (hereafter referred to as REUSECOST).

In developing the WATCOST MODEL, and then adding costing data and process configuration for water reclamation facilities in compilation of the REUSECOST Model, a number of requirements were set for the model. The two models therefore have the following features:

- The models focus on the water treatment and water reclamation components of the water supply system, but include estimates for the following:
    - Raw water or raw wastewater transport (feedwater)
    - Clean water storage (reservoirs)
    - Distribution networks (various levels of service)
- The models produce outputs for capital costs, operating costs and total costs (in costs per annum and per kilolitre of water produced).
- The costs are based on life-cycle costing.
- Data used for calculating costs were obtained from local water supply and reuse projects of the past ten years, converted to present value using appropriate growth indices.
- The databases are structured in such a way to enable easy, annual updating.
- The model is spreadsheet based (Excel).
- The model attempted to be user friendly, unambiguous and easy to operate, requiring minimal data inputs from the user (drop down menus are used).
- The databases contain a suite of proposed treatment processes, so that the user can compare costs of different treatment units for a given raw feedwater quality range and flows.
- The WATCOST model is not a decision support tool, but will be designed in such a way that a decision-making functionality can be added seamlessly at a later stage. The REUSECOST model has been integrated with the Water Reuse decision-support model developed in this project and presented in Chapter 4 of the guidebook.
- The models include for variations in costs for undertaking water supply and water reclamation projects in different geographic areas.
- The models allow for cost escalation by updating unit costs and tariffs on an annual basis.
- It includes the costs of soft issues such as training, monitoring and control, compliance and management.
- The costs include the establishment and maintenance of security systems for protecting all the components of the water supply systems, i.e. catchments, water sources (surface water, ground water, and alternative water sources), abstraction facilities and raw water supply pipelines, water treatment plants, clean water reservoirs, distribution networks and consumer points.
- The models were designed in such a way that it can be modified at any time by the project team, and later by a designated administrator.

3.2 COMPONENTS AND ELEMENTS OF THE REUSECOST MODEL

The proposed model consists of the following four main components:

INPUT
MODEL
OUTPUT
DATABASES

Each of these components and the elements contained in each are shown below.

INPUT

1. Flow rate

a. Estimated quantity of water to be produced at the end of the design period of the project or current phase of the project, in megalitres (thousand cubic meters) per day

b. The model will assume that the reclamation plant will be in operation for 24 h/d. *(Should the required number of operational hours per day be less (say 8 h/d), then the plant design size will be increased proportionally to provide the same required volume of water per day).*

2. Raw water quality or already selected treatment process(es) or process configuration(s)

a. Turbidity (range and average, but preferably normal distribution).
b. Organics (measured as colour, DOC, COD or UV254)
c. Electrical conductivity.
d. Chlorophyll a (where applicable).
e. Iron.
f. Nutrients (ammonia, nitrates, phosphates)
g. Any other relevant macro- or micro-determinands which may dictate the type of treatment process to be used (for guidance, refer to WRC Report 1443/1/07).
h. Microbiological quality (faecal coliforms or *E. coli*).

3. Project location

a. Name of the nearest large city (metropole).
b. Distance in km from this metropole.
c. Exact location of plant (GPS coordinates if possible).

4. Supply of abstracted raw water to the treatment plant

a. Distance of raw water source from the treatment plant
b. Terrain (topography)

5. Clean water storage

a. Number of reservoirs.
b. Required storage time.

6. Distribution networks

a. Estimated number of consumers.
b. Proposed number and types of connection points.
c. Terrain (topography).

7. Project life cycle (normally design period, in years)

MODEL

1. <u>Process Configurations</u>

The model will access the chosen process configuration from the database of process configurations. Each process configuration will then route the program to each of the unit processes contained in that configuration. There may be more than one technology that can be opted for in most of the unit treatment processes, and the model will calculate costs for each of these, so that the user can compare costs for different options.

If the user does not provide a preferred process configuration(s), then the user will be able to select process from a list provided by the model, based on input data on raw water quality provided by the user. *The selection of applicable process configuration options is based on the knowledge base of applicable treatment processes for given raw water qualities).*

2. <u>Cost calculations for unit treatment processes</u>

The model will then calculate costs for the required flow rate for each unit treatment process (and each technology option that it may comprise) based on the formulae and graphs derived from and contained in the costing data database of the model (see the **DATABASE** component below for more details on how the costing data will be obtained and organized).

3. <u>Cost calculations for raw water transport</u>

Based on the hourly flow rate provided in the input component, or selected pipe size if the raw water conveyance pipe already provide for later phases of the project, the topography of the route and the distance in km of the abstraction point from the treatment plant, a cost will be calculated for the raw water transport to the plant.

A link will be provided to the model of Prof SJ van Vuuren as contained in the WRC Report TT278/06 "*Life Cycle Costing Analyses for Pipeline Design, with supporting software*". This model can also be used for calculation of pipe costs for final water distribution (see **<u>Cost calculations for the treated water distribution</u>** on the next page).

4. <u>Cost calculations for clean water storage</u>

The required storage period for clean water and the daily flow as provided in the input component will allow the calculation of reservoir size(s), based on standard free board and inlet/outlet arrangements.

5. <u>Cost calculations for the treated water distribution</u>

Only a rough cost estimate will be provided, as this would require a more detailed design by the user to do a more accurate cost calculation. The rough cost estimate will be based on the number of connection points and km of distribution network piping.

6. <u>Cost calculations for maintenance</u>

Maintenance cost will be calculated as a percentage of the total cost for the water supply system, and will depend on the water supply system, i.e. different maintenance percentages for different water supply systems.

7. <u>Cost calculations for planning, design and construction supervision</u>

Based on the type of water supply system and the total cost for construction, equipment, infrastructure and maintenance, a cost will be calculated for the planning, design and construction supervision of the project. This will be based on proposed percentages by professional bodies such as ECSA.

MODEL (continued)

8. <u>Cost calculations for operational management</u>

Costs will be calculated for all activities related to operational management of the water supply system, and the water treatment plant in particular, over the project life time (i.e. life cycle costs). This will be based on the DWA classification of the treatment plant, which in turn will be based on the capacity of the treatment plant (in ML/d) and the process configuration.

9. <u>Cost calculations for other items</u>

Any further cost items that will become apparent during the development of the model will be added to the total costs, and will be based on either the total calculated cost or on some other item(s) related to the characteristics and capacity of the treatment plant.

10. <u>Allowance for project location</u>

Adjustments will be made to certain cost items for water supply projects that are situated in remote locations and that will, for example, result in increased delivery costs, technical back-up and skills shortages.

11. <u>Project life cycle</u> (normally design period, in years)

The project design period or life cycle in years will determine the amortisation costs, which will be based on the current interest rate. Interest rates will be one of the indices links in the model.

OUTPUT 1

1. Table with Capital Cost

The table with Capital Cost will contain the following elements:

Element	Applicable range		Design quantity	Design unit	No of items	Cost per item	Cost per element
	Min	Max					
WASTEWATER FEED							
Raw water intake tower							
Raw water pumps							
ADVANCED WATER TREATMENT (WATER RECLAMATION/DIRECT POTABLE REUSE)							
Unit Process 1							
Unit Process 2							
Unit Process 3							
Unit Process 4							
Unit Process 5							
CLEAN WATER STORAGE							
Reservoir 1							
Reservoir 2							
DISTRIBUTION							
Distribution network (total amount)							
Sub Total Capital Cost							
Treatment Plant Yard Piping (* %)							
Landscaping and Rehabilitation (* %)							
Site Electrical and Controls (* %)							
TOTAL CONSTRUCTION COST							
Professional Fees (Planning, Design, Engineering, Legal)							
TOTAL CAPITAL COST							

OUTPUT 2

2. Table with Operating Cost

The table with Operating Cost will contain the following elements:

Element	Unit	Unit cost	No of units per day	Cost per day (Million)	Cost per year (Million)	Cost per kilolitre (R/kL)
Electricity	kWh					
Human Resources						
Chemicals						
Safety						
Total Maintenance						
TOTAL OPERATING AND MAINTENANCE COST						

OUTPUT 3

3. Table with Total Cost

The table with Total Cost will contain the following elements:

Total Capital Amortization

TOTAL CAPITAL COST: Present value	
TOTAL CAPITAL COST: Future value (Amortized over x years at y% interest)	

Total Cost Summary	Cost per day (Million)	Cost per year (Million)	Cost per kilolitre (R/kL)
Total capital costs (Based on future value)			
Total operating and maintenance costs			

3.3 REUSECOST COSTING DATABASE

3.3.1 Process Configurations

The Process Configurations database contains a comprehensive number of possible process configurations that are currently used in the production water for drinking purposes by water reclamation. These are the same five configurations shown in Table 3.1.

Table 3-1: Examples of configurations

Configuration	Treatment Processes
1	Chemical treatment – Phase separation – filtration – disinfection
2	Chemical treatment – Phase separation – filtration – membrane filtration – disinfection
3	Reverse Osmosis – Advanced Oxidation – Blending – Membrane filtration – UV disinfection – Activated Carbon – Disinfection
4	Membrane filtration – Reverse Osmosis – Advanced Oxidation – Blending – Flocculation – Sedimentation – Filtration – Disinfection
5	Rapid sand filtration – Membrane filtration – Reverse Osmosis – Advanced Oxidation – Disinfection

3.3.2 Costing Data

Costing data were obtained for current water supply or water reclamation projects or projects that were completed in the past ten years. The costs are broken down as far as is possible to produce costs per unit treatment process for a wide range of treatment capacities, from small-scale treatment plants (community scale: for a number of households) to large water treatment plants (for the large cities or Water Boards).

The costs are plotted for treatment cost versus unit treatment process capacity. Lines are fitted and formulae established (for acceptable line fits), which are then used to calculate costs in the model for the flow rate that was entered in the input by the user.

Graphs should have as many data points as possible (depending on availability of data), but at least 5. Correlation coefficients (r^2-values) are indicated on the graphs to give an indication on the accuracy of local cost estimation of that particular unit treatment process. Data covers a wide range of treatment plant sizes (capacities), and it was endeavored to ensure that data-points are not centered around one size (capacity).

3.3.3 Indices

A range of indices were entered into this database, and will be hyperlinked to the original indices. Examples are current electricity tariffs, remuneration packages for treatment plant personnel and maintenance personnel.

3.4 WRC WATER REUSE COSTING MODEL (REUSECOST)

The REUSECOST Costing Model is available electronically on a CD in the back-page sleeve. The electronic copy of the model on CD contains the following:

- User Instructions
- Input Component (where the user will enter required information)
- Excel programming that does the cost calculations – the Model Component
- Output Component (that will provide the tables and graphic costing results)
- Database of costing information (not accessible to the user, only for doing cost calculations).

CHAPTER 4: DECISION SUPPORT MODEL FOR THE SELECTION OF WATER REUSE SYSTEMS

4.1 INTRODUCTION

The REUSEDSM spreadsheet-based decision support system was developed to provide a simplistic method to compare different reuse options using multi-criteria analysis. The model is based on a multi-criteria weighted sum analysis, and evaluates alternative water reuse options against a number of selection (decision) criteria. It is strongly recommended that weighing of the criteria should be done with input from subject field experts in the following disciplines:

- Planners
- Engineers (all disciplines)
- Decision-makers
- Managers (water supply; environmental; human resources; financial)
- Estimators
- Water quality scientists, health practitioners and engineers
- Social scientists.

4.2 DESCRIPTION OF THE WEIGHTED SUM METHOD

The weighted sum model is the simplest multi-criteria decision analysis for evaluating a certain number of alternative options against a number of decision criteria. By way of explanation, when the user want to weigh up three alternative options, namely **A1, A2** and **A3,** against three decision criteria **C1**, **C2** and **C3,** with each criterion carrying a weighting Ci.1, Ci.2, Ci.3, these weightings are normalised and are summed up to a value of 1.

When the decision (or selection) criteria are grouped under primary decision criteria headings, each consisting of a number of secondary decision criteria, then the matrix can be drawn up in such a way that a primary weighting (AiCi) is given for each of the options (A1, A2, A3), followed by a weighting for each of the secondary decision criteria (numerical values for these are assigned for each criterion in a scale of High (0.75), Medium (0.50) or Low (0.25). The actual weighting for each decision or selection criterion is then the product of the primary weight (AiCi) and the secondary weight (X_{ci}). These actual weights are then totalled to provide a weighted sum for each option (Ai_{score}). A final weight is then calculated as a fraction of percentage of the total weighted sum.

Table 4.1 shows the structure of the matrix developed for the water reuse model. Once the Matrix is populated with the various co-efficients, each alternative weight is then calculated via the weighted sum model. For example, the weighted score of alternative A1 will be:

$$A1_{score} = \Sigma A1Ci.A1Ci.i$$

Table 4-1: Matrix for the water reuse DSM

Primary decision criteria description	**Primary decision criteria weight for Options 1, 2 and 3** (total in each row to add up to 1.0)			**Secondary decision criteria description**	**Primary decision criteria weight for Options A1, A2, A3** (from Table *)		
	Option A1	Option A2	Option A3		Option A1	Option A2	Option A3
C1	A1C1	A2C1	A3C1	C1.1	A1C1.1	A2C1.1	A3C1.1
				C1.2	A1C1.2	A2C1.2	A3C1.2
				C1.3	A1C1.3	A2C1.3	A3C1.3
C2	A1C2	A2C2	A3C2	C2.1	A1C2.1	A2C2.1	A3C2.1
				C2.2	A1C2.2	A2C2.2	A3C2.2
				C2.3	A1C2.3	A2C2.3	A3C2.3
C3	A1C3	A2C3	A3C3	C3.1	A1C3.1	A2C3.1	A3C3.1
				C3.2	A1C3.2	A2C3.2	A3C3.2
				C3.3	A1C3.3	A2C3.3	A3C3.3
Weighted sum ($Ai_{score} = \Sigma AiCi.AiCi.i$)					$A1_{score}$	$A2_{score}$	$A3_{score}$
Final weight (fraction of total weighted sum)					Final weight A1	Final weight A2	Final weight A3

4.3 SUMMARY OF STEPS IN USING THE WATER REUSE DSM SPREADSHEET

Step 1:
Choose a main option theme from the list below. If more than one main theme needs to be evaluated, separate model application runs need to be performed for each

Main option theme examples:

- Reclamation and reuse system configurations (wastewater treatment plant and reclamation plant (advanced treatment plant)
- Direct versus indirect potable reuse
- Centralised versus decentralised treatment

Step 2:
List the different options to be compared. Plant configurations can be selected from a drop-down list that appears in the model, or may be entered manually entered as a new configuration. Descriptions of the five pre-set configurations in the model also appear in the report (section 2.3.2)

Step 3:
For each option, give a primary weight for each of the primary criteria. These weights must add to 1.0 (example shown in Table 4.2)

Primary criteria:

- Water quality
- Water treatment technologies
- Cost
- Social and cultural perceptions
- Environmental considerations

Step 4:
For each option, give a secondary weight for each of the secondary criteria by selecting from the drop down lists in the secondary criteria table (example shown in Table 4.3).

(Note: There are eight (8) secondary costing criteria. Two of these secondary criteria (brine disposal cost, and foreign exchange rate impacts) should be completed using the drop down lists, while the remaining six (6) should be estimated using the costing model, as performed in Step 5).

Step 5:
For each option, provide the cost information required to complete the secondary criteria weightings.

Note: Cost comparisons for the remaining costing criteria should be obtained from the REUSECOST model, or the user can enter the cost data if it is available.

Step 6:
The water reuse DSM will then calculate the weighted sum for each option, followed by calculation of the final weight (example shown in Table 4.4)

Step 7:
The DSM will provide a listing of the "best" option, followed by a prioritized list of the other options. The DSM shows which of the selection criteria played the decisive role in the selection process by using a colour code.

Table 4-2: Water reuse selection criteria coefficient weight descriptions

Main reuse selection criterion category	Reuse selection criteria	Weight class description for selection criteria		
		High	Medium	Low
Numerial value of weight		0.75	0.50	0.25
Water quality	Raw wastewater feed quality (type of wastewater treatment plant)	High quality (MBR; well-operated AS)	Medium quality (Biofilters)	Poor quality (Ponds; poorly operated AS)
	Efficiency of water quality monitoring programs (skills and financial capacity)	Comprehensive monitoring programmes	Satisfactory monitoring programmes	Poor monitoring programmes
	Likelihood of water-borne disease	Low likelihood	Occasional occurrence	High likelihood
	Product water quality requirements	Basic drinking water standards	High requirements	Very high requirements
Water treatment technologies	Number of treatment barriers available	Three or more	Two	One or none
	Maintenance requirements	Low	Medium	High
Cost	Capital cost	Lowest cost	Medium cost	Highest cost
	Personnel cost	Lowest cost	Medium cost	Highest cost
	Energy cost	Lowest cost	Medium cost	Highest cost
	Chemicals cost	Lowest cost	Medium cost	Highest cost
	Maintenance cost	Lowest cost	Medium cost	Highest cost
	Management cost	Lowest cost	Medium cost	Highest cost
	Brine disposal cost	Lowest cost	Medium cost	Highest cost
	Foreign exchange rates	Low	Medium	High
Social and cultural perceptions	National policies and planning	Supportive	Acceptable	Restricting
	Public acceptance	High	Some concern	Low
	Political interference	None or low	Sporadic	High
Environmental considerations	Climate changes (severe droughts; floods)	Low incidence	Moderate	High incidence
	Rising energy costs	Low	Moderate	High
	Environmental legislation	Supportive	Acceptable	Restricting

Table 4-3: Example of secondary selection criteria coefficient weight allocation

Main reuse selection criterion category	Reuse selection criteria	Weight class description for selection criteria		
		Option 1 Conventional processes	Option 2 Conventional and RO	Option 3 RO and AO
Water quality	Raw wastewater feed quality	0.75 (assume AS)	0.75 (assume AS)	0.75 (assume AS)
	Efficiency of water quality monitoring programs (skills and financial capacity)	0.50 (extensive program req.)	0.50 (extensive program req.)	0.75 (advanced systems)
	Likelihood of water-borne disease	0.75 (low)	0.75 (low)	0.75 (low)
	Product water quality requirements	0.50 (assume high)	0.50 (assume high)	0.50 (assume high)
Water treatment technologies	Number of treatment barriers available	0.75 (≥ 3)	0.75 (≥ 3)	0.50 (2)
	Maintenance requirements	0.25 (high)	0.50 (medium)	0.50 (medium)
Cost	Capital cost	0.25 (high)	0.50 (medium)	0.75 (low)
	Personnel cost	0.50 (medium)	0.50 (medium)	0.75 (low)
	Energy cost	0.75 (low)	0.25 (high)	0.25 (high)
	Chemicals cost	0.25 (high)	0.25 (high)	0.50 (medium)
	Maintenance cost	0.50 (medium)	0.25 (high)	0.25 (high)
	Management cost	0.25 (high)	0.50 (medium)	0.75 (low)
	Brine disposal cost	0.75 (low)	0.25 (high)	0.25 (high)
	Foreign exchange rates	0.75 (low impact)	0.50 (medium)	0.25 (high impact)
Social and cultural perceptions	National policies and planning	0.50 (acceptable)	0.50 (acceptable)	0.50 (acceptable)
	Public acceptance	0.75 (high)	0.50 (some conc.)	0.50 (some conc.)
	Political interference	0.50 (medium)	0.50 (medium)	0.50 (medium)
Environmental considerations	Climate changes (severe droughts; floods)	-	-	-
	Rising energy costs	0.50 (medium)	0.25 (high)	0.25 (high)
	Environmental legislation	0.50 (acceptable)	0.50 (acceptable)	0.75 (supportive)

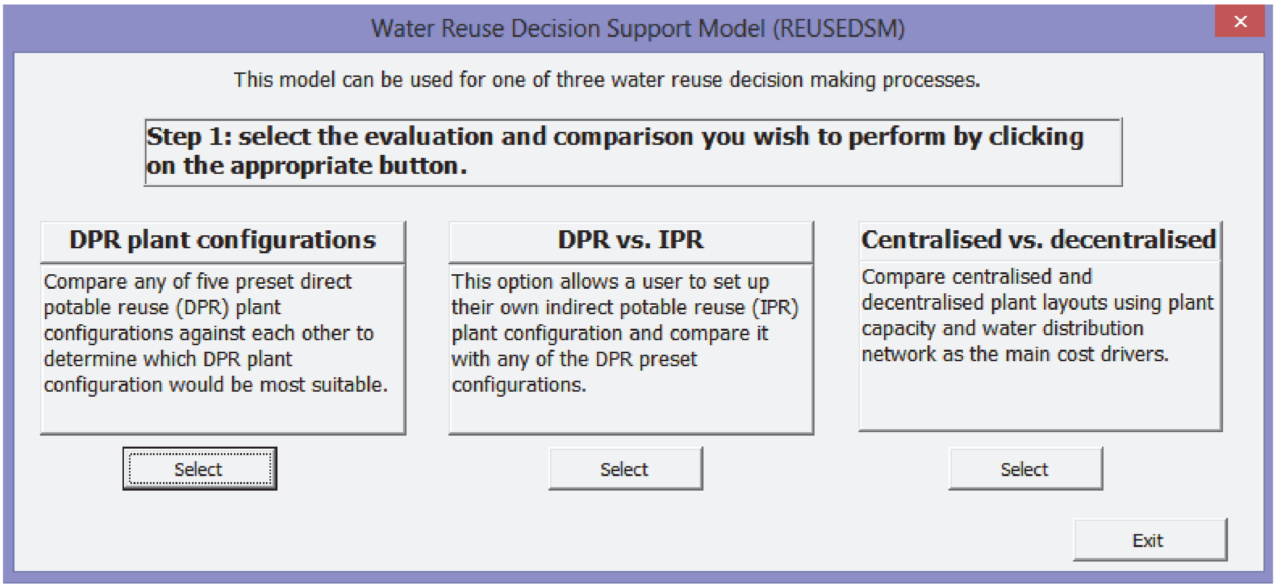
Table 4-4: Matrix of calculated weights and final weights for the example

Primary decision criteria description	**Primary decision criteria weight for Options 1, 2 and 3** (total in each row to add up to 1.0)			**Secondary decision criteria description**	**Primary decision criteria weight for Options 1, 2 and 3** (from Table *)		
	Option 1	Option 2	Option 3		Option 1	Option 2	Option 3
Water quality	0.15	0.10	0.10	Raw water quality (C1.1)	0.75	0.75	0.75
				Monitoring program (C1.2)	0.50	0.50	0.75
				Water-borne disease (C1.3)	0.75	0.75	0.75
				Product water quality (C1.4)	0.50	0.50	0.50
Water treatment technologies	0.25	0.20	0.30	No. of barriers (C2.1)	0.75	0.75	0.50
				Maintenance req.ments (C2.2)	0.25	0.50	0.50
Cost	0.30	0.35	0.30	Capital (C3.1)	0.25	0.50	0.75
				Personnel (C3.2)	0.50	0.50	0.75
				Energy (C3.3)	0.75	0.25	0.25
				Chemicals (C3.4)	0.25	0.25	0.50
				Maintenance (C3.5)	0.50	0.25	0.25
				Management (C3.6)	0.25	0.50	0.75
				Brine disposal (C3.7)	0.75	0.25	0.25
				Forex rates (C3.8)	0.75	0.50	0.25
Social and cultural perceptions	0.15	0.10	0.10	Policies and planning (C4.1)	0.50	0.50	0.50
				Public acceptance (C4.2)	0.75	0.50	0.50
				Political interference (C4.3)	0.50	0.50	0.50
Environmental considerations	0.15	0.25	0.20	Climate changes (C5.1)	-	-	-
				Rising energy costs (C5.2)	0.50	0.25	0.25
				Legislation (C5.3)	0.50	0.50	0.75
Weighted sum ($Ai_{score} = \Sigma AiCi.\ X_{C1}$)					**2.2375**	**1.8875**	**2.0500**
Final weight (fraction of total weighted sum)					**0.362**	**0.306**	**0.332**
Ranking					**1**	**3**	**2**

4.3.2 Using the REUSEDSM: Example 1

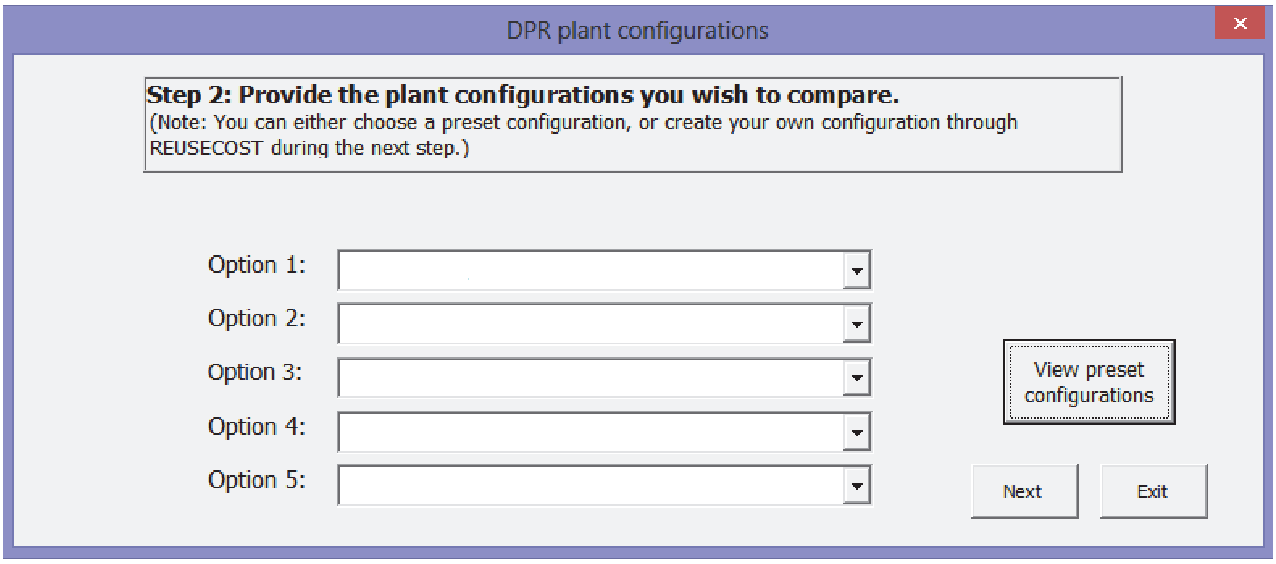
Note: weighting numerical values chosen arbitrarily only for purposes of the example)

Step 1: Choose a main option theme



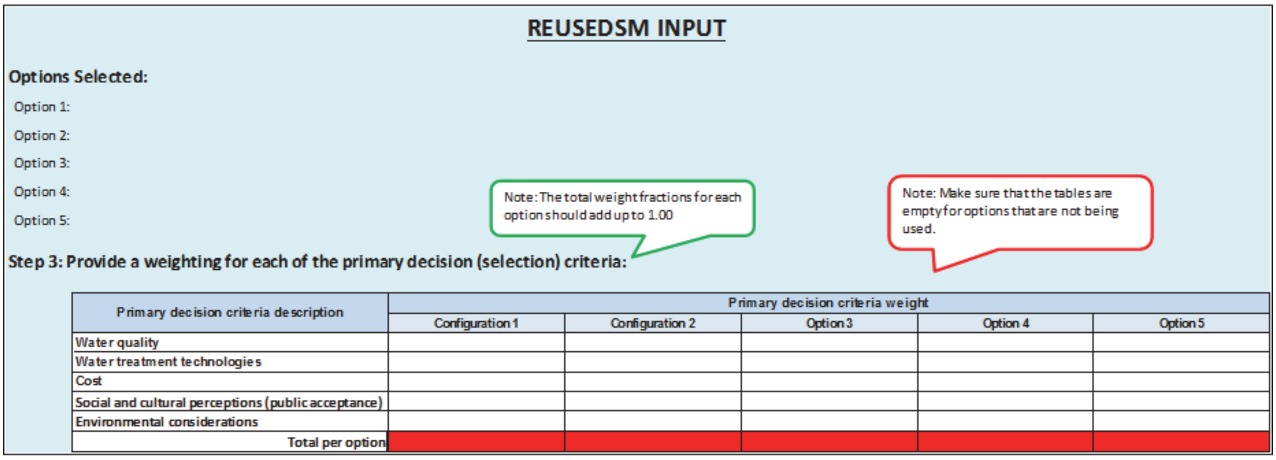
<u>Main option theme:</u>
Water reclamation treatment configurations

Step 2: List the different options to be compared.



<u>Potential options (for this example only):</u>
Configuration 1: Conventional processes (e.g. Windhoek)
Configuration 2: Conventional and RO
Configuration 3: RO and advanced oxidation

Step 3: For each option, give a primary weight for each of the primary criteria.



REUSEDSM INPUT

Options Selected:

Option 1:

Option 2:

Option 3:

Option 4:

Option 5:

Note: The total weight fractions for each option should add up to 1.00

Note: Make sure that the tables are empty for options that are not being used.

Step 3: Provide a weighting for each of the primary decision (selection) criteria:

Primary decision criteria description	Primary decision criteria weight				
	Configuration 1	Configuration 2	Option 3	Option 4	Option 5
Water quality					
Water treatment technologies					
Cost					
Social and cultural perceptions (public acceptance)					
Environmental considerations					
Total per option					

<u>Option 1: Conventional processes</u>

Water quality	0.15 (15%)
Water treatment technologies	0.25 (25%)
Cost	0.30 (30%)
Social and cultural perceptions (public acceptance)	0.15 (15%)
Environmental considerations	0.15 (15%)

<u>Option 2: Conventional and RO</u>

Water quality	0.10 (10%)
Water treatment technologies	0.20 (20%)
Cost	0.35 (35%)
Social and cultural perceptions (public acceptance)	0.10 (10%)
Environmental considerations	0.25 (25%)

<u>Option 3: RO and advanced oxidation</u>

Water quality	0.10 (10%)
Water treatment technologies	0.30 (30%)
Cost	0.30 (30%)
Social and cultural perceptions (public acceptance)	0.10 (10%)
Environmental considerations	0.20 (20%)

Step 4: For each option, select a weighting for each secondary criterion

Step 4: Provide a weighting for each of the secondary decision (selection) criteria:
(Choose from the drop down lists in the shaded cells)

Secondary decision criteria description	Secondary decision criteria weight				
	Configuration 1	Configuration 2	Option 3	Option 4	Option 5
Raw water quality					
Monitoring program					
Water-borne disease					
Product water quality					
Number of barriers					
Maintenance requirements					
Policies and planning					
Public acceptance					
Political interference					
Climate changes					
Rising energy costs					
Legislation					
Forex rates					
Cost of Brine disposal					

Step 5: Provide cost information for each of the options

Step 5: Provide a cost value (in R/kL) for each of the secondary cost decision (selection) criteria:
(Note: If you do not already have costing information available, click on the button below to make use REUSECOST to do a cost estimation.)

Secondary decision criteria description	Secondary decision criteria weight				
	Configuration 1	Configuration 2	Option 3	Option 4	Option 5
Capital					
Personnel					
Energy					
Chemicals					
Maintenance					
Management					
Total:	R -	R -	R -	R -	R -
	Go to REUSECOST	Go to REUSECOST	Go to REUSECOST	Go to REUSECOST	Go to REUSECOST

Back to Start

Generate Results

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In the spreadsheet, the weighted sums for each option are then calculated, followed by a calculation of the final weights.

The results for the example are shown in Table 3.3.

Step 6: The DSM model performs the calculations and generates the results

"Best" option:	Conventional treatment processes
Second "best" option:	RO and advanced oxidation
Third selection:	Conventional and RO

Step 7: ‘Best’ option is identified and displayed with the remaining results.

Table 4.3: Example of REUSEDSM results

REUSEDSM RESULTS

Ranking:

First: Option 1 (Configuration 1) with a normalized score of 0.55739

Second: Option 2 (Configuration 2) with a normalized score of 0.44261

This section is a visual representation of the product weights. The colours are used as an aid to show how the selected options compare.

Primary decision criteria description	Primary decision criteria weight					Secondary decision criteria description	Secondary decision criteria weight					Product of primary and secondary decision criteria weights				
	Option 1	Option 2	Option 3	Option 4	Option 5		Option 1	Option 2	Option 3	Option 4	Option 5	Option 1	Option 2	Option 3	Option 4	Option 5
Water quality	0.20	0.10				Raw water quality	0.75	0.25	0.00	0.00	0.00	0.15	0.03	0.00	0.00	0.00
						Monitoring program	0.75	0.25	0.00	0.00	0.00	0.15	0.03	0.00	0.00	0.00
						Water-borne disease	0.75	0.25	0.00	0.00	0.00	0.15	0.03	0.00	0.00	0.00
						Product water quality	0.75	0.25	0.00	0.00	0.00	0.15	0.03	0.00	0.00	0.00
Water treatment technologies	0.20	0.20				Number of barriers	0.75	0.25	0.00	0.00	0.00	0.15	0.05	0.00	0.00	0.00
						Maintenance requirements	0.75	0.25	0.00	0.00	0.00	0.15	0.05	0.00	0.00	0.00
Social and cultural perceptions	0.20	0.30				Policies and planning	0.50	0.25	0.00	0.00	0.00	0.10	0.08	0.00	0.00	0.00
						Public acceptance	0.25	0.75	0.00	0.00	0.00	0.05	0.23	0.00	0.00	0.00
						Political interference	0.50	0.75	0.00	0.00	0.00	0.10	0.23	0.00	0.00	0.00
Environmental considerations	0.20	0.30				Climate changes	0.50	0.75	0.00	0.00	0.00	0.10	0.23	0.00	0.00	0.00
						Rising energy costs	0.25	0.75	0.00	0.00	0.00	0.05	0.23	0.00	0.00	0.00
						Legislation	0.50	0.75	0.00	0.00	0.00	0.10	0.23	0.00	0.00	0.00
Cost	0.20	0.10				Forex rates	0.25	0.75	0.00	0.00	0.00	0.05	0.08	0.00	0.00	0.00
						Brine disposal	0.50	0.75	0.00	0.00	0.00	0.10	0.08	0.00	0.00	0.00
						Capital	0.33	0.67	0.00	0.00	0.00	0.07	0.07	0.00	0.00	0.00
						Personnel	0.92	0.08	0.00	0.00	0.00	0.18	0.01	0.00	0.00	0.00
						Energy	0.57	0.43	0.00	0.00	0.00	0.11	0.04	0.00	0.00	0.00
						Chemicals	0.56	0.44	0.00	0.00	0.00	0.11	0.04	0.00	0.00	0.00
						Maintenance	0.38	0.63	0.00	0.00	0.00	0.08	0.06	0.00	0.00	0.00
						Management	0.79	0.21	0.00	0.00	0.00	0.16	0.02	0.00	0.00	0.00
Weighted sum $(Ai_{score} = \Sigma AiCi.\ X_{C1})$												2.2603	1.79485	0	0	0
Normalized score (fraction of total weighted sum)												0.5574	0.4426	0.0000	0.0000	0.0000
Ranking												1	2	3	3	3

Back to REUSEDSM Input

Go to Capital Cost Output

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4.4 CONCLUSIONS ON THE DEVELOPMENT OF REUSEDSM

- Decsion support systems present a useful tool to assist water supply authorities and planners to identify, evaluate, compare, and select appropriate reuse.
- Although it is a relatively simple tool, it requires careful consideration of all the selection criteria against the different options, which ensures thorough planning.
- Providing weights to the selection criteria should be based on known information and include inputs from stakeholders, authorities and results from costing models.
- Reliability of the cost estimation with the REUSECOST model will improve as more costing data becomes available (as is the case at present).

Note:
The REUSEDSM model was designed, built and tested on a specific computer operating system and using a specific version of Excel. It is therefore recommended that the following requirements are met in order to ensure the optimal operation of the model:

- Operating system: Windows 8 (or any newer version)
- Excel 2013 (or any newer version)
- 2 GB Memory (RAM): if less RAM is used, the model will perform slowly.
- At least 10MB free storage space: this value can vary depending on the amount of files created (for different projects or types of comparison)

These requirements should be met otherwise the model will not perform as intended.

Decision-support software for analysing the inter-relationships of multi-factor environments

For more in-depth analysis of the inter-relationships of the multitude of factors involved in the evaluation and selection of water reuse options, the Parmenides Eidos provides decision-support software that provides an innovative approach to managing the entire decision-making process by visualising complex situations, building alignment among decision makers, and supporting the identification of possible courses of action.

The software is used by the Centre for Knowledge Dynamics and Decision-making of the University of Stellenbosch. For more information on the software and its application, the main author can be contacted, or contact the Centre directly at: http://www.informatics.sun.ac.za/index.php?page=contact

CHAPTER 5: FURTHER DEVELOPMENT AND IMPLEMENTATON OF DECISION SUPPORT MODELS FOR WATER REUSE PROJECTS

5.1 FEEDBACK FROM THE TECHNOLOGY TRANSFER WORKSHOPS HELD IN JANUARY 2014

The REUSEDSM and REUSECOST models were presented to the South African water sector at two technology transfer workshops in Pretoria and Stellenbosch Cape Town in January 2014. The aims of the workshops were to present the project report and the two models to water services providers, planners, regulatory authorities, financing institutions and the national treasury department, as well as to consulting engineering fraternity, and to demonstrate the use of the REUSEDSM in evaluating all the relevant selection criteria to enable WSAs to make an informed choice of water reclamation and reuse options to meet their specific needs. The workshops further shared knowledge and experience on the application of water reuse as a water supplement option, and stimulated discussions towards further improving the local knowledge base on water reclamation and reuse.

5.1.1 Workshop 1: Pretoria, 29 January 2014

The workshop was held on Wednesday 29 January 2014 at the Stone Cradle Conference Centre at Rietvlei, Pretoria. The workshop was attended by water sector practitioners from both the public and private sector. These included the Department of Water Affairs (Water Resources Planning Directorate), National Department of Treasury, TCTA, Rand Water, Johannesburg Water, various municipalities, Golder and Associates, Aurecon and other consulting engineers and consultants.

Discussions during and after the presentations showed a keen interest in the research project and the guidance that are provided in the project report on the evaluation and selection of water reuse options, and on cost estimating. A number of questions were raised regarding the extraction of water for reuse purposes from the WWTW final effluents, and the impact thereof on downstream users and ecosystems. The section on reuse terminology and definitions were welcomed, as it appears that there is still some misconceptions regarding potable and non-potable reuse, as well as planned versus unplanned reuse. On the cost and financing of water reuse schemes, it was indicated that external funding of a project can result in vastly different selection options being identified and evaluated than when the funding has to be done internally (either partially or fully). Almost equally important is whether infrastructure costs are taken into account in the cost estimations for transporting the wastewater from the wastewater treatment plants to reuse plants.

Considerable discussion was directed towards the challenges faced for the disposal of reuse plant concentrates (brine streams). There was general agreement that addressing these challenges requires innovative thinking. Another important point raised was whether the operation, maintenance and management of reuse plants should be done in-house or whether it should be contracted out? The attendees agreed that contracting out of the management and O&M of reuse plants are undoubtedly the preferred option, but that there still appears to be political resistance against this, even if that means the systems have a high risk of malfunction. The serious concern here is on the potential health effect on the users of the reclaimed water when the reclamation plants are operated by incompetent staff. Detailed investigations should be performed into how these options compare in existing treatment plants regarding O&M. The feasibility of private consortia being setup for the O&M of treatment plants for a fixed time period (i.e. 20 years) should also be investigated (BOOT type of PPP contracts).

5.1.2 Workshop 2: Stellenbosch, 30 January 2014

The second workshop was held on Thursday 30 January 2014 at the Spier Conference Centre in Stellenbosch. This workshop was also attended by water sector practitioners from both the public and private sectors. These included the Department of Water Affairs: Western Cape Region, University of Stellenbosch, Cape Peninsula University of Technology, City of Cape Town, a number of Western Cape municipalities, consulting engineers and private consultants.

Much of the discussions after the presentations concerned health aspects of drinking and using reclaimed water. It was pointed out that EDCs should not be the only major concern when it comes to harmful contaminants in the reuse process, but that micro-organisms and nanoparticles can be just as harmful and should receive as much attention in health programs. Many of the harmful substances are not chemicals, but biological substances. The need for effective operation and maintenance of not only reuse plants, but also WTWs and WWTWs, was highlighted, and it was even suggested that DWA should ensure that this function, on an institutional level, should not belong to municipalities, but should be privatized. This is in the interest of all the communities that are supplied with drinking water, and in particular potable reuse water.

It was felt that when external funding is granted for the construction of a treatment plant, one of the pre-requisites should be a suitable O&M plan to apply for the relevant operating funds over the life-cycle of the plant. It was also suggested that upstream WWTWs and downstream WTWs should be managed by the same institution; otherwise the one party blames the other party for poor water quality. The public opinion of communities regarding the institution that introduces reclamation is very important, and, as is well known, political acceptance is critically important. Blue and Green Drop programs should be used to gain confidence for reuse. Public acceptance specialists who can market the concept to the public is required.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS AND RECOMMENDATIONS

The National Strategy for Water Reuse (DWA, 2011) contains a number of undertakings by the Department of Water Affairs to support the planning and implementation of water reuse projects in South Africa. Some of these undertakings that will impact on the decision-making and costing process when different options are considered are highlighted below as recommendations for further development of water reuse decision support models.

a. Promote and assist with the decision-making process for water reuse. The Department undertakes to:
   - Provide guidelines for a sound and clear policy and legislative framework. Environmental legislation and requirements are in particular important as it can slow down the implementation phase significantly.
   - DWA points out the importance of cost/benefit investigations, but do not indicate how the department will assist in making costing information more readily available. This current WRC project does, however, strive towards starting this process on behalf of the Department.
   - Providing sufficient information to ensure effective decision-making. The intention is to educate users on benefits and acceptance of water reuse (this is also addressed in a separate WRC project currently being undertaken by CPUT), providing potential reuse practitioners with clear guidelines on how to implement water reuse projects, and providing a sound methodology on how to evaluate options to balance water requirement and supply. For the last one of these, the Reconciliation Strategy (All Towns Study) has already made a start towards developing such a methodology.

b. Review water quality standards. A WRC project currently being undertaken by Chris Swartz Water Utilization Engineers (Swartz *et al*, 2014) aims at developing health-based targets and water quality monitoring programmes for raw water feed to and from wastewater treatment plants, final water compliance and operational control within both the wastewater treatment plant and the water reclamation plant. These water quality targets and monitoring programmes are developed in close coordination with the Department's Water Resources Planning and regulation Directorates.

c. The Department intends to develop guidelines for the implementation of water reuse projects, which will, amongst other, address the choice of technology, operations and maintenance, and project financing. This current project, again, provides a good starting point for these intended guidelines.

d. Guidance will be provided on gaining knowledge on reuse technologies and concomitant training. This is encouraging, and it should be endeavoured to include this in water supply learning programmes and curricula.

e. The Department undertakes to encourage the WRC to make water reuse technology development a key focus area, and encourage the development of centres of excellence at selected universities.

f. The vast private sector capacity to act as implementing agencies should be leveraged to make use of these sought after management, engineering and financing skills and know-how, for which the Department undertakes to investigate the merits of establishing an industry-agreed evaluation and accreditation system for private agencies and organisations implementing water reuse projects. This should be done in collaboration with the Water Institute of southern Africa, through its newly established Water Reuse Division.

g. An important aim is the assessment of current and future needs for skilled persons to operate and maintain water reclamation and reuse plants. The results of this skills needs assessment should then be communicated to training and educational institutions.

h. Information should be made readily-available on how water reuse projects can be financed. According to DWA, the following financing alternatives are currently available:
    - Municipal Infrastructure Grant (MIG)
    - Loans from development and commercial banks
    - Public-private partnerships
    - Through bonds issues by agencies such as the Trans Caledon Transfer Authority (TCTA)

i. For water and wastewater systems, the advanced infrastructure model will likely include decentralization, remote management, resource recovery; source separated waste streams, and application of specific optimization of water quality.

6.2 OTHER RELATED WATER REUSE PROJECTS FUNDED BY THE WATER RESEARCH COMMISSION

Other water reuse related research projects, funded by the Water Research Commission, include the following:

- K5/1894 – Wastewater Reclamation for Potable Reuse – Graham Metcalf, Umgeni
- K5/2119 – Decision-support model for the selection, costing and application of drinking water treatment and supply options to address water shortages and improve water services delivery (with focus on upgrading options, water reclamation and desalination) – Chris Swartz, CSWUE
- K5/2121 – Investigation into the Cost and Water Quality Aspects of South African Desalination and Reuse Plants – Keith Turner, RHDVH
- K5/2208 – An investigation into the social, institutional and economic implications of reusing reclaimed wastewater for domestic application in South Africa – Chris Muanda, CPUT
- K5/2212 – Monitoring, management and communication of water quality and public acceptance in the direct reclamation of municipal wastewater for drinking purposes – Chris Swartz, CSWUE

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APPENDIX A

WATER QUALITY TARGETS FOR PHYSICAL, CHEMICAL AND MICROBIOLOGICAL DETERMINANDS

Table A1: Water quality targets for physical, chemical and microbiological determinands

Parameter	Unit	EPA		WHO		Australia		Windhoek		SANS 241	
		Target	Max	Target	Max	Target	Max	Target	Max	Target	Max
Colour	mg/L as Pt		15					8	10		15
COD	mg/L							10	15		
DOC	mg/L							3	5		
EC	mS/m										170
pH	-		6.5-8.5								5-9.7
TDS (calculated)	mg/L							1000	1200		1200
TSS	mg/L										
Turbidity	NTU		1					0.1	0.2		5
UV254	Abs/cm							n/a	0.06		
Aluminium	mg/L							n/a	0.15		0.3
Ammonia	mg/L							n/a	0.1		1.5
Iron	mg/L							0.05	0.1	0.3	2
Manganese	mg/L							0.01	0.025	0.1	0.5
Nitrate	mg/L		10		50						11
Nitrite	mg/L		1		3						0.9
Arsenic	ug/L	0	10		10						10
Chromium	ug/L		100		50						50
Carbon tetrachloride	ug/L	0	5		4						
Phenols	ug/L						150				10
Polychlorinated biphenyls (PCBs)	ug/L		0.5								
Chlorophyll	ug/L								1		
Blue-green algae	cells/ml										

Parameter	Unit	EPA		WHO		Australia		Windhoek		SANS 241	
		Target	Max	Target	Max	Target	Max	Target	Max	Target	Max
Microcystin-LR	Total		0.001		1 (ug/L)						1 (ug/L)
Clostridium	count/100mL							0	0		
Coliphages	count/100mL							0	0		
Cryptosporidium	org/2 L	0						0	0		
E. coli	count/mL							0	0		
Entamoeba histolytica	org/2 L										
Faecal coliform and *E. coli*		0						0	0		
Giardia lamblia	org/2 L	0						0	0		
HPC (Total bacterial)	count/mL	n/a	500					80	100		
Legionella											
Total Coliforms	count/100mL	0						0	0		

APPENDIX B

WATER QUALITY TARGETS FOR SELECTED EDCs AND CECs

Table 2.3: Water quality targets for selected EDCs and CECs

Parameter	Unit	EPA		WHO		Australian		Windhoek		SANS 241		Rand Water	
		Target	Max	Target	Max	Target	Max	Target	Max	Target	Max	Target	Max
Priority Pollutants													
EDCs													
DDT and metabolites	ug/L				1								
Pesticides													
Acetachlor	ug/L												20
Alachlor	ug/L	0	2		20								5
Atrazine	ug/L		3		100								5
Bromoxynil	ug/L												10
Endosulfan	ug/L												1
EPTC	ug/L												20
Mancozeb	ug/L												20
MCPA	ug/L				2								2
Metolachlor	ug/L				10								5
Monocrotophos	ug/L												1
Parathion	ug/L												1
Phorate	ug/L												1
Sodium Fluosilicate	ug/L												10
Terbufos	ug/L												1
2,4-D (2,4-dichlorophenoxy)	ug/L				30								10
4-Nitrophenol	ug/L						30						
Dementon-S	ug/L						0.15						
N,N-diethyltoluamide	mg/L						2.5						
Pharmaceuticals													
Carbamazepine													
Ibuprofen													

Parameter	Unit	EPA		WHO		Australian		Windhoek		SANS 241		Rand Water	
		Target	Max	Target	Max	Target	Max	Target	Max	Target	Max	Target	Max
DBPs													
Bromate	ug/L	0	10		10								
Chlorate	mg/L				0.7								
Chlorite	mg/L	0.8	1		0.7								
Dibromoacetonitrile	ug/L				70								100
Dichloroacetate	ug/L				50								50
Dichloroacetic acid	ug/L												50
Dichloroacetonitrile	ug/L				20								90
Formaldehyde	ug/L												900
Haloacetic acids (HAA5)	mg/L	0	0.6										
Monochloroacetate	ug/L				20								
NDMA	ug/L												
N-Nitrosodimethylamine	ug/L				0.1								
Trichloroacetate	ug/L				200								100
Trichloroacetic acid	ug/L												100
Trichloroacetaldehyde	ug/L												10
Trichloroacetonitrile	ug/L												1
2,4,6-Trichlorophenol	ug/L				200								10
Bromoform	ug/L		0		100						100		50
Chloroform	ug/L				300						300		50
Bromodichloromethane	ug/L		0		60						60		50
Dibromochloromethane	ug/L		60		100						100		50
Total THMs	ug/L	0	80					20	40				100