A WATER RECLAMATION AND REUSE GUIDE FOR SOUTH AFRICAN MUNICIPAL ENGINEERS

CD Swartz, JG Menge, JA du Plessis and GM Wolfaardt

IMESA

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A WATER RECLAMATION AND REUSE GUIDE FOR SOUTH AFRICAN MUNICIPAL ENGINEERS

Report to the

Water Research Commission

by

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FOREWORD

With South Africa being a water-scarce country, alternate sources of water supply and optimization are critical.

The reuse of water is one of the best solutions in optimizing limited water resources. The reuse of water is widely practiced in both developed and underdeveloped countries. South Africa is one of the few countries where potable drinking quality water is still used for flushing toilets and urban usage.

Utilizing reclaimed water for urban uses like irrigation of parks, golf courses, sport fields, etc. is becoming increasingly critical. Even for certain industrial use, potable drinking water is not necessary for many industries, especially wet industries. To become a more water sustainable country, wastewater reuse is the way to go.

There are five key considerations that affect choices related to water reuse as an option for water supply and augmentation:

- Water quality and security of supply
- Water treatment technology
- Cost relative to other water supply alternatives
- Social and cultural perceptions
- Environmental considerations

National water resources strategy indicates that water reuse is one of the important strategies to balance availability of water in future. The Department of Water Affairs (now the Department of Water and Sanitation) has provided a national water reuse strategy, but what is lacking is a guideline for municipal engineers when implementing reclamation and reuse projects. A proper guideline is also required for agricultural use with reference to what quality is used for what type of farming.

In South Africa, 60% of the fresh water is used by the agricultural sector and very little reused water is utilized. Therefore, considerable potential exists to substantially expand the use of treated wastewater for irrigation purposes in South Africa.

Indirect water reuse for potable purposes is well established in South Africa. It is common for a treated wastewater effluent to be discharged to a river system and for water to be abstracted downstream of this discharge point and to be treated and used for drinking water. However, the direct reuse of water for potable purposes has not been widely implemented in South Africa, but has been successfully implemented in countries like Singapore, Namibia, and Australia since 1970.

There are various reuse options but a guideline for the municipal engineers has not been established to implement the reuse projects cost-effectively. Thus, IMESA was invited to assist in putting this guideline together.

With the above context, this document provides guidelines for the Municipal Engineers when implementing Reclamation and Reuse projects.

Ms B Soni, President, IMESA	21 June 2022 Date

ABOUT THIS WATER RECLAMATION AND REUSE GUIDE

In South Africa there has been growing interest recently in water reclamation and reuse (direct and indirect potable reuse), for a number of reasons. Being an arid region, southern Africa faces serious challenges with decreasing availability of conventional water sources. The effects of prolonged droughts in the subcontinent are evident and result in contingency plans in the short term and rethinking of the water supply systems in the medium- and long term. The shortage of available freshwater has resulted in an increasing interest in the implementation of water reclamation and reuse of wastewater as alternative water supply strategy to sustain development and economic growth in Southern Africa.

In 2013, the Department of Water and Sanitation launched the second edition of the National Water Resources Strategy (NWRS-2), as required under the National Water Act (Act 36 of 1998). The NWRS-2 sets out the strategic direction for water resources management in the country and provides a framework for the protection, use, development, conservation, management and control of water resources for South Africa. Annexure D of the NWRS-2 document is the National Strategy for Water Reuse (NSWR), which sets the vision for the implementation of water reuse in South Africa. The NSWR recognizes the important role that good information plays in supporting sound decisions, and as such states the three aspects to be considered, which are;

- educating users with respect to the benefits and acceptance of water reuse
- providing people who are considering water reuse with clear guidelines on how to implement water reuse projects
- provide sound methodology in the evaluation of options to balance water requirements and supply.

The NSWR further recognises the importance of guidelines for the implementation of water reuse projects. Accordingly, these guidelines should address the management and control, project implementation, choice of technology, operations and maintenance, project financing, development and implementation of tariffs and public and stakeholder education, engagement, and consultation. Recently, the National Planning Commission (NPC) has reflected on the national pathway to a water secure country up to 2050 to enable inclusive economic growth, poverty eradication and reducing inequality. Of relevance, is the identified need for a national facility for research, development, innovation and testing, with a focus on water reuse and desalination. This guideline seeks to provide further support in the efforts of the country to achieve the set NDP goals.

Water reclamation and reuse has been studied in the region since the 1960s, resulting in the commissioning of the first direct water reclamation plant in Windhoek in 1968. Although the Windhoek plant has earned reputable international recognition as an effective multibarrier treatment system from a health perspective, there are no guidelines locally to assist other water supply authorities (water boards, municipalities) with planning or managing existing water reclamation and reuse projects.

For the successful application and sustainability of water reclamation and reuse as an alternative water supply augmentation option to alleviate water scarcity situations, it is important that there is a common understanding of the concepts and terminology used in planning, implementation, operation, maintenance, and management of water reclamation and reuse schemes. Water reclamation and reuse projects incorporate more advanced treatment processes and technologies compared to conventional surface water and groundwater treatment. Such projects will not be sustainable (*i.e.* will fail) if they are not based on sound scientific and engineering knowledge and principles related to the reuse and recycling of wastewater for a variety of potable and non-potable uses. Following the development and successful dissemination and use of 'A Desalination Guide for South African Municipal Engineers' (WRC Report No. TT 266/06 by JA du Plessis, AJ Burger, CD Swartz and N Musee) in 2006, the main aim of this project was to develop and compile a guide for municipal engineers, and disseminate knowledge on the planning and implementation of water reclamation and reuse schemes.

A number of water reclamation and reuse guides and studies have been funded by the Water Research Commission (WRC) since its inception in 1971. The very first WRC guide for the planning, design and implementation of water reuse schemes was published in 1982. Following recommendations from an International Conference on Water Reuse for Drinking Purposes, held in Durban in 2012, additional guidelines, manuals and strategies on water reclamation and reuse have been published. These include; a costing model and decision-support system (WRC Report No. 2119/01/14); monitoring, management, and communication guidelines for water reuse schemes (WRC Report No. TT 641/15); investigation into institutional and social factors influencing public acceptance of reclaimed water for potable uses in South Africa (WRC Report No. TT 734/17); framework guidelines for public engagement on water reuse (WRC Report No. TT 735/17); implementation plan for direct and indirect water reuse (WRC Report No. KV 320/13); emerging contaminants in wastewater treated for direct potable reuse (WRC Report No. TT 742/1/18); costing of desalination and reuse plants; and a communication strategy for water reuse (WRC Report No. 2805/2/20). The information in these reports have been extensively used in the compilation of this Guide.

The project to develop and compile the Guide was jointly funded by the WRC and the Institute of Municipal Engineering of Southern Africa (IMESA). This guide provides knowledge on state-of-the-art practices of all aspects of water reclamation and reuse systems, including process selection, decision-support, planning, design, implementation, and operation, maintenance and management of reuse projects and schemes. These guidelines should support sound decision making and implementation.

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A WATER RECLAMATION AND REUSE GUIDE FOR SOUTH AFRICAN MUNICIPAL ENGINEERS

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EXECUTIVE GUIDE ON PLANNING FOR WATER RECLAMATION AND REUSE

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WATER REUSE DEFINITIONS AND TERMINOLOGY

For the successful application and sustainability of water reuse as a source to alleviate water scarcity, it is essential that there is a common understanding of the concepts and terminology used in planning and, especially, public outreach processes. The most important concepts in municipal water reuse are summarised below.

Abbreviated list of terms and definitions in water reclamation and reuse (from MED WWR WG, 2007)

Name	Definition
Source water	Water in its natural state (but that may have received treated wastewater discharges upstream), before any treatment to make it suitable for drinking
Raw water	Water in its natural state before any treatment or the water entering the first treatment process of a water treatment plant
Treated wastewater reuse	Reuse is the term used in the EU regulations to describe the beneficial use of appropriately treated wastewater. Treated wastewater (or water) reuse is therefore the beneficial use of treated water
Direct reuse	The beneficial use of appropriate treated wastewater <u>without</u> interim storage in a surface water body or aquifer. The conversion of wastewater directly into drinking water, irrigation water, process water or cooling water without any interim storage
Indirect reuse	The beneficial use of appropriate treated wastewater <u>with</u> interim storage in a surface water body or aquifer. The use of reclaimed water for irrigation or other non-potable applications after a period of storage in a surface or a groundwater body.
Direct potable reuse (DPR)	The introduction of extensively treated reclaimed water either directly into the potable water supply distribution system downstream of a water treatment plant, or into the raw water supply immediately upstream of a water treatment plant.
Indirect potable reuse (IPR)	The use of reclaimed water for potable supplies after a period of storage in surface or as groundwater. The discharge of recycled water directly into groundwater or surface water with the intent of augmenting drinking water supplies.
Non-potable reuse (NPR)	The reuse of suitably treated wastewater for any other purpose than potable use, *e.g.* for irrigation, industrial use, source water for wetlands, etc.
Environmental buffer	An environmental buffer may consist of a stretch of river, a water supply reservoir, or a soil aquifer system to which recycled water is added. The need for an environmental buffer is an important component of risk management.
De facto reuse	The unplanned or incidental reuse of treated wastewater discharged into a surface body which after dilution is abstracted downstream for beneficial reuse or treatment to potable quality
Reclaimed water	Municipal wastewater that has been treated to specific water quality criteria so it can be beneficially reused. This is normally a higher quality than the quality of secondary treated effluent.
Recycled water	Water generated from sewage, greywater or stormwater systems and treated to a standard that is appropriate for its intended use. (In industry, recycled water can relate to cooling water recycling where there is minimum treatment)

These concepts can also be presented graphically, which results in an easier understanding of the definitions in the table.

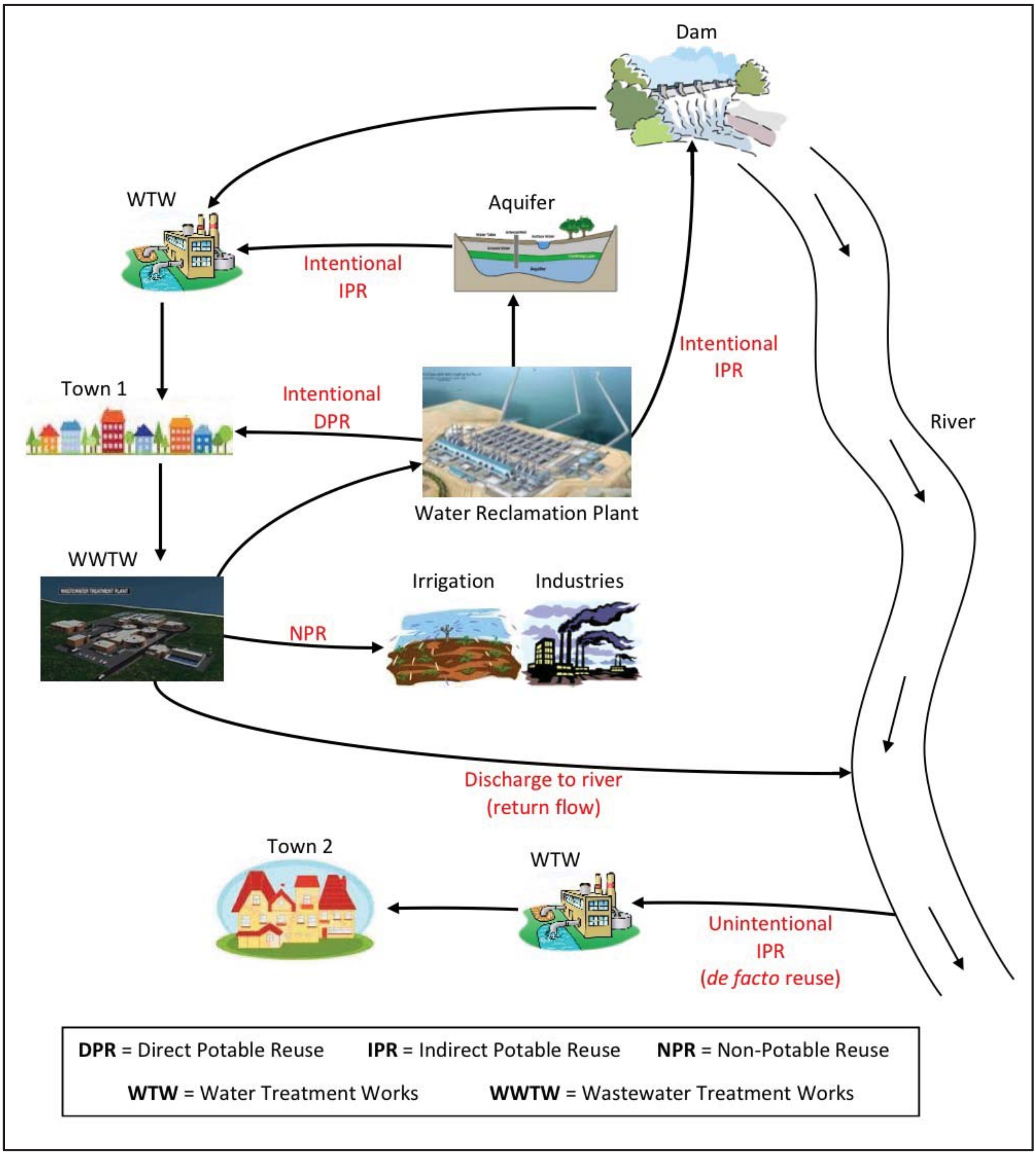

Diagram showing different types of water reuse (Swartz *et al.*, 2013)

It is also important that the definitions and terminology be updated on a regular basis as development of planning and implementation processes progresses. 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.

ACRONYMS AND ABBREVIATIONS

ACIP	Accelerated Community Infrastructure Programme
AIDS	Acquired Immunodeficiency Syndrome
AMD	Acid mine drainage
AMP	Asset Management Plan
AOC	Assimilable organic carbon
AOP	Advanced oxidation process
AOX	Adsorbable Organic Halide
ARV	Antiretroviral
ASP	Activated sludge process
ASR	Aquifer Storage Recovery
ATW	Advanced treated water
AWTP	Advanced water treatment plant
BAC	Biologically activated carbon
BDOC	Biodegradable dissolved organic carbon
BOD_5	Biological oxygen demand
BWRO	Brackish water reverse osmosis
CAFO	Concentrated animal feeding operation
CCP	Critical control point
CCPP	Calcium Carbonate Precipitation Potential
CEC	Chemical of Emerging Concern
CIP	Comprehensive Infrastructure Plan, Cleaning In Place
CMA	Catchment Management Agency
CoCT	City of Cape Town
COD	Chemical oxygen demand
CoGTA	Cooperative Governance and Traditional Affairs
Cond	Conductivity
ConvWTP	Conventional water treatment plant
CoW	City of Windhoek
CPE	Cytopathic effect
CSIR	Council for Scientific and Industrial Research
DAF	Dissolved Air Flotation
DALY	Disability-adjusted life years
DBP	Disinfection by-products
DBSA	Development Bank of Southern Africa
DDT	Dichloro-diphenyl-trichloroethane
DDW	Division of Drinking Water
DOC	Dissolved organic carbon
DPLG	Department Provincial and Local Government
DPR	Direct potable reuse
DSM	Decision-support model
DWA	Department of Water Affairs

DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
E. coli	Escherichia coli
EC	Electrical conductivity
EDC	Endocrine-disrupting chemicals
EEC	Environmental Engineering Consultants
EIA	Environmental Impact Assessment
EU	European Union
FOG	Fats, oils and grease
GAC	Granular activated carbon
HACCP	Hazard Analysis and Critical Control Points
HiPRO	Keyplan's High recovery Precipitating Reverse Osmosis
HIV	Human Immunodeficiency Virus
HPC	Heterotrophic plate count
HSDB	Hazardous Substances Data Bank
IDP	Integrated development plan
IPR	Indirect potable reuse
IRIS	Integrated Risk Information System
IWA	International Water Association
IX	Ion Exchange
LC	Lime Clarification
LRV	Log removal value
LSM	Living Standard Measure
MAR	Managed Aquifer Recharge
MBR	Membrane bioreactor
MCPA	2-methyl-4-chlorophenoxyacetic acid
MDG	Millennium Development Goal
MF	Microfiltration
MIG	Municipal Infrastructure Grant
MISA	Municipal Infrastructure Support Agent
MWIG	Municipal Water Infrastructure Grant
N	Nitrogen
NDMA	N-Nitrosodimethylamine
NEMA	National Environmental Management Act
NF	Nanofiltration
NGWRP	New Goreangab Water Reclamation Plant
NHRA	National Heritage Resource Act
NOM	Natural organic matter
NPR	Non-potable reuse
NSAID	Non-steroidal anti-inflammatory drug
NTU	Nephelometric Turbidity unit
NWA	National Water Act

NWRS	National Water Resource Strategy
O&M	Operation and maintenance
ORP	Oxidation Reduction Potential
P	Phosphorous
PAC	Powder activated carbon
PAH	Polycyclic aromatic hydrocarbon
PCP	Personal care product
PCR	Polymerase chain reaction
PFAS	Polyfluoroalkyl substance
PhAC	Pharmaceutically active compound
PPCPs	Pharmaceuticals and personal care products
PPP	Public Private Partnerships
RO	Reverse osmosis
RBIG	Regional Bulk Infrastructure Grant
RHIG	Rural Households Infrastructure Grant
RWU	Regional Water Utilities
SA	South Africa
SABS	South African Bureau of Standards
SAHRA	South African National Heritage Resources Agency
SANS	South African National Standards
SAT	Soil Aquifer Treatment
SCADA	Supervisory control and data acquisition
SDG	Sustainable Development Goal
SDI	Silt Density Index
SEMA	Specific Environmental Management Act
SF	Sand Filter
SIN	Substitute It Now
SS	Suspended solids
TCEP	Tris(2-carboxyethyl)phosphine
TCTA	Trans-Caledon Tunnel Authority
TDCPP	Tris(1,3-dichloro-2-propyl)phosphate
TDEX	The Endocrine Disrupting Exchange
TDS	Total dissolved solids
Temp	Temperature
TFS	Total fixed solids
THM	Trihalomethane
THMFP	Trihalomethane formation potential
TKN	Total Kjeldahl Nitrogen
TN	Total nitrogen
TOC	Total organic carbon
TS	Total Solids
TSS	Total suspended solids

TVS	Total volatile solids
UF	Ultrafiltration
UK	United Kingdom
USA	United States of America
US EPA	United States Environmental Protection Agency
USDG	Urban Settlements Development Grant
UV	Ultraviolet
WCWDM	Water Conservation and Water Demand Management
WHO	World Health Organisation
WQG	Water Quality Guidelines
WRC	Water Research Commission
WRP	Water Reclamation Plant
WSA	Water Supply Authority
WSOS	Water Services Operating Subsidy
WSP	Water service providers / Water Safety Plan
WTO/TBT	World Trade Organisation Technical Barriers to Trade
WTW/WTP	Water treatment works/plant
WUA	Water User Association
WWTW/WWTP	Wastewater treatment works/plant

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PART 1

EXECUTIVE GUIDE ON WATER RECLAMATION AND REUSE

PART 1: EXECUTIVE GUIDE ON WATER RECLAMATION AND REUSE

1.1 THE NEED FOR A GUIDE ON WATER RECLAMATION AND REUSE IN SOUTH AFRICA

Water scarcity is recognized as a major challenge for numerous countries across the globe in their endeavour towards sustainable life for humankind and the environment. Existing water sources are increasingly coming under stress due to growing water demand on a global scale, due to population growth and high rates of urbanization. In South Africa, the Second edition of the National Water Resource Strategy (DWA, 2013) highlighted the challenges facing South Africa in supplying in all its water needs. There is also a clear shift from a supply side management view towards a demands side management view. This is best illustrated in the lack of any mention of water reuse in the 2004 NWRS, while the 2012 NWRS2 highlight a number of key strategies which include greater focus on WCWDM, an increased value and utilisation of ground water, the reuse of water at the coast as well as in inland systems and desalination, including treatment of mine water. Water resource managers and planners are forced to look at unconventional water sources such as desalination (of seawater and brackish groundwater), water reuse and rainwater harvesting. Reuse has become an attractive option for water augmentation due to improvement in efficiency of treatment processes, reduced costs, and the fact that this water source is readily available and in close proximity to the point of application. Indirect water reuse already accounted for approximately 14% of water use in South Africa (DWA, 2013), mostly through wastewater return flows to rivers from which it is abstracted downstream, but a focussed implementation program for reuse is mainly still lacking. The most important drivers for water reuse are rapid population growth, urbanisation, and unpredictability of conventional water source sustainability (due to climate change and source pollution), while the limited available water resources in certain areas of South Africa makes it imperative.

It is however also a focus point at an international level. The Millennium Declaration, signed by 147 heads of state, in September 2000, established a comprehensive global framework to support concerted efforts towards poverty reduction and sustainable development. The Declaration led to the eight Millennium Development Goals (MDGs). Of the eight MDGs, six can be linked to the reuse of water. They are (WHO, 2006):

- Goal 1: Eradicate extreme poverty and hunger – irrigation can aid food security.
- Goal 3: Promote gender equality and empower women – peri domestic agriculture activities with reused water mostly favours women in the rural area.
- Goal 4: Reduce child mortality – the safe use of reused water improves the hygiene associated ill health.
- Goal 5: Improve maternal health – Improved nutrition using reuse agriculture applications reduce susceptibility to anaemia and other conditions that affect maternal mortality.

- Goal 6: Combat HIV/AIDS, malaria and other diseases – Improved health and nutrition reduce susceptibility to/severity of HIV/AIDS and other major diseases.
- Goal 7: Ensure environmental sustainability – The safe use of wastewater, excreta and greywater contributes to less pressure on freshwater resources and reduces health risks for downstream communities. Improved water management, including pollution control and water conservation, is a key factor in maintaining ecosystem integrity.

There has been a growing interest in South Africa for direct water reclamation (direct potable reuse) during the past decade, for a number of reasons. Being an arid region, southern Africa faces serious challenges with sustained availability of conventional water sources. Already the effects of prolonged droughts in the sub-continent are evident and result in contingency plans in the short term and rethinking of the water supply systems in the medium and long term. The shortage of available water in the region is leading to large-scale interest in, and application of, water reclamation and reuse as alternative water supply sources to sustain development and economic growth in the region. Water reclamation plants which have been constructed as a result of this water shortage include, amongst other, Beaufort West (direct potable reuse (DPR)), Ballito (DPR), George (indirect potable reuse (IPR)) and Mossel Bay (reuse for industrial purposes), while direct potable reuse initiatives in Durban (eThekwini Municipality), Port Elizabeth and Cape Town are at advanced planning, design, or construction stages. Planning is further underway for potable reuse in Botswana and Zimbabwe.

In Cape Town, as an example, recycled water is mostly used for industrial and commercial purposes and a small amount for the recharge of the Atlantis aquifer. Future plans include more aquifer recharge and also a direct potable reuse plant at the Zandvliet WWTP and further treatment at the Faure water treatment plant, which serves a large part of the municipal area. The future role of reuse is clearly highlighted in Cape Town's Water Strategy (City of Cape Town, n.d.) as illustrated in Figure 1-1.

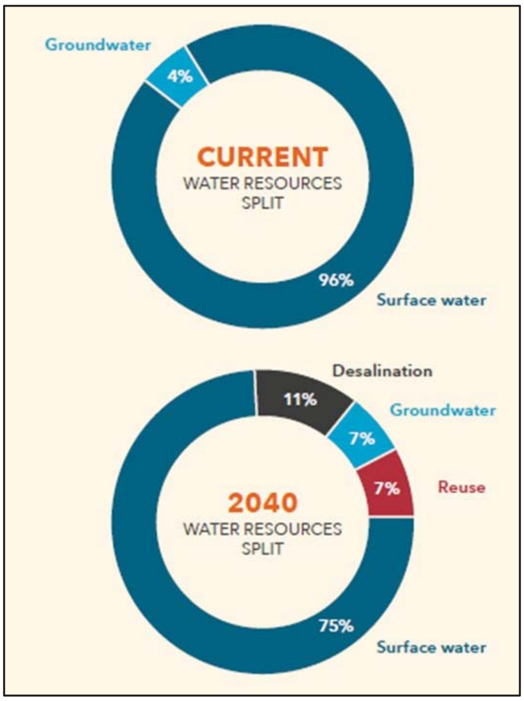

Figure 1-1: City of Cape Towns planned future reuse strategy (CoCT – Water Strategy)

South Africa has substantial potential to reuse wastewater for a variety of purposes. Table 1-1 shows some of the most important figures on water reuse potential in the country (Kalebaila and Bhagwan, 2019). To put the magnitude of water reuse potential in South Africa in context, the country currently reuses 4-5% of water, while in Israel up to 85% of its domestic wastewater is reused for agriculture (Kalebaila and Bhagwan, 2019).

Table 1-1: Water reuse potential in South Africa in 2019 (Kalebaila and Bhagwan, 2019)

Annual water use, effluent production and water reuse	
Total water requirement	20 045 x 10^6 m^3/a
Urban / domestic water use	2 170 x 10^6 m^3/a
Industry / mining water use	1 600 x 10^6 m^3/a
Agriculture / irrigated agriculture water use	10 221 x 10^6 m^3/a
Urban / domestic effluent return	1 100 x 10^6 m^3/a
Water reuse (direct)	50 x 10^6 m^3/a

1.2 LEGAL AND REGULATORY REQUIREMENTS

Water reuse projects typically involve a range of activities that are subject to a number of regulatory authorisations stipulated in various Acts, Regulations and Bylaws. These include provisions in:

- National Water Act (Act 36 of 1998);
- Mineral and Petroleum Resources Development Act (Act 28 of 2002);
- National Environmental Management Act (Act 107 of 1998);
- Water Services Act (Act 108 of 1997);
- National Environmental Management: Integrated Coastal Management Act (Act 24 of 2008), with reference to seawater desalination and
- Municipal bylaws.

While all of these will not be discussed in detail in this document, the key guiding principles will be highlighted, specifically the strategic guidance towards water-reuse and the environmental legislation, which is critical for the approval of any water reuse process.

1.2.1 South African National Strategy for water reuse

1.2.2 Water quality regulation in South Africa

1.2.2.1 Blue Drop and Green Drop programs for drinking water and wastewater quality regulation.

Municipalities in South Africa faces many challenges in providing effective water services to consumers. As a result, in 2008, the Department of Water and Sanitation (DWS) introduced the Blue Drop and Green Drop certification programmes. These programmes were designed to measure the most important indicators for sustainable and safe water and wastewater service delivery, such as: management commitment; safety and risk planning and mitigation; process management; quality compliance; staff qualifications; and adequate budgets.

The goal of the Blue Drop programme was compliance of water supply systems with national Drinking Water Quality Standards and to encourage and acknowledge continuous improvement and performance excellence in drinking water services management in South Africa through the use of incentive, risk, and benchmarking. The goal of the Green Drop programme was compliance of wastewater treatment works with the national Wastewater Discharge Standards and to create a paradigm shift by which wastewater operations, management and regulation is achieved. These programmes were developed to promote incentive-based regulations, establishing excellence as the benchmark for water and wastewater operations.

As a result, many municipalities invested in their water and sanitation staff and infrastructure, leading to improved performance of the water and wastewater sectors. These programmes also generated a wealth of data, which allowed the Department and water and sanitation sector at large to pan and manage the water value chain more effectively.

The first Blue Drop and Green Drop reports were released in 2009 and each year thereafter until 2014. Unfortunately, the Department has not commissioned these assessments since 2014. Some of the leading municipalities and entities have nonetheless undertaken self-assessment to enable improved management of their own systems.

While these programmes were in place, there was widespread improvement in the know-how and compliance across much of the water and sanitation sector.

1.2.2.2 Chemicals of emerging concern

CECs are not yet regulated in South Africa, but it is believed that the most important types of chemicals, indicators or surrogates will be included in future SANS 241 versions or in formal guideline documents of the Department of Water and Sanitation.

1.2.3 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). The type of water reclamation technologies used in water reuse projects will have a strong influence on the environmental footprint and energy usage depending on.

Reuse of water offers positive environmental benefits, specifically on the water environment through protection of aquatic ecosystems reducing the demand on water from a natural source and reducing the risk of polluting natural waters by using reclaimed water resulting less wastewater discharge. 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. For instance there are regions in the USA and elsewhere that implemented water reuse projects; not because of water shortages but to reduce the discharge of nutrients into 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 promote sustainability and water security.

1.2.3.1 Environmental Legislation 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 further state in Section 152 of Chapter 7 that:

"(1) The objective of local government is:

(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, including water reuse 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:

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. In 2010, a new and more comprehensive set of regulations were promulgated under Section 24 of the NEMA. They include:

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 R. 544 and R. 546 providing the list of activities that needs to be subjected to a Basic Assessment procedure and R. 545 providing the list of activities that need to be subjected to the Scoping procedure.

Since then, various amendments were made to the existing acts in an attempt to streamline environmental decision-making. To achieve this, the concept of the so-called “One Environmental System” has been introduced and in December 2014, new NEMA regulations (R. 982 / R. 983 / R. 984 and R. 985) were published, of which some were again replaced with a new set of regulations in 2017 as published in Government Notices consisting of:

- EIA Regulations regulating the process (GN No. R. 326 of 4 Dec 2014)
- Listing Notice 1 (GN No. R. 327 of 7 Dec 2014)
- Listing Notice 2 (GN No. R. 325 of 4 Dec 2014)
- Listing Notice 3 (GN No. R. 324 of 4 Dec 2014)
- National Exemption Regulations (GN No. R. 994 of 8 Dec 2014)
- National Appeal Regulations (GN No. R. 993 of 8 Dec 2014)

Of importance to the reuse of water, R. 327 and R. 325 list the activities to be subjected to the relevant procedures provided in R. 326 which allows for either a basic assessment or full Environmental Impact assessment process. R. 324 (Listing Notice 3) provide activities relevant to specific provinces and should be checked but does not normally relate to reuse activities.

Regulation 327 (listing Notice 1) provides for 67 different activities, amongst other:

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The development and related operation of infrastructure exceeding 1 000 metres in length for the bulk transportation of sewage, effluent, process water, wastewater, return water, industrial discharge, or slimes –

(i) with an internal diameter of 0,36 metres or more; or

(ii) with a peak throughput of 120 litres per second or more.

excluding where—

(a) such infrastructure is for the bulk transportation of sewage, effluent, process water, wastewater, return water, industrial discharge or slimes inside a road reserve or railway line reserve; or

(b) where such development will occur within an urban area.

Activity 14 of 67

The development and related operation of facilities or infrastructure, for the storage, or

for the storage and handling, of a dangerous good, where such storage occurs in containers with a combined capacity of 80 cubic metres or more but not exceeding 500 cubic metres.

Activity 16 of 67

The development and related operation of facilities for the desalination of water with a design capacity to produce more than 100 cubic metres of treated water per day.

Activity 25 of 67

The development and related operation of facilities or infrastructure for the treatment of effluent, wastewater or sewage with a daily throughput capacity of more than 2 000 cubic metres but less than 15 000 cubic metres.

Activity 34 of 67

The expansion of existing facilities or infrastructure for any process or activity where such expansion will result in the need for a permit or licence or an amended permit or licence in terms of national or provincial legislation governing the release of emissions, effluent, or pollution, excluding—

(i) where the facility, infrastructure, process, or activity is included in the list of waste management activities published in terms of section 19 of the National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008) in which case the National Environmental Management: Waste Act, 2008 applies.

(ii) the expansion of existing facilities or infrastructure for the treatment of effluent, wastewater, polluted water or sewage where the capacity will be increased by less than 15 000 cubic metres per day; or

(iii) the expansion is directly related to aquaculture facilities or infrastructure where the wastewater discharge capacity will be increased by 50 cubic meters or less per day.

Activity 46 of 67

The expansion and related operation of infrastructure for the bulk transportation of sewage, effluent, process water, wastewater, return water, industrial discharge, or slimes where the existing infrastructure—

(i) has an internal diameter of 0,36 metres or more; or

(ii) has a peak throughput of 120 litres per second or more: and

(a) where the facility or infrastructure is expanded by more than 1 000 metres

in length; or

(b) where the throughput capacity of the facility or infrastructure will be increased by 10% or more.

excluding where such expansion—

(aa) relates to the bulk transportation of sewage, effluent, process water, wastewater, return water, industrial discharge or slimes within a road reserve or railway line reserve; or

(bb) will occur within an urban area.

Activity 57 of 67

The expansion and related operation of facilities or infrastructure for the treatment of effluent, wastewater, or sewage where the capacity will be increased by 15 000 cubic metres or more per day and the development footprint will increase by 1 000 square meters or more.

Activity 63 of 67

The expansion of facilities or infrastructure for the transfer of water from and to or between any combination of the following –

(i) water catchments

(ii) water treatment works; or

(iii) impoundments

where the capacity will be increased by 50 000 cubic metres or more per day but excluding water treatment works where water is treated for drinking purposes.

Besides these activities in Regulation 327 as highlighted above, the following activities in Regulation 327 are not discussed, but might also have an impact on water reuse activities: Activity 9 / 12 / 48 / 50 /51 / 60

Regulation 325 (Listing Notice 2) also provides for 29 different activities, among others:

Activity 6 of 29

The development of facilities or infrastructure for any process or activity which requires a permit or licence or an amended permit or licence in terms of national or provincial legislation governing the generation or release of emissions, pollution, or effluent, excluding–

(i) activities which are identified and included in Listing Notice 1 of 2014.

(ii) activities which are included in the list of waste management activities published in terms of section 19 of the National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008) in which case the National Environmental Management: Waste Act, 2008 applies.

(iii) the development of facilities or infrastructure for the treatment of effluent, polluted water, wastewater or sewage where such facilities have a daily throughput capacity of 2 000 cubic metres or less: or

(iv) where the development is directly related to aquaculture facilities or infrastructure where the wastewater discharge capacity will not exceed 50 cubic metres per day.

Activity 11 of 29

The development of facilities or infrastructure for the transfer of 50 000 cubic metres or more water per day, from and to or between any combination of the following —

(i) water catchments

(ii) water treatment works; or

(iii) impoundments

excluding treatment works where water is to be treated for drinking purposes.

Activity 25 of 29

The development and related operation of facilities or infrastructure for the treatment of effluent, wastewater, or sewage with a daily throughput capacity of 15 000 cubic metres or more.

If any reuse action trigger any of the activities listed above, either a Basic Assessment or full Environmental Impact Assessment process as stipulated in R326, will have to be followed.

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 (see section 21 of the NWA), unless an authorisation has been granted in terms of the relevant published general authorisations (GA). 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.

For all of the abovementioned water uses a license is required and according to NEMA, an EIA process needs to be followed as stipulated in R. 326 if a license is required by any organ of state.

The general authorisations refer to above, is of specific interest when wastewater will be re-used for irrigation purposes. In this regard Government Gazette 42576 (12 July 2019), notice 383 of 2019 provides for the continuation of the GA published in Government Gazette 3682 (6 September 2013), notice 665. Notice 665 stipulate the water quality guideline that needs to be adhere to for different volume of wastewater that might be used for irrigation without a licence.

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 assess for a number of development categories, whether such a development might have a 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 300 m 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 erven 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 resource 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.

1.2.3.2 Residuals management

Before water can be reused, a level of treatment is almost always needed. The level of treatment and the residual products following from this treatment vary according to the technology applied and the purpose or use of the reusable water. This can vary from simply disinfection to the complication of the removal of salts and gasses associated with some of the treatment processes. 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 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.

1.2.3.3 Brine disposal options

A number of alternatives exist for the disposal of brine specifically and the choice of which to use is influenced by environmental considerations (legislation; permits by regulating authorities), location of the plant, and cost. The key elements for the disposal of brine have been highlighted in 'A Desalination Guide for South African Municipal Engineers' (JA du Plessis, AJ Burger, CD Swartz and N Musee) in 2006, but are presented below for completeness.

Ocean Disposal

For seawater or brackish water desalination, brine disposal in offshore 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.

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.

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 are concerned (e.g. from small desalination plants).

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.

Evaporation ponds

Solar evaporation, generally limited to small flows and areas of arid climate (with high evaporation rates and low rainfall) and inexpensive land. This is 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.

Land application

Disposal to percolation ponds or use as irrigation water.

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, although the potential of soil deterioration should be taken into account.

Co-disposal

Blending and disposal with wastewater treatment plant effluent or power plant cooling water, into ash.

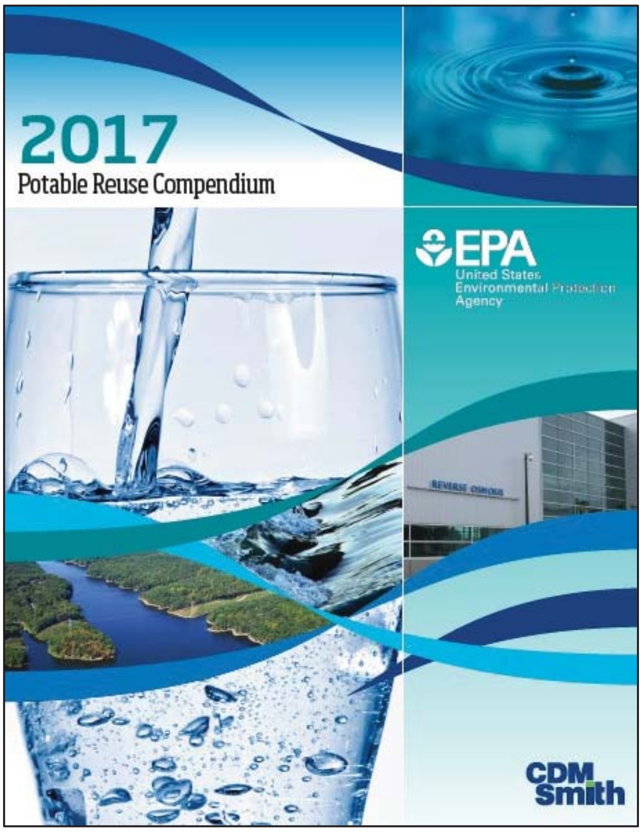
1.2.4 South African regulatory guidelines

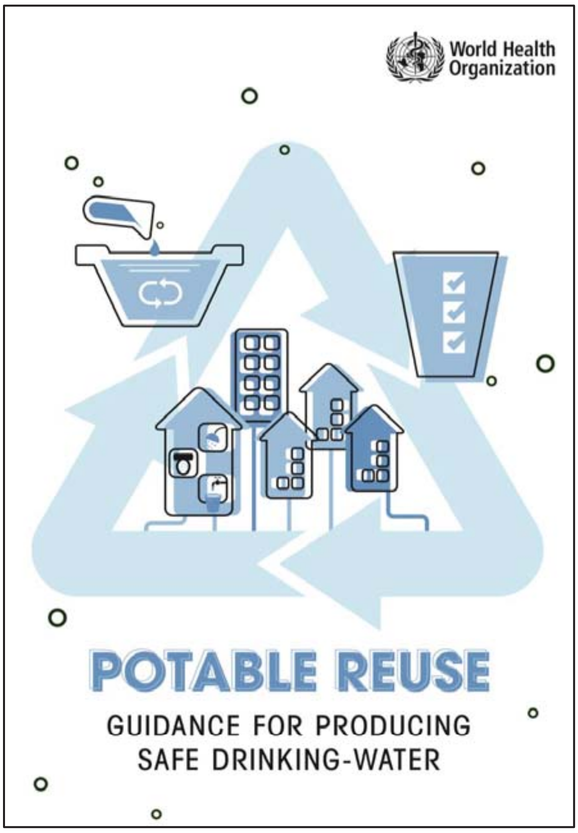
When planning and/or designing a new water reclamation and reuse scheme, the existing water quality guideline documents should be consulted. The selection of one or more guideline documents to consult should be done with due consideration of the site-specific circumstances of the project. The following represents important guideline documents in the Southern African context:

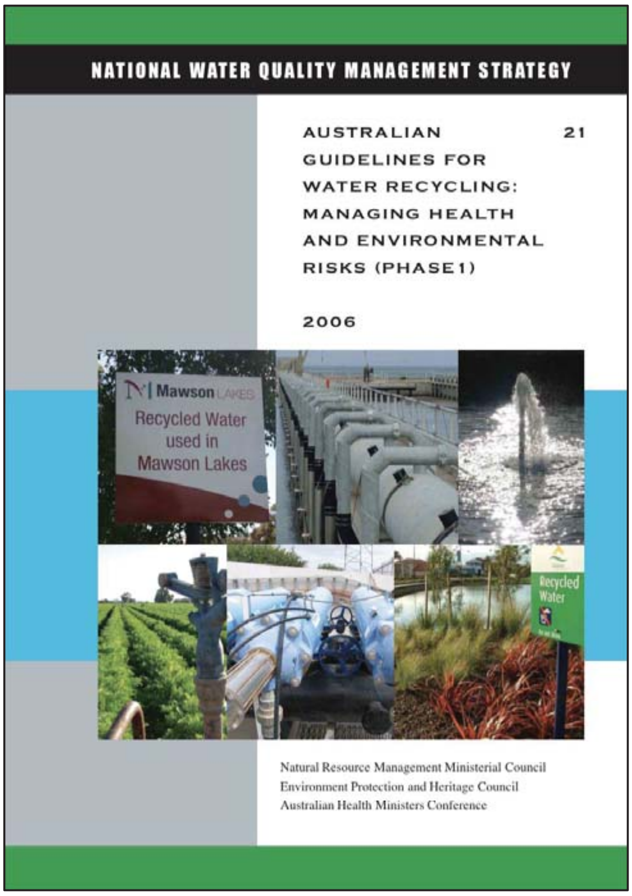
- South Africa, SANS 241:2015
- South Africa, Rand Water, Potable water Quality Criteria, 1994
- WINGOC operational and compliance monitoring protocols
- Proposed Water Quality Targets (see Section 5.5.2)

1.2.5 International guidelines and standards

Examples of guideline documents that are widely used across the globe for water reclamation and reuse projects include:


2017
Potable Reuse Compendium
EPA
United States
Environmental Protection
Agency
CDM
Smith


World Health
Organization
POTABLE REUSE
GUIDANCE FOR PRODUCING
SAFE DRINKING-WATER


NATIONAL WATER QUALITY MANAGEMENT STRATEGY
AUSTRALIAN GUIDELINES FOR WATER RECYCLING: MANAGING HEALTH AND ENVIRONMENTAL RISKS (PHASE1)
21
2006
Mawson
Recycled Water used in Mawson Lakes
Recycled Water
Natural Resource Management Ministerial Council
Environment Protection and Heritage Council
Australian Health Ministers Conference

1.3 PUBLIC AWARENESS, ACCEPTANCE AND PARTICIPATION

1.3.1 Introduction

Cain (2011) discussed the complex nature of using reclaimed water for potable use, resulting in uncertainty amongst regulators and the wider public, which may lead to resistance. However, verification and explaining the numerous recent advances in technology and design for treating municipal wastewater and reusing it for drinking water may lead to higher degree of acceptance and thus may significantly augment available water resources to meet growing demand, particularly in areas facing water shortages. The practical experience of Windhoek demonstrates that water reclamation can be a responsible way to augment potable water supplies in arid regions, provided there is comprehensive planning, training and ongoing commitment to continued success and quality control (Kasperson, 1974; Okun, 1985; Crook, 1985).

Several studies (Po et al., 2004; Po & Nancarrow, 2004) have identified factors that may significantly influence public acceptance of reclaiming water for a variety of (non-potable) uses, but there has been little research specifically relating to water reclamation for potable use. Studies such as those conducted by the USFDA (2009) provide insights into the perceived risks, benefits and knowledge about water reclamation, control over the quality of water, trust in authorities, experts and technology, and personal feelings and emotions, and therefore deserve broader consultation. This applies to several local studies sponsored by the WRC that researched public awareness in relation to reuse, with some recent findings being highlighted below.

1.3.2 Why public awareness is crucial

Muanda C, Cousins D, Lagardien A, Owen G and Goldin J (2017)
Direct reclamation of municipal wastewater for drinking purposes. Volume 2: Investigation into institutional and social factors influencing public acceptance of reclaimed water for potable uses in South Africa
WRC Report No. TT 734/17. Water Research Commission, South Africa. November 2017.

In a WRC funded project, Muanda *et al.* (2017) studied the acceptance of reuse water by the public in general, as well as in target groups. Public perceptions were investigated to gain insight into how best to address hindrances to the successful implementation of water reclamation. The main findings of the study are summarised as follows:

- Water reuse is increasingly being used as an option for non-potable as well as potable water augmentation, despite various institutional and social challenges that often relating to both the 'yuck' factor and safety concerns. This often leads to public resistance towards accepting water reuse.
- Water authorities are faced with the challenge of how to introduce water reuse and address public concerns and enhance social acceptance.
- Emotions underlying public perceptions include doubt and denial, mistrust, fear, and safety concerns.

- The guidelines proposed by Muanda *et al.* (2017) for municipal water service providers are intended for local authorities considering water reclamation and reuse as an augmentation option when conventional water resources are constrained, to enable them to address negative public perceptions.
- A section of the guideline document is referred to as a public awareness manual. It outlines the generic and basic knowledge that the public needs in order to understand water reclamation and suggests how best to respond to their concerns.
- Within each municipal context and at particular stages of the institutional process for introducing water reclamation, opportunities for public queries and institutional responses can serve simultaneously to enhance social learning and build trust in public institutions.
- Water institutions should engage with identified target groups in order to shift public resistance toward acceptance and promotion.
- The research proposes an approach that will address public resistance so as to improve acceptance of water reclamation.
- There is an absence of documentation providing guidance or a framework for examining the capabilities and readiness of water institutions to implement water reclamation.
- It is recommended that further research be undertaken in order to understand and evaluate water services institutions' readiness and capability to introduce water reclamation and implement a strategic approach to overcome public concerns.

1.3.3 Improving the public knowledge basis of water reuse

Slabbert S and Green N (2020)
Public Knowledge of Water Re-use and other Water Related Aspects
WRC Report No. TT 807/19. Water Research Commission, February 2020.

Until recently, there has been no baseline assessment available on the current status of public knowledge on water reuse in South Africa. To address this shortcoming, a study, funded by the WRC, was carried out to establish a baseline of public knowledge that is required before a communication strategy for a public education programme and a toolkit for primary target audiences can be developed (Slabbert, 2020). The aims of the study included a review and analysis of local and international perception studies on water reuse, best practice in water reuse communication strategies and campaigns, as well as consulting with relevant stakeholders in the water sector on a communication strategy for a public education programme for water reuse. A further aim was to develop a communication strategy for a public education programme for water reuse and a toolkit that has been tested and piloted.

The study stemmed from the following:

- Mention in the National Strategy for Water Reuse (Annexure D of the National Water Resources Strategy [NWRS]) (DWA NWRS, 2012) that a communication strategy for water reuse needs to be developed and implemented.

- Priority at the NSWR to efforts addressing the lack of understanding of different facets of water use, and specifically water reuse.
- Initial consultations with DWS officials in 2017 emphasised that an informed public should be the basis of the communication strategy for water reuse.
- Insufficient depth and clarity in the cited literature presenting a major barrier to the implementation of water reuse.

The NWRS proposes a targeted approach for the communication strategy which focusses on:

- A sustained public education programme, which addresses the diversity of perceptions and opinions, as it relates to indirect or direct water reuse.
- Appropriate material to inform the public and stakeholders.
- Mechanisms that will facilitate active communication and debate on the topic.
- Targeted media coverage.

Findings of the study:

The survey found that South Africans across all demographic groups have poor knowledge and understanding of the basic terminology that is needed for a meaningful public discourse on water reuse. For example, only 35% of South Africans know that greywater is the term for wastewater from bathing, washing clothes and dishes. Only 28,3% know what 'potable water' means.

South African's knowledge of water reuse and related aspects was tested with 18 statements. The composite result was presented as an index score out of 20. On average, South Africans scored 12 out of 20. Even for the highest LSM (Living Standard Measure) group (LSM 8-10) and for people with a post Grade 12 qualification the average scores were 13,05 and 12,65 respectively. This indicates that public knowledge of water reuse and related aspects needs to be improved and a public education campaign on water reuse should target all demographic groups.

The survey indicated that South Africans would support water reuse in a severe drought situation, including direct potable reuse. 48,5% of the population mentioned direct potable reuse as an action that they will support. As expected, the support for direct potable reuse was lower than the support for industrial and greywater reuse, but the difference was less than 10%.

Although the correlation was weak, the survey confirmed that knowledge of water reuse and related aspects correlate positively with support for water reuse. The study also found that general education levels seem to be related to support for water reuse. Respondents with a post Grade 12 qualification (54,6%) support direct potable reuse significantly more than respondents with only primary education (39%).

1.3.4 Communication programs and protocols

Slabbert S and Green N (2020) A communication strategy for water re-use in South Africa Volume I: Situational analysis and stakeholder engagement Volume II: Communication strategy and toolkit development WRC Report No. 2805/2/20. Water Research Commission, October 2020.

This 2-volume report concluded that consultation with the community is a vital element in developing recycled water schemes, particularly those involving drinking water augmentations. Proposals to augment drinking water supplies with recycled water also tend to polarise views, with some people strongly supportive and others strongly opposed. Communication needs to involve information provision and education. Consultation will be more effective if participants are well informed.

Public and stakeholder concerns can be very powerful and can mean the difference between acceptance and rejection of recycled water schemes. In some cases, public support has helped schemes to proceed; in other cases, public opposition has stopped schemes from being developed.

The aim of consultation needs to be to arrive at a sustainable outcome rather than to seek acceptance of a system preferred by its proponents. Informed deliberations need to include complete information on the status quo, the full range of alternatives available, and the costs and risks associated with each of these alternatives. Any issues raised during the consultation process need to be recorded and addressed. Feedback needs to be provided on responses to issues raised during consultation. Communication will necessarily be an iterative process.

Community consultation and education is a specialist area and expert advice should be sought or engaged to assist in designing and implementing processes.

The decision to introduce drinking water augmentation must be aligned with the needs and expectations of stakeholders and the community as a whole. Therefore, to maximise community acceptance, all stakeholders need to be consulted and involved in decision-making processes.

1.4 FEED WATER SOURCES AND WASTEWATER QUALITY

1.4.1 Reuse water sources

The future water supply options for South Africa are summarised and discussed in the National Water Resource Strategy (NWRS2) (DWA, 2013), which built on the first edition of the NWRS issued in September 2004. It is notable that the 2004 NWRS hardly refer to any aspect of the reuse of water in South Africa. The NWRS2, however, provide a consolidated picture of the possible extent of planned projects to increase the available water through reuse and desalination as highlighted in Table 1-2. While still relatively low volumes of water reuse are foreseen, the potential as a direct reuse resource of 50 x 10^6 m^3/a, and 1 100 x 10^6 m^3/a, from domestic and urban return flows, respectively, as highlighted in Table 1-2 (Part 1) do highlight significant progress.

Table 1-2: Projected (2030) reuse and desalination options in million m^3/a (NWRS2)

Water Management Area / Region	Reuse	Desalination
Western Cape	30	110
Algoa	35	10
Amatole	30	
KwaZulu-Natal coastal metropolitan area	40+	Unlimited
Vaal River		500 (Acid Mine Drainage)
Olifants River	11	22
Mangaung Metropolitan area	11	

According to the NWRS2, up to 14% of existing water use is made up of reuse water, although that is mostly through wastewater return flows to rivers from which it is abstracted downstream for indirect reuse. The significant focus on reuse is confirmed with reported pre-feasibility investigations of direct reuse opportunities for a total of about 280 million m^3/a underway, while initial studies for an additional 15 million m^3/a have been commissioned.

Reuse of return flows could be significantly increased, particularly in coastal cities where wastewater ordinarily drains into the sea.

Besides the indirect reuse of treated effluent, the treatment and direct reuse of the effluent from municipalities do remain the most convenient resource available. Acid mine water is also a very likely resource, which will be accessible through improved treatment technologies that are more cost effective.

The use of the effluent from wastewater treatments works need to be considered carefully, based on the water use license issued to a particular municipality. From an ecological point of view and given the high level of existing indirect reuse from downstream users, the availability of these resources needs to be verified before reuse can be considered.

At a household level the potential for reuse is typically situated at:

- Warm-up lag water for baths and showers
- Shower and bath water
- Laundry water, from washing machine or handwashing
- Hand basin washing water.

Typically, 50-80% of indoor water used in the home can be reused. However, there are some significant health and hygiene risks that need to be properly managed (City of Cape Town, 2013). The most common uses for reusable water at a household level include:

- Gardening
- Flushing of toilets
- Cleaning of vehicles.

For more detailed information on greywater requirements, the reader is referred to the following WRC report:

Carden K, Fisher-Jeffes L, Young C, Barnes J and Winter K (2018)
Guidelines for greywater use and management in South Africa
WRC Report No. TT746/17. Water Research Commission, March 2018.

1.4.2 Wastewater quality

The foreign substances (or pollution) present in wastewater may be categorised in various ways. The following classification is often used:

Mineral salts

Mineral salts are to a larger or lesser extent present in all waters. When concentrations are high, it can be tasted, like in sea water or brackish water. The same salts are also present in food (e.g. as table salt), and are also secreted by people in urine or sweat. These salts contribute to an increase in the salt content of sewage. Unfortunately, these salts are difficult to remove from sewage and it pass unchanged through the purification processes.

Domestic wastewater contains typically 300 to 350 mg/l more mineral salts than the clean water originally distributed in the town.

Organic substances

Organic substances are originally derived from plants. It includes food wastes (both animal and vegetable), milk, sugar, faeces, urine, sweat, dirt from clothes and fat. All these substances have one common characteristic, namely that they contain energy and can thus serve as a food supply for bacteria. An important aim of wastewater treatment is to remove the organic substances with the aid of suitable bacteria under controlled conditions, so that it is not available as food source for organisms present in nature and in the receiving waters.

Plant nutrients

Wastewater contains substantial amounts of nitrogen and phosphorous which are not removed fully during normal purification processes. Even finally purified wastewaters may therefore be “enriched” with these two substances, which means that luxurious plant growth will take place in the water. Although this will be beneficial if the water is used for gardening, it is unfavourable if the water is used for potable purposes.

Toxic substances

Toxic substances include heavy metals (chromium, copper, cadmium, etc.), mineral oils, as well as discharges of herbicides and pesticides from factories. These substances not only upset the biological purification processes, but also create a danger to workers on the sewer lines and at the purification works. Suitable trade waste regulations are usually promulgated to prevent such discharges.

Contaminants of emerging concern (CECs)

Dissolved organic constituents include low concentrations of an extensive range of organic chemicals from industrial and domestic sources (micro-pollutants). Examples include pharmaceuticals and personal care products (PPCPs), pesticides, preservatives, surfactants, flame retardants, disinfection by-products (DBPs), and chemicals released by humans such as dietary compounds and steroidal hormones (Khan, 2013).

Pharmaceuticals were detected in U.S. surface waters starting in the 1970s (EPA, 2017). In the 1990s, steroid hormones in wastewater were linked to ecological impacts in impacted surface waters. There are now well over 1000 research articles documenting the presence of trace chemical constituents, such as per- and polyfluoroalkyl substances (PFAS), in aquatic ecosystems impacted by human populations worldwide (EPA, 2017).

More information on chemicals of emerging concern is provided in Section 2.3.4.

Swartz CD, Genthe B, Chamier J, Petrik LF, Tijani JO, Adeleye A, Coomans CJ, Ohlin A, Falk D and Menge JG (2018) Emerging Contaminants in Wastewater Treated for Direct Potable Reuse: The Human Health Risk Priorities in South Africa WRC Report No. TT 742/3/18. Water Research Commission.

Organisms causing disease

Every person discharge, as part of their faeces, a large variety of microscopic organisms, e.g. bacteria, viruses, protozoic parasites, etc. Although not all of these organisms are pathogenic (i.e. causing disease), some (especially those discharged by diseased people) will cause disease if ingested in sufficient quantities, e.g. diarrhoea, diseases of the liver, parasitic worms, etc. The sewage treatment process should eliminate these organisms. Raw sewage contains typically 10^6 to 10^9 bacteria per ml, but not all of these will be pathogenic; in fact, sewage originating from healthy people will normally not contain any pathogens.

1.4.3 Removal efficiencies of CECs by wastewater treatment systems

1.4.3.1 International studies

Ferreiro and co-workers (2020) reported that with biological treatment in wastewater treatment plants, the removal rate of the CEC was dependent on the concentration and nature of each compound due to specific degradation biokinetics and biodegradability of the different compounds, respectively. It was found in the study that genistein, methylparaben, progesterone, testosterone, caffeine, and acetaminophen showed removal efficiencies above 99.5%. In contrast, irbesartan, carbamazepine, diuron, and phenytoin showed average removal rates below 20.0%. In addition, solutions with a higher concentration of CEC (above 1500 ng/L) presented high efficiencies above 80.0% in almost all cases.

The efficiency of CEC removal by wastewater treatment processes therefore varies widely, based on, amongst other, the biodegradability of the organic compounds. It is clear that wastewater treatment plants cannot sufficiently removal CECs to ensure that the treated water does not negatively impact on the environment or is safe for production of drinking water using conventional drinking water treatment processes only.

1.4.3.2 Local studies

A research project was undertaken to, amongst other, monitor EDCs in various stages of the three selected types of wastewater treatment plants determine and compare their removal efficiencies using a mass balance approach (Coetzee et al., 2016).

Results of the study indicate variable removal efficiencies (from 0 to 100%) for different EDCs. These differences in removal efficiencies can be attributed to:

- Differences in the chemical structure of the EDCs with different physicochemical properties. Chemical structures in the same application class can also differ, for example compounds used as antibiotics displayed variable removal efficiencies.
- Type of treatment technology used, and the operating conditions applied in the processes. Activated sludge processes were found to be more efficient than biological filtration systems. In activated sludge systems it was found that sludge age is an important control parameter which has an effect on the removal efficiencies of EDCs. At longer sludge ages EDC removal is more efficient. There is also an indication that nitrification promotes the removal of EDCs.

The main removal mechanisms of EDCs in wastewater treatment plants are adsorption and biodegradation. Thus, a large fraction of the EDCs is adsorbed onto the sludge surface. Aerobic digestion seems to reduce the concentrations better than anaerobic digestion. Findings also suggest that during anaerobic digestion some compounds are transformed to intermediates which either exhibit similar estrogenic characteristics or are even more estrogenic than the original compound.

Investigations done on treatment technologies used in rural and remote areas are very limited. With regards to waste stabilization ponds systems only evaluations for the removal of estrogens, bisphenol A and 4-nonyl-phenol were found (Coetzee *et al.,* 2013).

The available data is sufficient to confirm that there is reason for concern, as EDCs are discharged into water resources and evidence of endocrine disrupting in the aquatic environment is undeniable. However, more research is needed to relate the operating conditions in a plant to the removal efficiencies for the different EDCs in particular for biological filtration, stabilization ponds and sludge stabilization processes such as anaerobic digestion. Furthermore, to enhance the quality of the research findings it is recommended that a mass balance approach should be used to evaluate the fate of different EDCs in wastewater treatment plants, and to determine at what concentrations they have endocrine disrupting, or other toxicological effect.

1.4.4 Proposed water quality targets for DPR in Southern Africa

1.4.4.1 Overview

A wide variety of pathogenic viruses, protozoa and bacteria may be transmitted by water. These micro-organisms cause diseases such as gastroenteritis, giardiasis, hepatitis, typhoid fever, cholera, salmonellosis, dysentery and eye, ear, nose, and skin infections, which have worldwide been associated with polluted water

(DWAF, 1996). Ideally drinking water should not contain any known pathogenic microorganisms and it should be free from bacteria indicative of pollution with excreta.

It is impossible to routinely test the water supply for all pathogens related to water borne diseases because of the complexity of the testing and the time and cost related to it. Therefore, indicator systems which are able to index the presence of pathogens and related health risks in water are used.

Typically, an indicator organism should fulfil the following criteria (Swartz *et al.,* 2015):

- It should be present when the pathogen is present, and it should be absent in unpolluted water.
- it should be present in numbers greater than the pathogens it indicates.
- its survival in the environment and resistance to treatment processes should be comparable to that of pathogens.
- it should not be harmful to human health; and
- it should be easy to identify and isolate.

At present there is no single indicator which complies with all the above criteria. The traditional indicators of drinking water quality include the coliform group. The faecal coliforms, or thermo-tolerant coliforms, and *E. coli* have been differentiated from the total coliforms as being more specific indicators of faecal pollution. The standard or heterotrophic plate count is also used in many countries, including South Africa, as a useful parameter in the quality control of water and water treatment processes since it is an indicator for disinfection efficiency for final treated water that can also be used throughout the distribution system.

Exceptions where pathogen presence is set in water quality guidelines.

Because the potential presence of pathogens in water cannot be predicted solely by faecal indicators, it may be necessary, under certain circumstances, to monitor for the presence of pathogens in addition to routine indicators – provided that the facilities are available. WHO (2011) has recommended that, under certain circumstances, it is necessary to monitor for: *Salmonella* spp., Shigella spp., Vibrio cholera, Yersinia enterocolitica, Campylobacter fetus, enteropathogenic E. coli and enteric viruses? In Australia it has been recommended to monitor for Salmonella sp., Vibrio cholerae, Shigella spp., Yersinia, Leptospira, Legionella, Giardia, Naegleria fowleri, enteric viruses, nematodes, cestodes and trematodes. The EEC specifies that water intended for human consumption should not contain pathogens and, if it is intended to supplement the microbiological analysis of water intended for human consumption, the samples should be examined for pathogens including Salmonella, pathogenic staphylococci, enteroviruses, and faecal bacteriophage.

***Giardia, Cryptosporidium*, viruses, and other pathogens should never exceed the limits.**

International Guidelines to Assess the Safety of Water

The main aim of water quality guidelines is to protect public health. A guideline value represents the concentration of a constituent that does not exceed tolerable risk to the health of the consumer over a lifetime of consumption (WHO, 2011). Guideline values are not normally set at concentrations lower than the detection limits achievable under routine laboratory operating conditions. Moreover, some guideline values are established considering available techniques for controlling, removing, or reducing the concentration of the contaminant to the desired level. According to the World Health Organisation (2004), the potential consequences of microbial contamination are such that its control must be of paramount importance and must never be compromised. Generally, the greatest microbial risks are associated with ingestion of water contaminated with human and animal excreta. Water must therefore, as the first line of defence, be protected from contamination by human and animal waste.

The methods used to determine whether water is safe vary according to guidelines and standards. According to the majority of international guidelines and standards, water intended for human consumption should be safe, palatable, and aesthetically pleasing. This implies that the water should be free of pathogenic microorganisms and other substances that may present a health risk. Similarly, guidelines exist for all other uses of water, namely agricultural water use, industrial water use, recreational water use, etc.

At present, a number of South African water quality guidelines and specifications are available and are used by all concerned at their discretion. South African water reuse quality guidelines are currently not legally enforceable. The WRC has started the process (2014) of updating the South African water quality guidelines of 1996 to include updated guideline levels and chemicals of emerging concern for which quantitative and qualitative data is available.

1.4.4.2 Proposed water quality targets

Table 1-3 shows preliminary proposed water quality targets for direct potable reuse in Southern Africa (Swartz *et al.,* 2015):

Table 1-3: Proposed water quality targets

Parameter	Unit	Proposed Guidelines (adapted from CoW guidelines) (Swartz *et al.*, 2015))		Existing Guidelines ranges			
				International		Southern Africa	
		Target value	Maximum allowed	Target value range	Maximum allowed range	Target value range	Maximum allowed range
Physical							
pH	-	7.8-8.4	5-9.7			5-9.7	8.4-9.7
Colour	mg/L as Pt	8	10		15	8	10-15
EC	mS/m	+30 (1)	154				45-170
TDS (calculated)	mg/L	+200 (2)	1000			1000	1000-1200
Turbidity	NTU	0.1	0.2	1	1-5	0.1	0.2-5
Free Chlorine	mg/L	0.9-1.2	1.5				
Total hardness		184	200			184	200
CCPP (calculated)	mg/L		4			8	4-10
DOC (3)	mg/L	0.01	0.05			3	5
TKN	mg/L as N	1.56	1.95			1.56	1.95
UV_{254}	Abs/cm	0.02	0.06			0.06	0.06-0.065
Chemical							
Macro determinants							
Aluminium	mg/L	0.15	0.3			0.15	0.15-0.3
Ammonia	mg/L		0.1				0.1-1.5
Barium	mg/L	0.5	2		0.7-2	0.5	0.5-2
Boron	mg/L	0.5	4		0.5-2.4	0.5	0.5-4
Bromide	mg/L		4		7		1
Chloride	mg/L		250				100-300
Copper	mg/L	0.5	2		1.3-2	0.5	0.5-2
Fluoride	mg/L	1	2		0.7-4	1	1-2
Iodine	mg/L		0		0.06		0.5
Iron	mg/L	0.05	0.1			0.05-0.3	0.1-2
Lithium	mg/L		2				2.5
Magnesium	mg/L		50				50
Manganese	mg/L	0.01	0.025		0.4	0.01-0.1	0.025-0.5
Nitrate	mg/L		10		10-50		6-11
Nitrite	mg/L		0.05		1-3		0.05-0.9
Phosphate	mg/L	0.02	2.27			0.02	2.27
Potassium	mg/L	20	100			20	20-100
Sodium	mg/L	100	400		50	100	100-400
Sulphate	mg/L		200				200-500
Zinc	mg/L	1	10			1	1-10
Micro determinants							
Antimony	µg/L			0	6-20		20-50
Arsenic	µg/L	50	300	0	10	50	10-300
Cadmium	µg/L	5	20		3-5	5	3-20
Chromium	µg/L	50	200		30-100	50	50-200
Cobalt	µg/L	0.25	1			0.25	1-500

Parameter	Unit	Proposed Guidelines (adapted from CoW guidelines) (Swartz *et al.*, 2015))		Existing Guidelines ranges			
				International		Southern Africa	
		Target value	Maximum allowed	Target value range	Maximum allowed range	Target value range	Maximum allowed range
Gold	µg/L	2	10			2	2-10
Lead	µg/L	50	200	0	10-15	50	10-200
Mercury	µg/L	1	5		2-6	1	1-6
Nickel	µg/L	0.25	1		70	0.25	1-250
Phenols	µg/L	5	40		150	5	5-40
Selenium	µg/L	10	50		10-50	10	10-50
Silver	µg/L	20	100			20	20-100
Tin	µg/L	10	50			10	50-100
Titanium	µg/L		100				100
Toluene	mg/L		0		0.7-1		0.7
Microbiological							
Algae							
Chlorophyll A	µg/L		1				1
Blue-green algae (Cyanobacteria)	cells/mL		200				200
Microcystin	µg/L		1		1		0.1
Bacteria							
E. coli	count/mL	0	0	0	0	0	0
Faecal coliform	count/100 mL	0	0	0		0	0
Total Coliforms	count/100 mL	0	0	0		0	0
HPC (Total bacterial)	count/mL	80	100		500	80	100
Clostridium	count/100 mL	0	0			0	0
Entamoeba histolytica	org/2 L	0	0				0
Viruses							
Coliphages (Indicator)	count/100 mL	0	0			0	0
Viruses (enteric)	count/1000 L	0	0				
Rotavirus	count/1000 L	0	0				
Adenovirus	count/1000 L	0	0				
Noravirus	count/1000 L	0	0				
Parasites							
Cryptosporidium	org/1000 L	0	0	0		0	0
Giardia lamblia	org/1000 L	0	0	0		0	0
Disinfection By-Products (DBPs)							
Formaldehyde	µg/L		900			900	900
NDMA	ng/L		60		0.7-100		
Bromate	µg/L	0	10	0	10	0	10
Bromoform	µg/L	9	40		0-100		50-100
Chloroform	µg/L	20	40		300		50-300
Bromodichlorom-ethane	µg/L	20	40		0-60		50-60

Parameter	Unit	Proposed Guidelines (adapted from CoW guidelines) (Swartz *et al.*, 2015))		Existing Guidelines ranges			
				International		Southern Africa	
		Target value	Maximum allowed	Target value range	Maximum allowed range	Target value range	Maximum allowed range
Dibromochloromethane	µg/L	20	40		60-100		50-100
Total THMs	µg/L	20	40	0	80	20	40-100
Priority Pollutants (Chemicals of Emerging Concern)							
Hormones							
17α-ethinyl estradiol	µg/L		0.0015		0.0015		
Estriol	µg/L		0.05		0.05		
Estrone	µg/L		0.03		0.03		
Pesticides							
Alachlor	µg/L	2	5	0	2-20		5
Atrazine	µg/L	2	5		2-100		5
MCPA	µg/L		2		2		2
Metolachlor	µg/L		5		0.02-10		5
Pharmaceuticals							
Ibuprofen	µg/L		400		400		
Carbamazepine	µg/L		100		100		
Sulfamethoxazole	µg/L		35		35		
Diazepam	µg/L		2.5		2.5		
17α-estradiol	µg/L		0.175		0.175		
17β-estradiol	µg/L		0.175		0.175		

(1) Based on the raw water EC values

(2) Based on the raw water TDS values

(3) DOC for conventional plants (not using NF or RO treatment processes) should be below 1.0 mg/L

Other Determinants	
Agricultural chemical compounds	Any contaminant/determinants that are not listed in the above table must comply with international guidelines as listed below.
Industrial chemical compounds	
Endocrine disruptive chemicals	

1.5 SELECTION AND COSTING OF WATER RECLAMATION TECHNOLOGIES

Numerous options are available when Water Service Authorities (WSAs), which include all local authorities, the Department of Water and Sanitation (DWS), planners and funders (such as the Development Bank of Southern Africa (DBSA)) consider water reuse to improve water resource 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. It is difficult to obtain reliable information in South Africa comprising 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 (Swartz *et al.,* 2014).

1.5.1 Key drivers affecting water reuse choices

Figure 1-2 shows key considerations for water reuse schemes as options for water supply augmentation (Swartz *et al.,* 2014). Based on these considerations, a simplified decision-making tool for water reuse planning was presented in this WRC report, based on the considerations in the diagram.

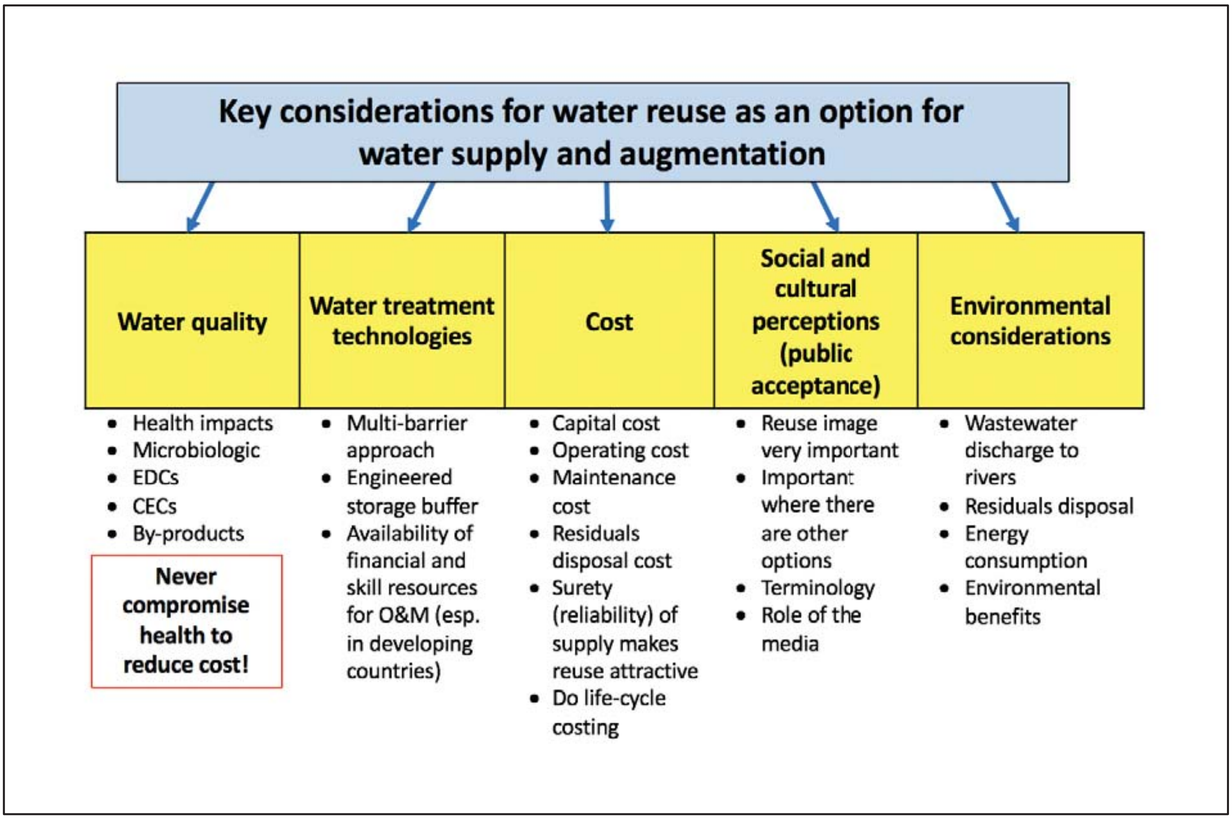


Figure 1-2: Key considerations for water reuse schemes as options for water supply augmentation (Swartz *et al.,* 2014)

1.5.2 Costing models

Numerous options are available when Water Services Authorities (WSAs), the Department of Water and Sanitation (DWS), 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 were new existing costing models in the local public domain to provide planners, engineers and local and provincial government managers with the necessary tools to do first-order-of-magnitude costing of water supply or water reuse projects. A first WRC project was therefore carried out to develop a costing model for drinking water supply projects, in which the WATCOST model was developed in 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).

However, there was a need to also develop a decision-support and costing model specifically for the water reuse and reclamation projects, and this was subsequently carried out in a follow up WRC project "*Guidelines for the Selection and Costing of Water Reclamation and Reuse Systems*" (WRC Report No. 2119/1/14 by Swartz et al., 2014). This model was titled the REUSECOST model.

More information on the REUSECOST model is provided in Part 2, Section 2.6 of the guide.

1.6 ENVIRONMENTAL ASPECTS OF WATER REUSE

South African legislation is very clear that the protection of our environment is a constitutional right as highlighted in Section 24 in Chapter 2 of the Constitution of South Africa (Act 108, 1996). The constitution further highlights it in Section 152 (1) that it is the objective of local government "to promote a safe and healthy environment" although the environment is listed as a concurrent National and Provincial legislative function. It is therefore the responsibility of both National and Provincial government to ensure that appropriate legislation is in place to ensure a safe environment, but it is indeed the local authority's responsibility to ensure that this legislation is executed, and that planning is done with a safe environment in mind.

Water reuses impact the environment on various levels, which is not only technology specific, for example related to the energy consumption of the process needed to ensure effective water reuse, but also on a strategic level related to the reduced environmental impact of water reuse as appose to that of the development of new water resource option, such as dams.

Some of the benefits from the reuse of wastewater include lower freshwater requirements from natural resources, less capital investments in bulk treatment infrastructure due to lower growth in the demand for treatment capacity, plant growth and the reclamation of otherwise wasted nutrients, less energy and chemical use during treatment, groundwater recharge and an increased awareness of the scarcity of natural water resources.

Internationally, the focus on reuse is also frequently not as a result of inadequate water security, but specifically to reduce the waste stream and its negative impacts on the environment when discharging the waste stream back into natural environments (river and lakes). The positive impacts of reuse on the environment are also well known and reuse projects need to be evaluated against the development of new resources with this in mind.

While the discharge of the waste streams back into the natural environment remains the largest environmental challenge, the different levels on which water reuse can be implemented, requires a far wider perspective, with specifically the involvement of the civil society, which does not only touch on awareness programmes to ensure the effective management of reuse options at a household level, but is also as far reaching as the religious-social environment.

1.7 MANAGEMENT OF WASTES AND RESOURCE RECOVERY

Wastes from any water and wastewater treatment plant should be properly managed and disposed of, if necessary. It should not have a negative impact on the environment or on human and animal health. The same applies to water reuse plants, but in this instance, it is very important that it be carried out and controlled (regulated) carefully, because of the potential detrimental effect the concentrated impurities and pathogenic material may have on humans and the environment.

The residuals from reuse plants may include screenings, backwash solids, liquid streams, and RO brine (NWRI, 2015). Solids may be returned to the WWTW after some form of treatment, and liquid streams (excluding RO brine) may also be returned to the WWTW for re-treatment.

Management of RO and NF concentrates (brine streams) presents a particular problem, especially where the reuse plant is located inland. These brine streams require extensive treatment before discharge to the environment to ensure that all impurities and salts do not have a damaging effect on the environment. Evaporation ponds are an expensive option due to the vast earthworks required and, especially, due to the fact that the ponds have to be lined to prevent seepage to the groundwater. The related treatment technologies are sophisticated and also very expensive.

Management of waste streams therefore require careful attention in the planning and costing stages of a water augmentation projects. Disposal options and waste stream treatment technologies are presented and discussed in Part 4 of the guide.

1.8 FINANCING AND FUNDING OF REUSE SCHEMES

1.8.1 Institutional arrangements and water sector regulations

The National Water Act (Act 36 of 1998) provides for the establishment and transformation of institutions to assist DWS in giving effect to its core mandate – the development, protection, conservation and allocation of water resources, and regulation of water services and water use. Currently DWS is in the process of institutional reform and re-alignment in order to effectively contribute to the national government's development objectives.

At present, DWS manages most of the national water resources infrastructure through its Water Trading Entity while the Trans-Caledon Tunnel Authority (TCTA) finances and project manages the implementation of economically viable water projects, as directed by the Minister. TCTA projects are financed off-budget and the investment costs are repaid through user charges.

It is recognized that the Water Trading Entity is not the most appropriate or efficient institutional arrangement for managing national water infrastructure. Thus, the intention is to establish an alternative, and appropriate National Water Resources Infrastructure institutional model for developing, financing, and managing national water infrastructure. Figure 1-3 presents a diagram showing institutional support across the water value chain.

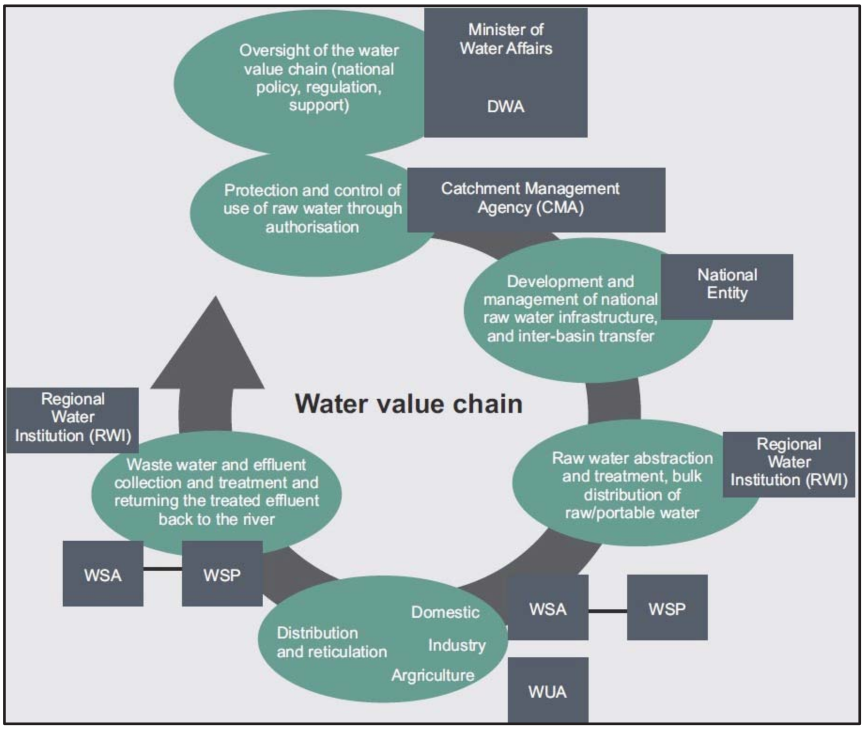


Figure 1-3: Diagram showing institutional support across the water value chain

Management of water resources is envisioned to take place at the catchment level, which will be administered by nine (presently under review to establish only six) Catchment Management Agencies (CMA) countrywide. Regional and bulk water infrastructure and support to local government in the local delivery of water will become the responsibility of newly established Regional Water Utilities (RWU) (currently Water Boards) that will be formed to achieve optimum economies of scale. These will support the local Water Services Authorities (WSA) and Water Service Providers (WSP).

The development of institutional and organizational roles in the regulation of water in South Africa Associations (WUA) will be developed through transformation of existing irrigation boards or establishment of new WUAs that will manage and regulate local water resources and infrastructure used for irrigated agriculture. Figure 1-4 shows a diagram of Institutional and organisational roles in regulation of water in South Africa.

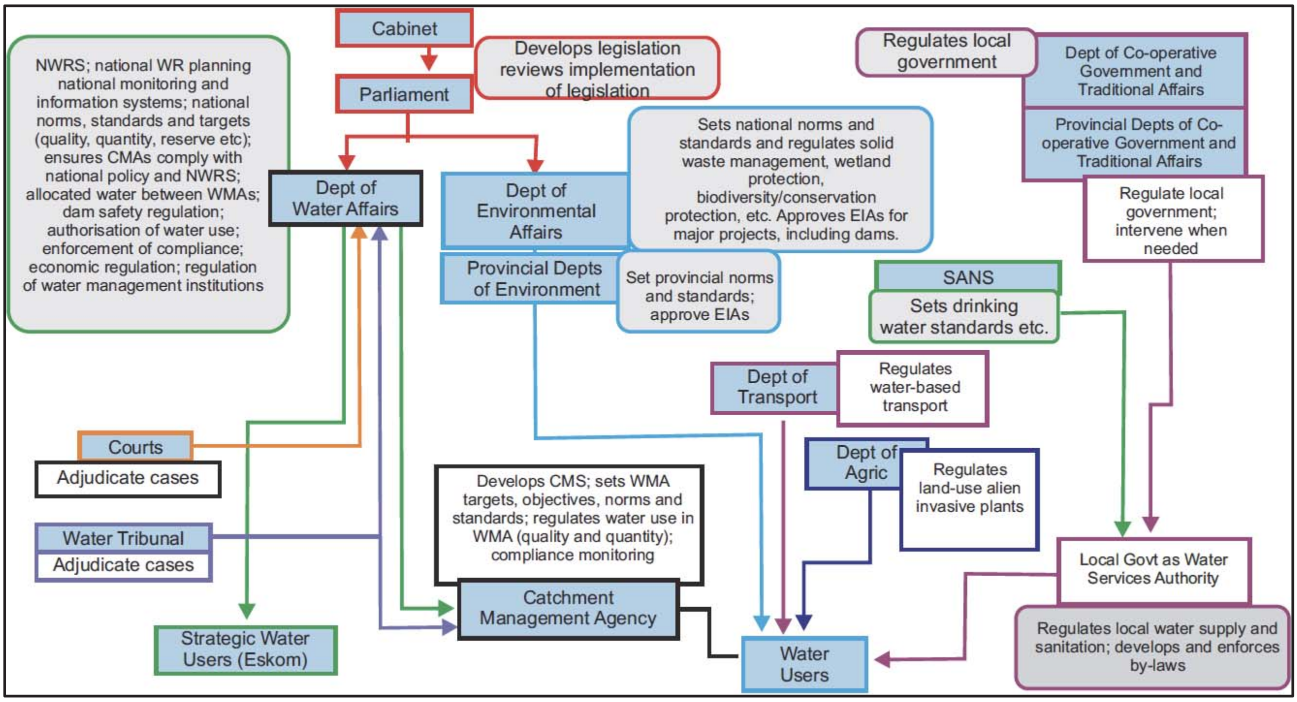


Figure 1-4: Institutional and organisational roles in regulation of water in South Africa

1.8.2 Funding alternatives for water infrastructure projects in South Africa

Sufficient and effectively managed financial resources for the development and life cycle financing of water resources and water services is a key cornerstone required to ensure feasibility and sustainability of the water sector in South Africa. Without sufficient finance and proper financial management, the water sector will not be able to contribute to protection of the environment, social obligations, and economic growth in every sector dependent on water including domestic, agriculture, mining, industrial and energy sectors.

Public Funding (Department of Water and Sanitation and other departments)

Most public funding of water infrastructure in South Africa are typically channelled via the DWS departmental budget with various types of grant funding allocated to municipalities and other water institutions. Most water infrastructure projects are funded by a combination of grant funding and equitable share funding allocated by DWS on an annual basis.

The DWS grant funding programmes used to develop water infrastructure including desalination and water reuse schemes include the following:

Equitable share funding

The Equitable Share funding is an annual operating grant allocated to municipalities aimed at supporting the affordability of municipal services to be provided to the indigent portion of consumers within each region. The Equitable Share grant allocation is typically based on the level of service available to municipal consumers including access to potable water, sanitation, solid waste removal and electricity.

Municipal Infrastructure Grant

The Municipal Infrastructure Grant (MIG) funding are allocated to municipal infrastructure projects approved by DWS and provides municipalities with grant funding in support of their capital expenditure budgets to improve service delivery typically within urban municipal areas. MIG allocations to municipalities are based on water and sanitation backlogs.

Regional Bulk Infrastructure Grant

The Regional Bulk Infrastructure Grant (RBIG) funding is allocated to municipalities or other water institutions to develop regional bulk water supply projects the service urban and rural areas. This funding is allocated on a project basis with approval by DWS and municipalities or water boards typically acting as implementing agents who will ultimately take ownership of infrastructure and be responsible for management, operation, and maintenance thereof.

Municipal Water Infrastructure Grant

The Municipal Water Infrastructure Grant (MWIG) funding is aimed at accelerating the delivery of water infrastructure to households that do not have access to clean water. This is aimed specifically at eradication of service delivery backlogs in poor communities (rural and urban).

Urban Settlements Development Grant

The Urban Settlements Development Grant (USDG) funds informal settlement upgrading, which includes provision of an integrated set of services including water and sanitation.

Rural Households Infrastructure Grant

The Rural Households Infrastructure Grant (RHIG) has been rescheduled as a direct transfer to municipalities. This will create better alignment between the construction and maintenance of infrastructure, as well as strengthen community consultation. This change should improve the performance of the grant, which is intended to provide on-site water and sanitation but is currently focused on providing VIP toilets.

Water Services Operating Subsidy

The Water Services Operating Subsidy (WSOS) funds water service authorities currently or previously managed directly by the Department of Water and Sanitation.

Accelerated Community Infrastructure Programme

The Accelerated Community Infrastructure Programme (ACIP) funding is aimed at acceleration of the universal achievement of providing access to basic water and sanitation services at community level. This funding is allocated to water conservation and demand management projects, community infrastructure and wastewater infrastructure refurbishment.

Municipal Infrastructure Support Agent

The Municipal Infrastructure Support Agent (MISA) is a Government Component within the Ministry for Cooperative Governance and Traditional Affairs (CoGTA), established in terms of Presidential Proclamation No. 29 of 2012. It is a Schedule 3 entity regulated in terms of the Public Service Act (1994), as amended. Its principal mandate is to provide technical support to, and assist municipalities to strengthen their internal capacity for delivery and maintenance of basic service infrastructure. This initiative is an integral part of the Department of Cooperative Governance's programme towards improving municipal infrastructure provisioning and maintenance for accelerated and sustainable service delivery, in line with the objectives of Local Government Turnaround Strategy.

Disaster funding

Most of the desalination and water reuse schemes developed in the Southern Cape region and Beaufort West were built in reaction to severe drought conditions. In these cases, a regional disaster was proclaimed, and special disaster funding applications were submitted to National Treasury to assist in the funding of capital expenditure required for the rapid development of water reuse and desalination infrastructure since surface and ground water resources were no longer reliable.

Project/Infrastructure Financing Utility

A project/infrastructure financing utility consist of an implementing agent or government utility that raises commercial finance and possibly public funding in order to implement a specific project which will be operated by DWS or a water institution. In this instance it is critical that the project is ring fenced, financially feasible and capable of servicing the commercial financing commitments or loans through revenue generated by the infrastructure.

In the case of water reuse and desalination plants it could be fairly easy to ring fence a project depending on its interface with existing water supply infrastructure.

This financial model is most suitable where a single point of delivery of product water is applicable such as a water reuse plant supplying industrial water to an industry or defined industrial area.

Independent Water Utility

Financing of water infrastructure by an Independent Infrastructure Utility is not a common practice in South Africa with most water infrastructure being owned and operated by local or provincial government. However, with DWS's drive to create regional water utilities (currently water boards), this could become more common. In this instance the water infrastructure utility will raise commercial finance against its balance sheet and income it can generate from existing and planned infrastructure. This type of project funding is not project based and therefore more resilient to changes in demand, etc. which may offer a lower risk profile than project-based financing.

1.8.3 Public Private Partnerships (PPPs)

The majority of the water-related business opportunities for the private sector in South Africa require partnership with national, provincial, or local government institutions. South Africa has established a firm regulatory framework that enables municipal, provincial, and national government institutions to enter into public private partnership (PPP) agreements.

The definition of a PPP is consistent across all three spheres of government. A PPP is defined as commercial transaction between a government institution and a private party in terms of which the private party:

- performs a government institutional function on behalf of the institution; and/or
- acquires the use of state property for its own commercial purposes; and
- assumes substantial financial, technical, and operational risks in the transaction; and
- receives a benefit for performing the government institutional function or from utilizing the state property, either by way of:

− being paid by the revenues from government institution; or

− charges or fees to be collected by the private party from users or customers of a service provided to them.

− a combination of the revenues and such charges or fees.

The PPP Regulations provide precise and detailed instructions for PPPs. These regulations define the elements of a PPP and set out the stages and approvals it will have to go through. The PPP project cycle enables the three regulatory tests of affordability, value for money and risk transfer to be applied at every stage of preparing for, procuring, and managing a PPP agreement. More detail on PPP's and the associated legal and regulatory framework is provided in Appendix B.

1.8.4 Concessions

Concessions are fairly uncommon in the South African public water sector and are more applicable to the private sector, particularly the industrial and mining sectors. Concession funding of water sector projects involves private sector companies financing, implementing, and operating water infrastructure for a set period of time. Typical project finance is done through equity, debt financing or a combination thereof.

1.8.5 Funding considerations specific to water reuse and desalination

Developing and operating sustainable water reuse and/or desalination water supply infrastructure requires the use of sound business case engineering decision-making that is closely tied to the project's strategic planning process. The following funding consideration and key elements are fundamental to successful project implementation and operation:

- The most critical element of developing water reuse and desalination projects is that it needs to be 'fit-for-purpose'. It is therefore critical that these projects are developed as part of an integrated water resource portfolio with an in-depth analysis of water demand and water quality requirements from the specific plants. This is in most cases the determining factor in the financial and technical feasibility and overall success of these types of projects.
- For water reuse and desalination plants there is a direct correlation between the quality of water and cost to produce treated water. It is therefore critical to do sufficient sampling and testing of raw water (whether wastewater, sea water or from other sources) during the feasibility phase and an in-depth analysis of product water quality requirements.
- Accurate capital and operational expenditure estimate and detailed life cycle costing are required and should include adequate risk factors that allow for unexpected changes in demand, escalation and changes in rates and availability of consumables (especially electricity).
- Revenues from water rates should be adequate to annual operating, maintenance and repair costs, replacement and improvement costs, adequate working capital, and servicing of debt finance (if applicable) as well as some reserves.
- Accounting practices should adhere to generally accepted accounting principles and regulatory requirements and should be aligned to the project's specific funding mechanism and development model.

- Budgeting of the operational phase should include sufficient allowances for asset management, preventative maintenance, and future infrastructure replacement and/or re-investment.
- Quality of material and skills required to cost effectively operate and maintain water reuse and desalination facilities should be adequately planned and incorporated into its financial and implementation models.
- Equitable distribution of rates when implementing a water reuse or desalination plant into a water resource portfolio should be clearly detailed and communicated to end consumers.

1.9 SKILLS REQUIRED FOR OPERATION AND MAINTENANCE OF WATER RECLAMATION AND RECOVERY PLANTS

Process controllers need to be aware of the potential consequences of system failure, and of how decisions can affect public and environmental health. It is therefore essential that process controllers have appropriate experience and qualifications, i.e. all personnel involved in the operation of a recycled water system need to have the appropriate skills and training to undertake their responsibilities. Process controllers should be appropriately skilled and trained in the management and operation of recycled water supply systems because their actions can have a major impact on water quality, and on public and environmental health.

Process controllers should be capable of acquiring the skills necessary to perform daily operation of the plant and to report any deviations from normal operating parameters. There are a few exceptions, however: chemical cleaning of membranes, for example, need not be performed by the plant operators; this can be performed by the supervisor or technician.

It is advisable that at least one member of the water supply authority has an adequate understanding and knowledge of membrane treatment processes. This would require some form of training in membrane treatment, albeit short courses or as part of formal training. This personnel member would be either a technician, technologist, or engineer.

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 follows.

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 to contract out for speciality maintenance work, such words missing

Technical support for desalination plants is necessary to ensure that any deviation from normal operating regimes is addressed rapidly and effectively, so that service delivery (volume of water produced and quality of product water) is not compromised. The support would normally comprise rapid response to callouts, trouble shooting and corrective action to normalize the situation. It would also include action plans to rapidly identify/forecast similar problems in future and communicating this to the municipal engineer.

More information on skills required (topics and subject matter) for operation and maintenance of water reclamation and recovery plants are provided in Part 3 of the Guide.

1.10 FLOW DIAGRAM FOR STEPS TO BE FOLLOWED WHEN PLANNING AND IMPLEMENTING A WATER RECLAMATION AND RECOVERY PROJECT

1.10.1 Steps for planning a water reclamation and recovery project

1.10.1.1 Main steps

The main steps to include in the planning of a water reclamation and recovery project are as follows:

- Determine the treatment objectives
- Consider process configurations
- Select unit treatment processes for the treatment configuration
- Evaluate treatment processes against selection criteria
- Select most feasible options
- Do conceptual process design
- Do a risk assessment
- Develop monitoring programs
- Do costing
- Provide recommendations for implementation.

The flow diagram in Figure 1-5 presents the main steps to be followed when planning the feasibility and implementation of a water reclamation and reuse project.

1.10.1.2 Inputs required during the planning process

The following key principles of the Australian Guidelines for Water Recycling (AGWR) (Law et al., 2015) are of critical importance for planning and implementing a water reuse project:

- Protection of public health. This must be recognised and reinforced as the highest priority
- Robust and reliable multiple barriers must be installed. The use of multiple barriers is the key to production of a safe drinking water, and they must be maintained and monitored throughout the life of the schemes
- Community participation and support
- Institutional capacity must be in place
- Personnel skills, training and accountability are essential
- Regulatory surveillance and auditing. Surveillance and auditing verify that schemes are managed and operated at levels that protect human health.

1.10.2 Flow diagram of the planning steps to be followed

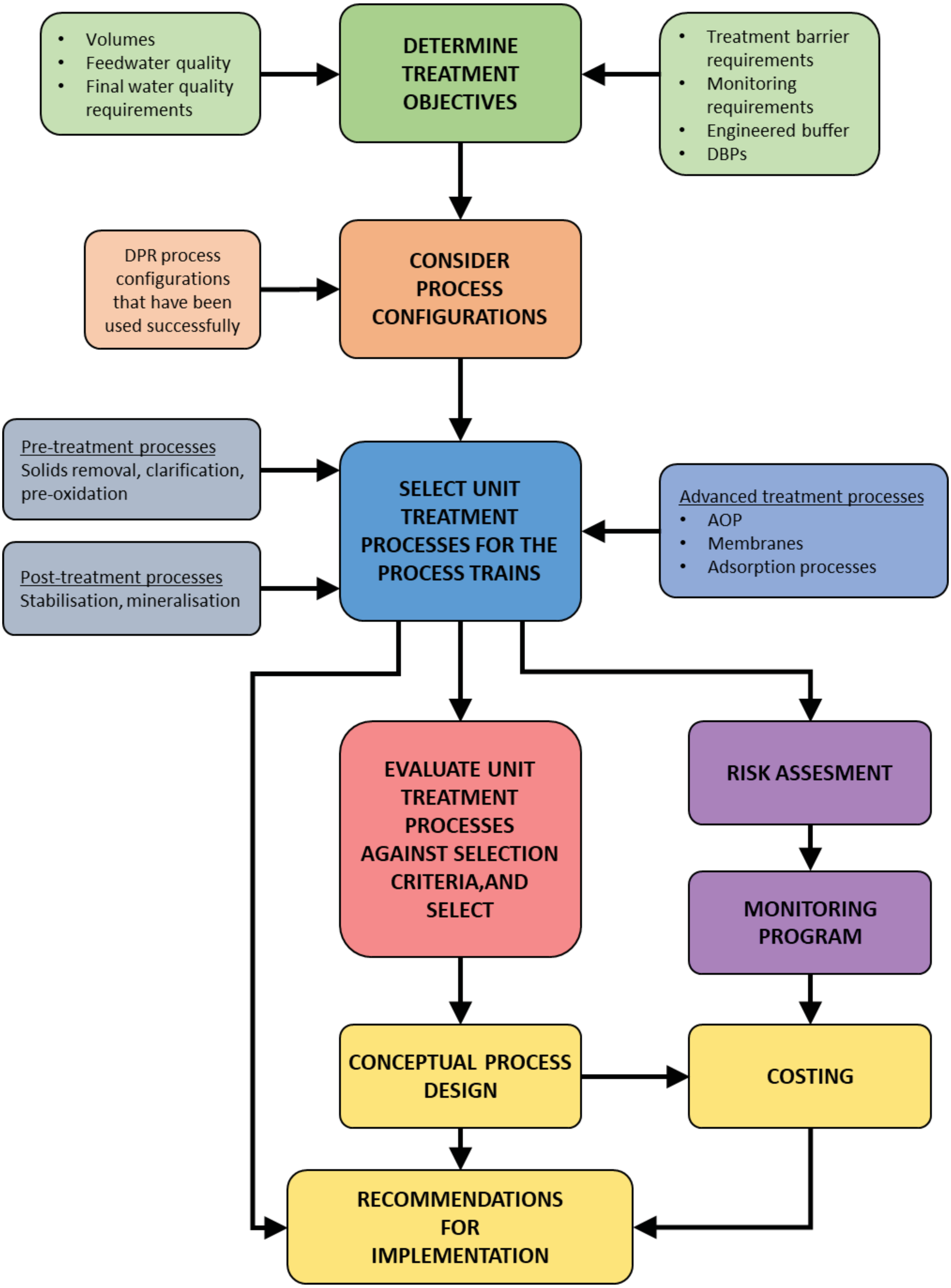


Figure 1-5: Flow diagram of steps to be followed in planning a water reclamation and recovery project

Part 2:

GUIDELINES AND PROCEDURES FOR THE SELECTION AND COSTING OF TREATMENT PROCESSES

PART 2: GUIDELINES AND PROCEDURES FOR THE SELECTION AND COSTING OF TREATMENT PROCESSES

2.1 INTRODUCTION

Part 2 of the Guide provides more information on the treatment processes involved in water reuse and reclamation, and then focuses on the selection and costing of these processes and process configuration in which they are applied in water reuse projects.

As an introduction to the treatment process, an overview is first provided of the types of water reuse schemes and applications.

2.1.1 Water Reuse Applications

The main user groups of reclaimed water are for:

- non-potable reuse
- potable reuse
- groundwater recharge (managed aquifer recharge).

2.1.1.1 Non-potable reuse

The main uses of treated wastewater from municipal wastewater treatment works in the past has been for the irrigation of public open spaces (parks), sports fields (municipal, schools and clubs), golf courses and for cooling (related to industry and power generation). The return flows from wastewater treatment works can also be important for urban water systems (rivers, lakes, dams, and wetlands), including ecosystem services. Treated wastewater and grey water can also be used for firefighting, toilet flushing, cooling systems, street cleaning, dust control and a variety of applications that do not require potable water.

The main non-potable reuse applications are listed below (DWA NSWR, 2012).

Urban reuse (golf courses and recreational fields irrigation)

In the past, the municipal and urban reuse of treated wastewater was not actively promoted due to the cost of such systems and the potential public health risks. In addition, reuse of water, for example in the irrigation of recreational areas and golf courses, may be in competition with other essential water uses.

However, the irrigation of sports fields and golf courses are encouraged if it is strictly managed, as communities cannot allow valuable potable water to be used for irrigation purposes, especially in areas experiencing water scarcity.

Agricultural reuse (food crops irrigation; livestock watering)

Even though the agricultural sector uses about 60% of total water use in South Africa (DWA NSWR, 2012), only a small proportion of irrigated agriculture directly utilises treated wastewater. Considerable potential exists to substantially expand the use of treated wastewater for irrigation purposes in South Africa. This will bring many benefits. Irrigation is often labour intensive and expanding the area under irrigation will create jobs. Wastewater return-flows are typically available close to urban areas and thus close to urban markets for agricultural produce, provided suitable land is available for irrigation; the Phillipi Horticultural Area, which delivers a notable portion of Cape Town's fresh produce is a good example. Treated wastewater can substitute freshwater, thus making more freshwater available for other uses (DWA NSWR, 2012). A key requirement for the agricultural sector to utilise this resource is a guaranteed quality profile of water, which does not pose health risks through the products, and is acceptable to consumers.

Any reuse of water for agricultural purposes must be done with due consideration, and be balanced by other requirements, as well as historical allocations of water in the specific water management area.

Environmental reuse (wetlands, river or streamflow augmentation, ecological impacts)

Water supports and sustains natural and man-made aquatic ecosystems by, for example, maintaining minimum flows and appropriate flow regimes in streams, rivers, and estuaries, recharging wetlands, and maintaining the water levels of man-made water features such as urban lakes and dams.

Reuse water can play an important role in the above applications, supplementing or even partially substituting for freshwater.

Care must be taken to clearly define receiving water quality objectives and to manage the impact of water reuse on water quality. More advanced treatment may be required to further encourage this form of water reuse and to meet strict receiving water quality requirements.

Industrial reuse (boiler water make-up, oil and gas, food manufacturing, other)

The reuse of water is already widely implemented by water intensive industries (through process water recycling and cascading water uses). The extent of reuse and the specific details as to how water is reused is industry- and process-specific.

Many industries do not require high quality water for process applications and can therefore use treated wastewater from municipalities and treated effluents from other industries. The wastewater from the upstream user must, however, be treated and prepared to meet the requirements of the downstream industrial application.

Mining sector (reuse of effluent, acid mine drainage)

Mining and minerals processing facilities use large volumes of water and recycling, and reuse is widely implemented to reduce costs and to meet environmental requirements.

The issue of acid mine drainage (AMD) is pertinent to the mining sector. AMD can have severe impacts on the natural aquatic environment and downstream users if left to decant and flow untreated into the freshwater resources. The collection, treatment and reuse of AMD turns the negative impacts into a positive beneficial water use.

2.1.1.2 Potable reuse (direct potable reuse; indirect potable reuse)

Reuse water can be treated to a standard fit for domestic use (drinking purposes). Treated water can be supplied directly to households (direct reuse) or discharged back to a water resource where it is blended with other water and subsequently abstracted, treated and distributed for use (indirect reuse).

There are many potable water reuse schemes in operation in the world. The majority of these schemes are based on an indirect reuse approach. Indirect water reuse for potable purposes is well established in South Africa. It is common for a treated wastewater effluent to be discharged to a river system and for water to be abstracted downstream of this discharge point and to be treated and used for drinking water (de facto reuse).

Examples of potable reuse plants globally and in Southern Africa are provided in Chapter 2.

The main concerns related to both the direct and indirect reuse of water for potable purposes include the following:

- the presence of pollutants such as pharmaceuticals, health care products, pesticides, industrial chemicals, and heavy metals
- the cost involved for adequate treatment, especially if the source water contains recalcitrant compounds to be removed
- associated risks in terms of the ability to design and manage treatment processes with a suitable level of confidence needed to safeguard public health when re-using water for drinking purposes
- public perceptions and acceptance of direct and indirect reuse.

2.1.1.3 Groundwater recharge (managed aquifer recharge)

Managed aquifer recharge is the intentional recharge of water to suitable aquifers for subsequent recovery or to achieve environmental benefits. The managed process assures potential protection of human health and the environment.

There are a number of methods used to recharge aquifers, including injection wells or infiltration structures such as ponds, basins, galleries, and trenches. Examples are the Atlantis Project near Cape Town and the Windhoek Aquifer Recharge Project. These methods help to reduce transport and storage costs and water loss through evaporation. Water from a variety of sources can be used in the recharge process. These include water from watercourses, stormwater, and treated wastewater.

Natural treatment processes in the aquifer can improve the quality of the water. Some pre-treatments of the source water may be required to make sure that the quality of the receiving groundwater is maintained or improved. Appropriate risk assessment should be conducted to determine the level of treatment needed for the source water.

2.2 OVERVIEW OF WATER REUSE

2.2.1 Introduction

While the reuse of water for non-potable purposes is also of interest to the municipal engineer, the focus of this guide is on potable reuse. In the chapter on water quality requirements for reuse water (Chapter 4), the specific requirements for non-potable reuse are provided. The current chapter considers the various potable water reuse schemes.

2.2.2 Potable Reuse

The original planners and researchers of the Windhoek water reclamation project are considered pioneers in direct potable reuse (DPR) in Southern Africa, after the first direct potable reuse plant was commissioned in 1968 by the City of Windhoek (CoW) in response to severe droughts and drinking water shortages in Namibia, with no other viable water sources for the city. Worldwide recognition of this achievement followed after the 2013 IWA Water Reuse Specialist Group conference in Windhoek. As the first DPR plant in the world, considerable research and development had taken place in Windhoek to study health impacts, process efficiency and water management strategies. This was extended even further after the construction and commissioning of the New Goreangab Water Reclamation Plant (NGWRP) in 2002. After more than 50 years of operation of direct potable reuse in Windhoek, no adverse health effects have been experienced.

Although development of treatment technologies, barriers and monitoring systems is making direct and indirect potable reuse increasingly attractive as a drinking water source, there are still a number of challenges and issues that are receiving attention, and which are currently studied further at research institutions across the world.

2.2.2.1 Direct potable reuse (DPR)

Leverenz HL, Tchobaoglous, G and Asano T (2011)
Direct potable reuse: a future imperative.
Journal of Water Reuse and Desalination | 01.1 | 2011.

Direct potable reuse (DPR) refers to the introduction of purified water, derived from municipal wastewater after extensive treatment and monitoring to assure that strict water quality requirements are met at all times, directly into a municipal water supply system. The resultant purified water could be blended with source water for further water treatment or even direct pipe-to-pipe blending of purified water and potable water.

An important element of a DPR system is the ability to provide water of a specified quality reliably all the time.

2.2.2.2 Indirect potable reuse (IPR)

Because of the past limitations in providing this level of quality control in real-time and the large number of unknown factors, there was a preference for indirect potable reuse (IPR) projects instead of DPR projects. IPR systems make use of an environmental buffer, such as a surface reservoir or groundwater basin, to store water and ostensibly provide enhanced quality. In early IPR projects where the product water was not of the highest quality, the environmental buffer was thought to have provided a level of in situ advanced treatment.

In an IPR process, secondary or tertiary treated effluent is introduced into an environmental buffer before being withdrawn for potable purposes. The purpose of the environmental buffer is to provide storage, transport, and, in some cases, an additional barrier for the protection of public health; however, the environmental storage of highly treated water, if not stabilized or mixed with other water, can also add contaminants, and degrade the water (e.g. dissolution of metals from the groundwater aquifer or microbial and other contaminants in surface impoundments). Further, the environmental buffer was presumed to provide loss of water identity and a measure of safety, in that it provided time to correct issues in the event that off-spec product water was detected.

Natural systems are employed in most potable water reuse systems to provide an environmental buffer. However, it cannot be demonstrated that such "natural" barriers provide any public health protection that is not also available by other engineered processes (e.g. advanced treatment processes, reservoir storage). Environmental buffers in potable reuse projects may fulfil some or all of three design elements: (1) provision of retention time, (2) attenuation of contaminants, and (3) blending (or dilution). However, the extent of these three factors varies widely across different environmental buffers under differing hydrogeological and climatic conditions. In some cases, engineered natural systems, which are generally perceived as beneficial to public acceptance, can be substituted for engineered unit processes, although the science required to design for uniform protection from one environmental buffer to the next is not available. The lack of clear and standardized guidance for design and operation of engineered natural systems is the biggest deterrent to their expanded use, in particular for potable reuse applications.

2.2.2.3 Unplanned (de facto) potable reuse

Description

Literally, de facto reuse is a term used to describe a situation where wastewater is unintentionally reused for some beneficial purpose. The term is used to distinguish between other situations where wastewater is intentionally reused for beneficial purposes (refer to Figure 2.1 in Part 1 of the Guide). The term de facto reuse refers to one or both of the following situations (NRC, 2012):

- where secondary treated wastewater from one town or city enters an environment from where another town or city abstracts its raw water for treatment at a (most often) conventional water treatment plant (WTP)
- where untreated wastewater from an informal settlement enters a water source from where another town or city abstracts its raw water for treatment at a (most often) conventional WTP.

The most common water sources associated with de facto reuse are river systems, although it is not uncommon for surface water sources (lakes or dams) and groundwater aquifers to also serve as a source (MED WWR WG, 2007). De facto reuse is an inherent health risk, since in most cases the receiving WTP was not designed to completely remove the pollutants that will be present in the reuse water (NRC, 2012).

Since de facto reuse is so undesirable, it is commonly assumed that it only occurs in rural areas and in countries where safe drinking water is not a high priority, but this is a faulty assumption. Urban areas and first world countries also experience de facto reuse. Furthermore, the health risk of de facto reuse is seasonal since catchment areas receive less stormwater runoff during low flow (dry) seasons. During these periods, the portion of wastewater in the river is higher and therefore poses a larger health risk (Swayne et al., 1980).

Occurrence of de facto reuse in South Africa

Swartz CD, Lourens C, Robbertse J and Slabbert SJC (2021).
The status and extent of de facto water reuse in South Africa
Final Report submitted to the Water Research Commission. WRC Project no. 2731. June 2021.

A large number of water services authorities (WSAs) and water service providers (WSPs) in South Africa are dependent on polluted water sources for drinking water supply to the communities and industry that they serve. The drinking water treatment plants that were originally provided for drinking water production were not designed to treat poor quality water and consisted of conventional water treatment processes. As the raw water quality deteriorated, provision was made to add new or modify existing treatment processes, but this was only done in South Africa on a project-by-project basis, and only at the larger water treatment plants, resulting in a high risk for pollutants (in particular micro-pollutants) to pass through the treatment plants and have a health impact on the communities. This problem already exists at present, and it is suspected that it may have a negative impact on the end-users (health impact as well as aesthetical impact, *e.g.* taste and odour problems associated with algal blooms). The most important is, however, the health impact.

These plants are now considered to be de facto reuse plants because they in fact reuse wastewater that is discharged to rivers and dams and then abstracted downstream for potable use. This implies that the process configurations for treatment plants treating these waters should also include advanced treatment technologies to ensure removal of all unwanted pollutants from the incoming water.

As a result of, in particular, the health implications of the rapidly growing occurrence of de facto reuse, it has become a high priority to quantify the extent of de facto reuse in South Africa. A WRC project is currently being undertaken to determine the national extent and health impact of de facto reuse, and to provide the necessary knowledge base for remedial actions to be undertaken (Swartz *et al.,* 2020). The findings of the study will help water resource planners and public health agencies understand the extent and importance of de facto water reuse. The study will also allow the assessment of how available treatment technologies compare in terms of treatment performance (e.g. nutrient control, contaminant removal and control, and what the limitations and challenges of current technologies are.

Conclusions from the WRC de fact project (Swartz *et al.,* 2020)

The following conclusions have been made on completion of the project:

- South African rivers contain a high percentage of wastewater (as expected).
- The percentages are especially high during dry periods when the base river flow is low.

- Poor operation of wastewater treatment plants leads to poor effluent quality being discharged, leading to a higher percentage mass loading impact on the rivers.
- Concentrations of CECs in wastewater treatment plant effluents are generally comparable to those from other studies globally, but further correlations are currently in progress.
- CECs studied include ARVs and drugs which are not included in international studies.
- The drinking water quality guideline values from Australia and WHO for some CECs are very strict and are currently further investigated with regard to developing guidelines for South Africa.
- Guideline values for the ARVs and drugs will be developed by the CSIR Stellenbosch and Stellenbosch University.

Further research should aim at developing the use of a single reliable indicator to predict the effect of wastewater in water supplies on treatment plant requirements. Measures and facilities should be provided at water treatment plants on a priority/cost basis at treatment plants most negatively impacted to improve the water quality, *e.g.* powder activated carbon (PAC).

2.2.3 Constraints and challenges on the application of direct and indirect potable reuse

Both direct and indirect potable reuse have demonstrated a number of shortcomings and challenges in the application thereof in drinking water augmentation schemes. The most important issues and constraints are summarised in Table 2-1.

Table 2-1: Direct and indirect potable reuse applications, experience, and challenges (adapted from Lazarova et al., 2013)

Type of reuse		Application	Issues and constraints	Experience
Indirect potable reuse (IPR)	**Replenishment of aquifers**	• Groundwater replenishment by means of infiltration basins or direct recharge by injection wells. • Barrier against brackish or seawater intrusion • Ground subsidence control	• Groundwater contamination • Toxicological effects of organic chemicals • Salt and mineral build-up • Public acceptance	• Successfully practiced since 1970s • Multiple barrier treatment ensures safe potable water production. • Efficient control by means of advanced modelling tools
	Replenishment of dams	• Surface dam augmentation • Blending with water from public dams before further water treatment	• Health concerns • Public acceptance	• Successfully practiced since 1970s • Multiple barrier treatment ensures safe potable water production. • Improvement of water quality
Direct potable reuse (DPR)		• Pipe to pipe blending of directly purified wastewater and potable water from other sources	• Health concerns and issues of unknown chemicals • Public acceptance • Economically attractive in large-scale reuse	• Multiple barrier treatment ensures safe potable water production. • No health problems related to recycled water in Namibia since 1968

2.2.4 Some prominent DPR and IPR plants across the world

2.2.4.1 International

A number of prominent full-scale direct and indirect water reuse plants are summarised below, with the international plants shown in Table 2-2 (a) and (b) and the Southern African plants in Table 2-3 (a) and (b).

Table 2-2 (a): List of prominent DPR plants across the world (excluding Southern Africa) (adapted from DWA NWRS, 2012) **(as of March 2020)**

Plant Name	State/ Province	Country	ML/d	Commissioned	Status	Treatment train	System
Cloudcroft NM	New Mexico	USA	0.1	2011	Operational	MBR (MF) - RO - UV/AOP - UF - UV - GAC - Cl	DPR: Blending subsequent to UV/AOP
Big Spring Raw Water Production Facility	Texas	USA	7	2013	Operational	MF - RO - UV/AOP	DPR: Blending then conventional WTP
Wichita Falls	Texas	USA	19	2014	Operational	MF - RO - Buffer Blending - ConvWTP	DPR: 50:50 blending with lake water

Cl = Chlorination disinfection, MF = Microfiltration, UF = Ultrafiltration, RO = Reverse Osmosis, AOP = Advanced Oxidation Process, UV = Ultraviolet, ASR = Aquifer Storage Recovery, BAC = Biological Activated Carbon, GAC = Granular Activated Carbon, PAC = Powder Activated Carbon, MBR = Membrane Bioreactor, SAT = Soil Aquifer Treatment, O3 = Ozonation, IX = Ion Exchange, LC = Lime Clarification, SF = Sand Filter, ConvWTP = Conventional water treatment plant

Table 2-2 (b): List of prominent IPR plants across the world (excluding Southern Africa) (adapted from DWA NWRS, 2012) **(as of March 2020)**

Plant Name	State/ Province	Country	ML/d	Commissioned	Status	Treatment train	System
Montebello Forebay	California	USA	165	1962	Operational	Media filtration - Cl	IPR: Groundwater recharge via soil-aquifer treatment
Water Factory 21	California	USA	60	1976	Superseded 2004	LC - air stripping - RO - UV/AOP - Cl	IPR: Groundwater recharge via seawater barrier
Upper Occoquan Service Authority	Virginia	USA	204	1978	Operational	LC - media filtration - GAC - IX - Cl	IPR: Surface water augmentation
West Basin Water Recycling Plant	California	USA	47	1993	Operational	MF - RO - UV/AOP - Cl	IPR: Groundwater recharge via direct injection
Scottsdale Water Campus	Arizona	USA	53	1999	Operational	Media filtration - MF - RO - Cl	IPR: Groundwater recharge via direct injection
Gwinnett County	Georgia	USA	227	1999	Operational	UF - O_3 - GAC	IPR: Surface water augmentation
Toreele Reuse Plant	Wulpen	Belgium	7	2002	Operational	UF - RO - UV	IPR: Groundwater recharge via infiltration ponds
NEWater	Kranji	Singapore	55	2003	Operational	UF - RO - UV	IPR: Surface water augmentation

Plant Name	State/ Province	Country	ML/d	Commissioned	Status	Treatment train	System
NEWater	Bedok	Singapore	86	2003	Operational	UF - RO - UV	IPR: Surface water augmentation
Alimitos Barrier	California	USA	10	2005	Operational	MF - RO - UV	IPR: Groundwater recharge via direct injection
Chino Basin Groundwater recharge Project	California	USA	69	2007	Operational	Media filtration - SAT - Cl	IPR: Groundwater recharge via soil-aquifer treatment
NEWater	Ulu Pandan	Singapore	148	2007	Operational	MF - RO - UV/AOP	IPR: Surface water augmentation
Groundwater Replenishment System	Orange County	USA	265	2008	Expanding to 380 ML/d	UF - RO - UV/AOP	IPR: Groundwater recharge via direct injection and spreading basins
Loudoun County	Virginia	USA	42	2008	Operational	MBR (MF) - GAC - Cl	IPR: Surface water augmentation
Western Corridor Project	SE Queensland	Australia	232	2008	Operational	UF - RO - UV/AOP - Cl	IPR: Surface water augmentation into drinking water reservoir
Arapahoe County/Cottonwood	Colorado	USA	34	2009	Operational	Media filtration - RO - UV/AOP - Cl	IPR: Groundwater recharge via spreading
Groundwater Replenishment Trial	Perth	Australia	5	2010	Operational	UF - RO - UV	IPR (trial): Groundwater recharge via direct injection
NEWater	Changi	Singapore	228	2010	Operational	UF - RO - UV	IPR: Surface water augmentation
Dominguez Gap Barrier	Los Angeles	USA	10	2012	Operational	MF - RO	IPR: Groundwater recharge via direct injection

Cl = Chlorination disinfection, MF = Microfiltration, UF = Ultrafiltration, RO = Reverse Osmosis, AOP = Advanced Oxidation Process, UV = Ultraviolet, ASR = Aquifer Storage Recovery, BAC = Biological Activated Carbon, GAC = Granular Activated Carbon, PAC = Powder Activated Carbon, MBR = Membrane Bioreactor, SAT = Soil Aquifer Treatment, O3 = Ozonation, IX = Ion Exchange, LC = Lime Clarification, SF = Sand Filter, ConvWTP = Conventional water treatment plant.

2.2.4.2 South Africa

Table 2-3 (a): List of prominent DPR plants in Southern Africa (adapted from DWA NWRS, 2012) **(as of March 2020)**

Plant Name	City/ Province	Country	ML/d	Commissioned	Status	Treatment train	System
Old Goreangab WRP	Windhoek	Namibia	7	1968	Superseded 2002	Clarification - DAF - SF - GAC - Cl_2	DPR: Blending prior to treatment
New Goreangab WRP	Windhoek	Namibia	21	2002	Operational	PAC - O_3 - Clarification - DAF - SF - O_3 - BAC - GAC - UF - Cl_2	DPR: Blending prior to treatment
eMalahleni WRP	Mpumalanga	South Africa	30	2007	Operational	Neutralisation - Clarification - UF - RO - Cl_2	DPR: Direct injection into distribution system.
Optimum Coal WRP	Mpumalanga	South Africa	15	2009	Operational	Neutralisation - Clarification - UF - RO - Cl_2	DPR: Direct injection into distribution system.
Beaufort West Municipality WRP	Western Cape	South Africa	2.3	2011	Operational	SF - UF - RO - UV/AOP - Cl_2	DPR: Blending with conventionally treated sources
Hermanus WRP	Western Cape	South Africa	5		Feasibility study		
Ballito WRP	KwaZulu-Natal	South Africa	12		Operational	SF - UF - RO - AOP - Cl_2	
Zandvliet/Faure Direct Potable Reuse Scheme	Cape Town, Western Cape	South Africa	70	Planned 2022	Construction		DPR: Treatment in Faure WTP before injection

Table 2-3 (b): List of prominent IPR plants in Southern Africa (adapted from DWA NWRS, 2012) (as of March 2020)

Plant Name	State/ Province	Country	ML/d	Commissioned	Status	Treatment train	System
Outeniqua WWTP, George	Western Cape	South Africa	10	2010	Operational	Screening-UF-Disinfection	IPR: Surface water augmentation

Cl = Chlorination disinfection, MF = Microfiltration, UF = Ultrafiltration, RO = Reverse Osmosis, AOP = Advanced Oxidation Process, UV = Ultraviolet, ASR = Aquifer Storage Recovery, BAC = Biological Activated Carbon, GAC = Granular Activated Carbon, PAC = Powder Activated Carbon, MBR = Membrane Bioreactor, SAT = Soil Aquifer Treatment, O3 = Ozonation, IX = Ion Exchange, LC = Lime Clarification, SF = Sand Filter, ConvWTP = Conventional water treatment plant.

All of the regions in Table 2-2 and Table 2-3 are either arid or semi-arid areas, characterised by water scarcity as a result of low rainfall and prolonged periods of droughts. Reuse has also developed in more temperate regions with less water scarcity, albeit more for non-potable reuse such as for industrial purposes and to augment the water supply to cities with rapidly increasing populations. The projects that are reported on in this Guide consist of direct and indirect potable reuse plants, either direct potable reuse schemes or planned indirect potable reuse schemes. Unplanned or *de facto* potable reuse is therefore not included (e.g. water treatment plants abstracting water downstream of the Hartbeespoort Dam or in the Middle Vaal River). Because of its importance in water source planning in South Africa, de facto reuse was discussed separately in Section 2.2.2.3 of this report.

2.2.5 Water Reuse in developing countries

Water reuse has an indirect influence on the development of tourism, by allowing the development of water-related activities and thus creating jobs. The expansion of water reuse has provided employment benefits in the water industry sector, with qualified jobs in the development, operation and maintenance of additional wastewater treatment and water reuse solutions as well as in research and development, considering the innovation potential of this area. Employment benefits also extend to suppliers of systems, equipment and chemicals for additional wastewater treatment and reuse.

Other possible social benefits associated with the implementation of water reuse projects include (EU, 2016):

- Contributing to food security and sustaining agricultural employment for many households.
- Increased quality of life, wellbeing and health as reuse allows the maintenance of attractive landscapes in parks and sports facilities and improvement of urban environment (e.g. urban parks and fountains).
- Supporting the sustainability of rural communities (both with reference to their long-term maintenance and their environmental impact) by providing relatively secure water sources for rural businesses.
- Being a cohesion tool that encourages the drinking water, wastewater and environment agencies and other stakeholders to work closely together using an integrated approach, thereby helping all to recognise the benefits and risks of treated wastewater reuse.
- Helping to achieve Sustainable Development Goals (SDGs) (specifically goal 6) through increased water availability and sanitation, protection of the environment through the use of appropriate technology solutions.

2.3 WATER QUALITY RISK ASSESSMENT

2.3.1 Public health considerations

If not treated properly, reclaimed water can act as a possible exposure pathway to a high number of emerging contaminants and their metabolites (Swartz *et al.,* 2018). Many of these compounds may pass through conventional wastewater treatment systems without removal and accumulate in potable water supplies. The possible presence of emerging contaminants in the final reclaimed water is of critical concern because of potential adverse impacts to human health. Specific health effect criteria in the evaluation of water recycling for human consumption include:

- primary health concerns of wastewater reuse that are the long-term health outcomes of ingesting chemical contaminants found in recycled water.
- health risks of using recycled water as a potable water supply compared against similar risk by conventional water supplies.
- the need for extensive toxicity programs.

2.3.2 Treatment barrier requirements for potable reuse

2.3.2.1 Definition of Treatment Barriers

Treatment barriers are an integrated system of procedures, processes and tools that collectively prevent or reduce the contamination of drinking water from source to tap in order to reduce risks to public health.

2.3.2.2 The Multiple Barrier Approach

To ensure public health protection, it is crucial to incorporate numerous barriers in the reuse treatment trains. Multi-barriers refer to a series of unit treatment processes operating to prevent harmful microorganisms and chemical constituents from passing into the treated water system. In the US, potable reuse requirements mandate the use of multiple barrier approaches. In all cases (California, Texas, Singapore, etc.), multiple barrier systems, coupled with rigorous process controls and monitoring requirements, are used to protect human health.

2.3.2.3 Number of Treatment Barriers Required for DPR

In the application of the multi-barrier concept for DPR, each pollutant class shall have at least two active barriers at any one time. The design criteria are then based on the (n+1) approach where n is considered as the minimum number of active barriers. With this (n+1) approach, there will be three barriers in place for each pollutant class at any given time, and in the event of one barrier failing, at least two other barriers will still be in place.

2.3.3 Log Reduction Credits

2.3.3.1 Microorganisms Reduction Criteria (Acute Health Effects)

In understanding the human health impact from microorganisms and chemicals in wastewater, the following three aspects should be considered:

- Current knowledge regarding health effects associated with DPR
- Applicable knowledge health concepts
- National and international regulations and guidelines that will impact the implementation of DPR.

In 2013, an Independent Advisory Panel **(IAP**) convened by the National Water Research Institute (**NWRI**) (Trussell et al., 2013) suggested criteria for the microbial evaluation of potable water reuse treatment trains for the protection of public health. It selected a 12-log reduction criterion for enteric viruses, a 10-log reduction for cryptosporidium and giardia, and a 10-log reduction for total coliform bacteria. The criteria are summarised in Table 2-4.

Table 2-4: Microbial Reduction Criteria for Potable Reuse Plants

Contaminant	Minimum Log-Reduction
Enteric virus (rotavirus and adenovirus)	12
Total coliform bacteria (coliform or campylobacter)	10
Cryptosporidium (protozoa and helminths)	10
Giardia[1]	10

2.3.4 Contaminants of emerging concern

2.3.4.1 Overview

In the recent past, the increase in the human population as well as the production of contaminants and increased reliance on pharmaceuticals and other chemically related products have contributed to the generation of different waste constituents originating from industries, agricultural activities, domestic operations, and municipal treatment works, among others. Chemicals of emerging concern identified in reclaimed water can include the following:

- Pharmaceuticals and veterinary medicines (prescribed and over-counter drugs)
- Personal care products (active ingredients in cosmetics, fragrances, soap, insect repellents, toothpastes, e.g. antiseptics (triclosan/triclocarban)
- Pesticides and herbicides
- Flame retardants (active ingredient incorporated into consumer products such as electronics, plastic, and children's toys)
- Perfluorinated and brominated substances (used as dirt-repellent coatings, spray for leather and textiles.

2.3.4.2 Priority lists for chemicals of emerging concern

Ncube et al. (2012) suggested a protocol for the selection and prioritisation of contaminants in drinking water in which Rand Water was used as a case example. A priority list of organic contaminants was identified which could then be used by Rand Water to optimise their resources and efficiency without compromising of public health. It was derived from primary lists of organic pollutants of concern, which was based on occurrence criterion in both international and national literature.

In the recent study by Swartz *et al.* (2018), a priority list of 20 CECs was compiled. Developing this first national CEC recommended prioritisation list involved filtering an overall list of CECs for the following:

- Compounds detected in South African potable waters.
- Compounds which are persistent
- Compounds that are not removed by water treatment processes.
- Pharmaceuticals prescribed in the largest volumes.
- Pesticides identified as high-risk priority pesticides in South Africa.
- Chemicals representing each of the groups of CECs.
- Indicator compounds known to occur in high concentrations in wastewaters to illustrate process efficiencies compounds that have an established analytical detection method.

The recommended priority list is shown below (Table 2-5) and forms a framework for discussion for potential monitoring for reclaimed potable water.

Table 2-5: Recommended priority list of contaminants of emerging concern (CECs) for assessing water quality for direct potable reuse (Swartz et al., 2018)

Group	Type	Chemicals
Industrial chemicals	Flame retardants	TDCPP and TCEP
	X-ray contrast fluid	Iopromide
	PAH	Benzo(a)pyrene
Pesticides, biocides, and herbicides	Herbicide	Atrazine
	Herbicide	Terbuthylazine
	Insecticide	Imidacloprid
	Pesticide	Simazine
Natural chemicals	Stimulant	Caffeine
	Hormone	17-beta estradiol
Pharmaceuticals and metabolites	Antiretroviral drugs	Lamivudine Stavudine
	Anti-epileptic drugs	Carbamazepine
	Anti-malarial drugs	Cinchonidine Cinchonine
	Analgesic	Paracetamol
	Antibiotic	Sulfamethoxazole
Personal care products	Anti-microbial	Triclosan
Household chemicals and food additives	Plasticiser	Bisphenol-A
Transformation products	By-product	N-Nitrosodimethylamine (NMDA)

NOTE!

It is important to note that the priority list cannot be seen as an exhaustive list, as each reclaimed potable water reuse project should interrogate the relevance of each of the chemicals. This is to consider whether extra chemicals might need to be added to the priority list. For example, total DDT may need to be included in areas where DDT usage is known to occur. DDT was not included in the prevalence screening as the extraction process focusses on polar water-soluble compounds and was not present in the library of compounds selected for.

2.3.5 Databases for contaminants of concern

Some of the more comprehensive databases for contaminants of concern are (Swartz *et al.,* 2018):

- IRIS (Integrated Risk Information System) database, with more than 550 compounds, available at http://cfpub.USEPA.gov/ncea/iris/
- SIN (Substitute It Now) list with 406 compounds available at http://www.chemsec.org/ what-we-do/sin-list.
- HSDB (Hazardous Substances Data Bank) database, with information on 5 756 compounds available at http://sis.nlm.nih.gov/enviro/hsdbchemicalslist.html.
- Country lists. Many countries have drawn up their own lists of CECs. A reference to some of these lists is available at http://ec.europa.eu/environment/archives/ document/pdf/bkh_ annex_ 02_03.pdf.
- TEDX (The Endocrine Disrupting Exchange) database, with more than 1000 compounds available at http://endocrinedisruption.org/endocrine-disruption/tedx-list-of-potential-endocrine-disruptors/overview.
    - The Household Products database with information and ingredients on 14 000 consumer brands in the USA, available at http://hpd.nlm.nih.gov.

The USEPA has a CEC Removal Database consisting of published scientific studies on the removal of CECs from water and wastewater. The database is available at:

http://water.USEPA.gov/scitech/swguidance/ppcp/results.cfm.

A report on 'Treating Contaminants of Emerging Concern: A Literature Review Database (August 2010)' is available at the website, providing examples for municipal wastewater and treated effluent.

Table 2-9 summarises the potential sources of chemicals of emerging concern in the environment.

2.3.6 South African water quality standards and guidelines for different uses

2.3.6.1 South African National Standards for Drinking Water (SANS 241)

This SANS 241 was approved by National Committee SABS/TC 147, Water, in accordance with procedures of the SABS Standards Division, in compliance with annex 3 of the WTO/TBT agreement. The World Health Organization Guidelines for drinking-water quality was used as a guide in deriving the numerical limits given. In the event of changes to specific determinand limits by the WHO, these changes may be implemented in SANS 241 on approval by TC 147.

SANS 241 consists of the following parts, under the general title Drinking water:

Part 1: Microbiological, physical, aesthetic, and chemical determinands.

Part 2: Application of SANS 241-1.

Part 1: Microbiological, physical, aesthetic, and chemical determinands.

This part of SANS 241 specifies the quality of acceptable drinking water, defined in terms of microbiological, physical, aesthetic, and chemical determinands. Water that complies with this part of SANS 241 is deemed to present an acceptable health risk for lifetime consumption (this implies an average consumption of 2 L of water per day for 70 years by a person that weighs 60 kg).

Water services institutions or water services intermediaries (or both) should ensure that water provided by them complies with the numerical limits given in this part of SANS 241. Water services institutions or water services intermediaries (or both) should monitor and maintain monitoring programmes informed by the routine water quality monitoring programme and risk assessment processes described in SANS 241-2.

Part 2: Application of SANS 241-1.

This part of SANS 241 deals with the evaluation of water quality risks, monitoring and verification of water quality to enable the management of the identified water quality risks. It is not intended to provide a comprehensive water management plan, which is required for the implementation of a water safety plan that deals with related issues such as water quantity, finance, and maintenance.

This part of SANS 241 is applicable to all water services institutions or water services intermediaries (or both). Assessment of the fitness for use of drinking water against the determinants and numerical limits specified in SANS 241-1 provides the minimum assurance necessary that the water is deemed to present an acceptable health risk for lifetime consumption.

It provides the key elements for implementing management actions to comply with SANS 241-1, which include the following:

- water quality risk assessment – assessment of risk from raw water through the treatment works to the point of delivery.
- water quality monitoring – establishment and implementation of operational and compliance water quality monitoring programmes, including the location of sampling points, sampling frequency and determinants.
- response monitoring – incident management and monitoring of drinking water quality when the numerical limits specified in SANS 241-1 are exceeded.
- verification of water quality – calculation of compliance with the numerical limits in SANS 241-1.
- a water safety plan – a comprehensive water quality management system based on the principles of preventive risk management and incorporating the outcomes in (a) to (d) above.

The provision of water deemed to have an acceptable health risk as defined by SANS 241-1 remains the ultimate responsibility of the water services institution or water services intermediary (or both). Water services institutions or water services intermediaries (or both) shall use a risk-based management approach to ensure that safe drinking water is produced at all times and that public health is protected.

The latest version of the SANS 241 Standards was published in 2015. The standards are currently in review and being updated, and it is expected that a new version will appear in 2021.

The SANS 241 standards, comprising Part 1 and Part 2, can be obtained from the South African Bureau of Standards (SABS).

2.3.6.2 The DWAF Water Quality Guidelines (1996)

The South African Water Quality Guidelines developed by the Department of Water Affairs and Forestry (now Department of Water and Sanitation) are divided into different volumes according to the various water uses:

Volume 1:	Domestic Water Use
Volume 2:	Recreational Water Use
Volume 3:	Industrial Water Use
Volume 4:	Agricultural Water Use: Irrigation
Volume 5:	Agricultural Water Use: Livestock Watering
Volume 6:	Agricultural Water Use: Aquaculture

These guidelines make use of the "fitness for use" concept. The "fitness for use" of water is a judgment of how suitable the quality of water is for its intended use. Several volumes of these exist for the different water uses, i.e. the characteristics of water use involve determining and describing those characteristics which will help determine its significance as well as those that dictate its water quality requirements. Target water quality ranges are given for various constituents. The DWA guidelines generally specify target ranges that fall into the "No Effect Range" which is the range of concentration at which the presence of the constituent would have no known or anticipated adverse effect on the fitness of water for a particular use. These ranges were determined assuming long-term continuous use and they incorporate a margin of safety.

The guidelines were developed so that they could as far as practically possibly serve as a source of information for water resource managers to make judgments about the "fitness for use" of water for different domestic purposes. A total of 42 parameters are presented in the DWAF 1996 Guideline which are summarised in Table 2-6 (Additional metal determinants and latest limits were also added from SANS241:2015). No attempt was made to prioritise the various parameters that should be assessed.

Table 2-6: Summary of chemical determinants contained in DWA and South African National Standard (SANS) 241

Parameter	Source	DWA WQG for Domestic Use (1996)		SANS 241: 2015
		Target in mg/L unless otherwise stated	Maximum in mg/L unless otherwise stated	Target (max) µg/L unless stated
Aluminium as Al	Earth's crust (geology) dissolves in acidic water	0.15	0.5	300
Ammonia as N	Agricultural runoff	1.0	2.0	1500
Antimony as Sb	Industrial pollution and geology	-	-	20
Arsenic as As	Industrial pollution and geology	0.1	0.2	10
Barium as B	Geology and industrial pollution	-	-	0.7
Boron as B	Geology and industrial pollution	-	-	
Cadmium as Cd	Geology and industrial pollution	5 µg/L	10 µg/L	5
Chloride as Cl^-		100	200	300
Cyanide as CN^-	Geology and industrial pollution	-	-	70
Total Chromium as Cr	Industrial pollution	0.05	1.0	50
Copper as Cu	Industrial pollution	1.0	3.0	2000
DOC	Natural humics, synthetic organics. Agri pesticides lead to formation of THMs	5.0	10.0	10
Fluoride as F^-	Geology, industrial pollution	1.0	1.5	1500
Iron as Fe	Geology, mining	0.1	0.3	300
Lead as Pb	Industrial pollution	10 µg/L	50 µg/L	10
Magnesium as Mg	Geology, industrial pollution	30	50	70*
Manganese as Mn	Geology, mining	0.05	0.1	100
Mercury as Hg	Geology, industrial pollution	1 µg/L	5µg/L	6
Nickel as Ni	Geology and industrial pollution	-	-	70
Nitrate as N	Agriculture and urbanisation. Vegetation breakdown and faecal pollution	6	10	50
Nitrite as N	Agriculture and urbanisation. Vegetation breakdown and faecal pollution	-	-	3
Phenols	Industrial pollution, pesticides, and disinfectants	1 µg/L	10 µg/L	10
Selenium as Se	Geological, industrial	20 µg/L	50 µg/L	10
Sulphate as SO_4^{2-}	Geological, (→ acid mine drainage) industrial	200	400	250
Total Trihalomethanes (THMs)	Former when water containing organics is chlorinated	100 µg/L	200 µg/L	200
TDS	Inorganic salts, minerals in rocks and decomposing plant material	450	1000	1200
Turbidity as NTU	Suspended material from clay/soil and organic matter	1	5	1
Uranium as U	Geology and industrial (mining) pollution	-	-	15
Vanadium as V	Industrial pollution	0.1	1.0	200
Zinc as Zn	Geology and industrial pollution	3	5	5000

2.3.7 Risk assessment

Water suppliers have a responsibility to provide water that is safe and acceptable to the persons utilizing the water. Of main concern is public health of the water supply, and the water supplier should be aware of any risks involved in supplying safe drinking water and have risk management strategies in place. Apart from public health, it is also necessary for water suppliers to be aware of the risks of not complying with legal requirements for drinking water quality and water treatment operations.

2.3.8 The risk management process

In the EU funded project TECHNEAU, a generic framework was developed for risk assessment in drinking water systems (TECHNEAU, 2010). The generic framework is aimed at providing a comprehensive structure for integrated risk management. The framework involves the complete water supply cycle, *i.e.* from catchment to consumer ("source-to-tap"). It considers both water quality and water quantity at different levels of complexity. To provide the necessary basis for integrated risk management for both basic and complex systems on the operational as well as strategic levels, the framework includes all major steps in the risk management process.

To be efficient and functional, the framework must also include a set of reliable and well-established tools, adapted to specific decisions to be made and considering type of water supply system, level of complexity, and level of decisions, *i.e*. operational, or strategic. Principal levels of sophistication of risk assessment tools are:

- Qualitative, *e.g.* based on checklists and classification of risk levels, providing relative ranking of lists and identification of critical points for risk reduction.
- Quantitative, *e.g.* based on models for combining and structuring events and chains of events, and estimations of quantitative risk levels. This level of sophistication facilitates quantitative comparison of estimated risk levels with established risk tolerability levels.
- Quantitative including decision analysis methods, facilitating strategic analysis of risk reduction measures, e.g. estimations of the risk reduction – investment trade-offs in prioritization of risk reduction options.

The Hazard Analysis and Critical Control Points (HACCP) tool is used widely in risk assessment for water reuse projects.

2.3.9 Use of HACCP framework

2.3.9.1 The HACCP process

The main thrust of HACCP (Hazard Analysis and Critical Control Points) and a Water Safety Plan (WSP) is to understand the risks associated with the process and to take the focus on process control away from the end-point testing towards control of the critical operations earlier in the process. It acknowledges that there is a lack of knowledge about significant pathogens and the behaviour of certain trace chemicals in modern water supply systems and it emphasises the importance of relying on more than the treatment barrier to control them.

Hazard Assessment and Critical Control Point (HACCP) is an acceptable framework for guiding the process of risk management in water supplies (WHO, 2001). A HACCP system is guided by risk-based scientific evidence which evaluates the hazards and establishes control systems more focused on the prevention than on the final product. The HACCP system focuses on controlling hazards as close to their source as possible.

HACCP receives wide international acceptance and is practiced in various countries. The WHO guidelines published in 2004 are based on HACCP. The EU guidelines of 1998 are also based on the same guidelines, but they adopt and publish them before the WHO published theirs. The popular use of HACCP has occurred because conventional systems in developed countries in recent years have experienced disease outbreaks. For example, in 1998 there were 25 known cryptosporidiosis outbreaks from public drinking water supplies in the UK.

Elements of HACCP include:

- Risk analysis of the process – identifying appropriate control measures – defining specific corrective actions.
- Setting up procedures, looking at improvements, communicating this through all the levels
- Enhances cooperation between different disciplines.
- More systematic approach and better documentation
- Authorities have more faith in operators.
- It acknowledges and meets the consumer requirements.
- Knowledge is captured and retained.
- Help for small operators which do not have access to expertise.
- It focuses on specific risk assessment setting priorities in the monitoring program.

2.3.9.2 Hazard Assessment and Critical Control Points

Given the complexity provided by pollution of contaminants and waterborne contamination, simplistic approaches to risk management will be ineffective. Arrangements are complicated and multiple individuals and stakeholders are involved in both identifying hazardous scenarios and managing barriers. This complexity necessitates the use of systems to manage risk.

A HACCP system general stipulates the following principals or checklist (CAC/RCP 1997; WHO, 2001):

- *Hazard analysis and determination of preventative measures.* Hazards are identified, likelihood of occurrence and severity is assessed, and preventative measures are identified and put in place.
- *Identification of Critical Control Points (CCP).* These are process steps and operational procedures which can be controlled to minimize risk.

- *Determination of critical limits of every CCP.*
- *Monitoring of the CCP.* A monitoring system needs to be in place which observes, measures and records data needed to assess whether a CCP is under control.
- *Corrective measures*. Establish corrective actions for CCPs which are not under control.
- *Verification/validation.*
- *Registers.* To establish documentation concerning all relevant procedures and records to meet these principles and applications.

2.3.9.3 Critical control point management in potable water reuse

Multiple barrier systems are a component of potable reuse schemes because they provide several individual processes capable of stopping the flow of pathogenic organisms and chemical substances into treated effluent water. In a multiple barrier scenario, no single treatment step is responsible for meeting target effluent requirements; instead, each step is partially or completely redundant of another (WRRF, 2014a). Design plans incorporate multiple barriers into the treatment scheme: monitoring at multiple and various points of the treatment process, real-time or near real-time monitoring, operator certification, training, a combination of treatment steps, and wastewater effluent control programs that strive to limit the number of toxic substances entering the waste stream prior to wastewater treatment. The purpose of multiple barriers is to decrease the probability of process failure by adding units of reliability and redundancy to the treatment scheme; this ensures that if one step of the process fails, another treatment unit will reliably provide public health protection (Khan, 2013). Regulatory agencies employ an approach called log removal value (LRV) or log removal credit (LRC) to verify the functionality of multiple barriers for pathogen control. Regulatory agencies grant LRVs based on pathogen removal and/or inactivation knowledge of the individual unit treatment process (Khan, 2013). The LRVs required to achieve effluent targets, as set by regulation, or permitting mechanism, are calculated, and compared to actual treatment results for validation (Khan, 2013). The California Division of Drinking Water (DDW), for example, controls pathogens and forces multi-barrier design in groundwater replenishment reuse systems by requiring that the recycled municipal wastewater achieves at least 12-log enteric virus reduction, 10-log *Cryptosporidium* oocyst reduction, and 10-log *Giardia* cyst reduction (see Cal. Code Reg. tit. 22 § 60320.108, 60320.208). California DDW requires at least three individual treatment processes in the treatment works, and each step is credited with a maximum of 6-log reduction (see Cal. Code Reg. tit. 22 § 60320.108, 60320.208). The purpose of the maximum log removal and/or inactivation credit value is to ensure that reuse projects are designing systems that achieve *de minimis* risk levels utilizing the multiple barrier approach.

2.4 WATER RECLAMATION PROCESSES AND CONFIGURATIONS

2.4.1 Treatment needs

The very nature of water reuse suggests that nearly any substance used or excreted by humans has the potential to be present at some concentration in the treated product. Modern analytical technology allows detection of chemical and biological contaminants at levels that may be far below human and environmental health relevance. Therefore, if wastewater becomes part of a reuse scheme (including de facto reuse), the impacts of wastewater constituents on intended applications should be considered in the design of the treatment systems. Some constituents, such as salinity, sodium, and boron, have the potential to affect agricultural and landscape irrigation practices if they are present at concentrations or ratios that exceed specific thresholds. Other constituents, such as microbial pathogens and trace organic chemicals, have the potential to affect human health, depending on their concentration and the routes and duration of exposure. Additionally, not only are the constituents themselves important to consider but also the substances into which they may transform during treatment. Pathogenic microorganisms are a particular focus of water reuse treatment processes because of their acute human health effects, and viruses necessitate special attention based on their low infectious dose, small size, and resistance to disinfection.

A portfolio of treatment options, including engineered and managed natural treatment processes, exists to mitigate microbial and chemical contaminants in reclaimed water, facilitating a multitude of process combinations that can be tailored to meet specific water quality objectives. Advanced treatment processes are also capable of addressing contemporary water quality issues related to potable reuse involving emerging pathogens or trace organic chemicals. Advances in membrane filtration have made membrane-based processes particularly attractive for water reuse applications. However, limited cost-effective concentrate disposal alternatives hinder the application of membrane technologies for water reuse in inland communities.

Reuse systems should be designed with treatment trains that include reliability and robustness. Redundancy strengthens the reliability of contaminant removal, particularly important for contaminants with acute affects, while robustness employs combinations of technologies that address a broad variety of contaminants. Reuse systems designed for applications with possible human contact should include redundant barriers for pathogens that cause waterborne diseases. Potable reuse systems should employ diverse processes that can function as barriers for many types of chemicals, considering the wide range of physiochemical properties of chemical contaminants.

2.4.2 Water reclamation technologies

The majority of conventional as well as advanced treatment technologies for water reclamation have already been tested and proven for South African conditions. Water reclamation has been studied in South Africa since the 1960s 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, eMalahleni Water Reclamation Plant, and the Beaufort West Water Reclamation Plant) (DWA, 2012).

A summary of treatment technologies used in water reclamation appears in Table 2-7.

Table 2-7: Applicable water treatment technologies for water reuse (adapted from DWA, 2012)

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.) • Ultraviolet (UV) radiation • Ozonation
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) • Ozonation • Biologically enhanced adsorption (BAC) • Adsorption by activated carbon (granular/powder) • Membrane separation (nanofiltration /reverse osmosis)
Disinfection by-products	• Modify disinfection agent in upstream processes. • Advanced oxidation • Adsorption by activated carbon (PAC/GAC) • Membrane separation (nanofiltration /reverse osmosis)

2.4.3 Unit treatment processes for potable water reuse

Table 2-8 shows a summary of the technologies and treatment systems often used for potable water reuse.

Table 2-8: Summary of the Technologies Considered for the Conceptual Design of DPR2

Treatment Option	Use	Notes
Filter screens (in-line, self-cleaning and/or exchangeable)	Remove large, suspended solids in unfiltered and filtered secondary effluent.	Filter screens are needed to protect downstream membranes.
Flow equalisation	Eliminate diurnal flow rate variations, reduce the size of downstream units, and reduce variations in water quality.	Constant flow with consistent water quality to the advanced treatment process reduces wear and tear on equipment (e.g. stress cracks in equipment from cycling) and results in improved performance.
Ozone followed by biologically active filtration (BAF)	Pre-treatment step used before MF or UF to achieve a reduction in pathogenic microorganisms and trace organics.	The use of ozone/BAF may eliminate the need for RO for advanced water treatment, assuming TOC is used as a performance indicator and not as a regulatory compliance measure.
GAC	Removal of trace organic compounds.	Can be used in conjunction with other technologies for the removal of trace organic compounds.
(MF)	Remove residual suspended particles by mechanical sieving.	Typical membrane pore size range is 0.1 to 0.2 micrometres (µm).
(UF)	Remove residual suspended particles by mechanical sieving.	Typical membrane pore size range is 0.008 to 0.04 µm. UF is often used in place of MF.
Cartridge filtration	Remove suspended and colloidal impurities from chemicals added to prevent fouling on RO membranes.	Typical filter cartridge pore size range is 5 to 10 µm.
ED	Remove salt from solution with ion-exchange membranes.	ED is designed mainly for desalination, and is less effective for suspended solids, total organic carbon, or other contaminants.
NF	Remove dissolved constituents and colloidal solids, primarily divalent ions and trace organics, by means of size exclusion and solution/diffusion.	Typical membrane pore size range is 0.001 to 0.02 µm with a molecular weight cut-off range of 200 to 1,000 Daltons. NF has been used in place of RO when only softening or partial demineralisation is needed.
RO	Remove dissolved constituents and colloidal solids, including salts and trace organics, by means of size exclusion and solution/diffusion.	Typical membrane pore size range is 0.0001 to 0.002 µm. RO concentrate for wastewater is typically 15% of flow.
AOP	Destroy or alter chemical constituents that are not removed completely by conventional biological treatment processes or by filtration, especially trace organics.	AOP may contain a range of processes, but most commonly uses ozone with H_2O_2 or UV with H_2O_2. More recent projects are implementing UV with sodium hypochlorite for AOP.

Treatment Option	Use	Notes
Post-treatment (when RO is used, stabilisation or remineralisation are typically involved)	Stabilisation involves the addition of a chemical (typically, lime) to the RO product water to increase hardness and alkalinity and reduce its corrosive properties.	A variety of different corrosivity indices (e.g. Aggressiveness Index, Langelier Saturation Index, calcium carbonate precipitation potential) are used to assess the stability of product water.
Engineered storage, with or without free chlorine	Used to store water but should not be a requirement. In-line measurement can obviate the need for an engineered storage buffer.	In some cases, travel time in the pipeline from the reuse plant may serve the same purpose.

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 (DWA, 2012):

- 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 main treatment technologies are discussed below.

2.4.3.1 Reverse Osmosis-Based Configuration

Nanofiltration (NF) and reverse osmosis (RO)

NF membranes are capable of removing small organic compounds and divalent ions such as Ca^{2+} and Mg^{2+}. RO removes all salts, including the monovalent ions Na and Cl, and is therefore used for desalination. Due to the very low molecular weight cut off capability of RO membranes, they are prone to fouling and adequate pre-treatment is required to ensure optimal performance of the RO process.

Applications of NF and RO include:

- Total dissolved solids reduction (RO)
- Inorganic ion removal (up to divalent for NF)
- Fluoride, calcium, and magnesium hardness (NF often called softening membranes)
- Nutrients (nitrate, nitrite, ammonia, and phosphates)
- Dissolved organics removal, including pharmaceuticals, pesticides, and other CECs (RO only)
- DBP precursors and many DBP’s
- Colour.

Microfiltration and Ultrafiltration (UF)

Both MF and UF processes require low transmembrane pressures to operate. MF membranes can operate either in cross flow separation or dead-end filtration, in which it achieves separation by a sieving action. Cross flow separation is where only part of the feed stream is treated with the remaining water passing through the filter untreated. This water is normally recycled. Dead-end separation results in all the feed water being treated.

2.4.3.2 Ozone-Biological activated filtration (BAF)

In the US, some utilities are evaluating alternative treatment trains capable of producing a similar quality product water as full advanced treatment trains (i.e. RO treatment configurations). Ozone-BAF is one such alternative, providing a potential substitute for RO, addressing trace chemical constituents without producing a brine stream (EPA, 2017).

Ozone-BAF is a simple process using a combination of chemical and biological oxidation processes. Both the unit processes comprising the treatment combination use mature treatment technologies that are currently widely used in drinking water treatment. The ozone-BAF process generally consists of an ozone pre-treatment step followed by biological filtration in a media filter (which should be activated carbon for water reuse plants). Ozone is a strong oxidant, and when used in conjunction with BAF, it can reduce COD, trace organics, iron and manganese, taste and odour compounds, colour, and disinfection by-product precursors. During ozonation, high molecular weight organic compounds (long chains) are broken down into smaller chain compounds that are more readily biodegradable by the BAF, regardless of the composition of the filter media (sand filters or activated carbon) (EPA, 2017).

Depending on contact time requirements to remove target contaminants, a biofilter can be a rapid-rate filter, a mono-media deep-bed contactor, or a GAC filter cap on top of a sand or anthracite filter bed (EPA, 2017). As with conventional rapid-rate filters, upstream coagulants and oxidants improve contaminant removal. GAC's adsorptive properties aid in producing the desired filtered water quality; GAC must be regenerated periodically, particularly where adsorption may play a more dominant treatment role than the biological mechanism of contaminant removal (EPA, 2017).

Water Quality

Considering that ozone-BAF leverages a biofilm established on filter media, there is concern over the potential to generate pathogenic bacteria from microbial biomass sloughing. However, research shows that the potential is low and post-disinfection processes can sufficiently mitigate any potential microbial breakthrough (EPA, 2017).

An important difference between the ozone-BAF process and RO processes is that the full advanced treatment train (RO-train) can reduce TOC to below 0.5 mg/ℓ. In practice, when ozone-BAF is used in lieu of RO this generally results in < 95 percent TOC reduction. Ozone-BAF is typically paired with other treatment trains that can increase overall organic carbon removal, but the low TOC levels achieved with RO are difficult to match with any other treatment scheme. However, the nature of the TOC remaining after an ozone-BAF process, such as an increase of assimilable organic carbon, may differ in composition from that remaining after an RO-based process, and therefore **acceptable TOC concentrations may be site-specific.**

One of the potential disadvantages of using ozonation as a process step in direct potable reuse is the formation of bromate, which is a disinfection by-product formed during ozonation (Lahnsteiner et al., 2018) that has been shown to have health risks. Bromate formation is acknowledged as one of two main problems associated with DPR in Windhoek, the other being high TDS (WHO, 2017b).

Ozone-BAF requires careful operator attention to maintain optimized ozone dosing, proper filter loading, and sufficient backwashing. A poorly operated facility could see wide variations in product water quality; this is a significant difference from the full advanced treatment process (RO-train), where product water quality remains relatively consistent and independent of operating conditions or operator attention.

Ozone-BAF does not remove TDS, therefore it will be limited to applications where the water's salt concentrations are not a concern. **However, ozone-BAF can be coupled with side stream TDS removal in certain cases to achieve local TDS requirements.**

In the California Groundwater Replenishment Using Recycled Water regulations, ozone-BAF is an alternative process that requires approval on a case-by-case basis, if accepted. Ozone-BAF is allowed in California for surface spreading operations, but full advanced treatment is currently the only treatment train specifically approved for direct injection of reclaimed water into groundwater (CDPH, 2014).

The WHO have established a provisional guideline value of 10 µg/l due to limitations in available analytical and treatment methods (WHO, 2017a). The NamWater guidelines (NamWater, 1998) do not contain any limit for bromate, whilst the draft Namibian Water Quality Standard proposes a value of 10 µg/L and the draft Namibian Water Quality Ideal Guideline a value of 5 µg/l. Bromate is difficult to remove once formed, with removal possible using RO (WHO, 2017b) or else concentrations can be limited by controlling disinfection conditions (WHO, 2017a).

The formation of bromate is in particular a risk when high concentrations of ozone are dosed to the water, which is often the case in DPR applications. For this reason, considerable research has been conducted over the past decade to understand the bromate formation process and how it can be managed. This has included research by WINGOC at the NGWRP on ways to optimise the ozonation processes to maintain the bromate levels below the target levels of 30 µg/l (and later 10 µg/l). While problems are still experienced from time to time to maintain the levels below the target values, the research has established measures that can be taken to manage the bromate formation satisfactorily. These measures include:

- Reducing the ozone concentrations and increasing the contact time to still achieve a
- sufficient CT value
- Controlling the recycle streams in the plant
- pH control
- Dosing chloramines

- Blending with water from low- or bromate-free sources.

Another option for lowering bromate formation includes AOP with ozone and hydrogen peroxide (Lahnsteiner et al., 2018).

2.4.3.3 Granular Activated Carbon (GAC)

The adsorption capacity of activated carbon is related to the available surface area of carbon in relation to contaminants in the water. Contacting can be achieved by a number of configurations that include activated carbon beds (GAC) and powder activated carbon (PAC) dosing systems. GAC is normally provided as an activated carbon bed which is designed based on a mass transfer zone.

As contaminated water is progressively passed through an activated carbon bed, saturation of surface adsorption sites is reached. It is common practice to operate activated carbon beds in series such that if one bed becomes saturated, the pollutant concentration does not break through and instead becomes contained by a subsequent activated carbon bed. Once a bed is saturated it is taken offline and the activated carbon is regenerated or replenished.

One of the major attributes of activated carbon is its ability to remove a wide variety of organic compounds to very low levels (99.99% reduction). Its uses have involved adsorption of (Aurecon, 2016b):

- Non-biodegradable organic compounds
- Colour compounds and dyestuffs
- Aromatic compounds including phenols
- CECs.

Among the disadvantages of using activated carbon filters is the possibility of the filters acting as a site for microbial growth. The activated carbon filter bed becomes favourable for bacterial growth towards saturation because the microbes use the adsorbed contaminants as a food supply and the activated carbon itself also gives them a place to anchor and grow. Once activated carbon is saturated it can be regenerated by various methods that include thermal reactivation. In this process, reactivation involves treating the spent carbon in a high temperature oven at 800 degrees Celsius. The high temperature that the carbon is subjected to destroys the adsorbed organic compounds rendering the surface of the carbon useable for further organics adsorption.

2.4.3.4 Ultraviolet Light Radiation (UV)

When UV radiation penetrates the cell wall of a pathogenic organism, it destroys the cell's ability to reproduce. The efficiency of UV disinfection depends on the characteristics of the water, the intensity of UV radiation and the effective contact time the microorganisms are exposed to the radiation.

The source of UV radiation can either be low pressure or medium pressure arc lamps with low or high intensities. Effective inactivation of microorganisms can be achieved within a wavelength range of 250 to 270 nm. The intensity of radiation emitted by the lamp dissipates as the distance from the lamp increases. Medium pressure lamps have approximately 15 to 20 times the germicidal UV intensity of low-pressure lamps. The medium pressure lamps disinfect faster and have a higher penetration capability because they operate at a higher temperature, but they have higher energy consumption (Aurecon, 2016b).

Advantages of the UV process include:

- High disinfection efficiency against a wide range of microorganisms including chlorine resistant ones
- Environmentally safe, compared to chemical disinfection technologies; no by-products; no danger for overdosing
- No impact on physical, chemical, and organoleptic properties of water and air
- Disinfection process takes 1-10 seconds
- Stream water is treated so there is no need for contact reservoirs
- pH and water temperature do not affect UV disinfection process
- Low power consumption, capital, and operational costs
- UV systems are compact and easy to operate
- No need for special operational safety precautions
- UV disinfection process is easy to automate
- No corrosion of process equipment.

2.4.3.5 Advanced Oxidation Processes (AOP)

AOP refers to a set of chemical treatment procedures enhanced by ultrasound, UV activation, hydrogen peroxide or ozone dosing. The method relies on the action of highly reactive species such as hydroxyl (OH) radicals for the removal of organic pollutants not treatable by conventional techniques due to their high chemical stability and/or minimal biodegradability.

The mechanism of hydroxyl (OH) radicals' production depends highly on the sort of AOP technique that is used. For example, ozonation, UV/H_2O_2 and photocatalytic oxidation rely on different mechanisms of OH radicals' generation which will be briefly discussed in the following section.

AOPs are considered highly competitive in the removal of a wide spectrum of organic pollutants. The target pollutants of advanced oxidation processes include materials such as aromatics, pesticides, petroleum constituents and volatile organic compounds. These contaminant materials are converted, to a large extent, into compounds such as water, carbon dioxide and salts.

2.4.3.6 Engineered Storage Buffer (ESB)

With early reuse systems, where the product water was not of the highest quality, IPR with an environmental buffer, was used to provide a measure of safety. Advances in water treatment technology, experience, and improved monitoring can now favour DPR over IPR, with an Engineered Storage Buffer (ESB) taking the place of the environmental buffer of an IPR system.

ESB systems can include various types of reservoirs (above or below ground), large diameter subsurface pipes, confined aquifers or engineered subsurface aquifers (Tchobanoglous, 2011). Essentially the environmental buffer of IPR or the ESB of a DPR system provide the following advantages (ATSE, 2013):

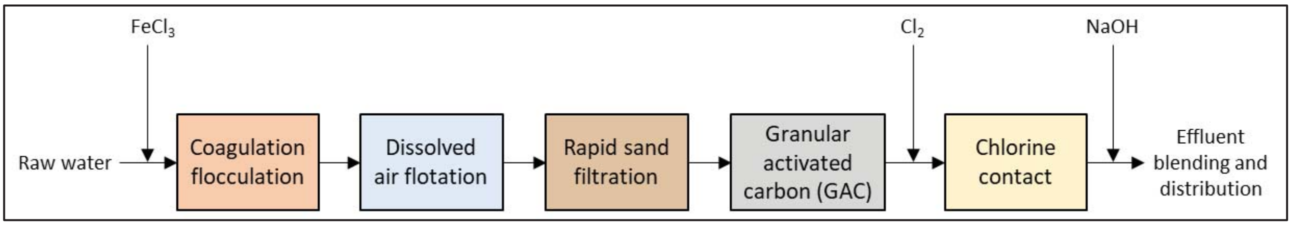
- These measures "buy time" to identify problems and product water quality which is out of specification and time to implement corrective measures (i.e. "time to react")

- Blending of reclaimed water with that from other sources, including for balancing water quality aspects
- Balancing variability between water supply and demand.

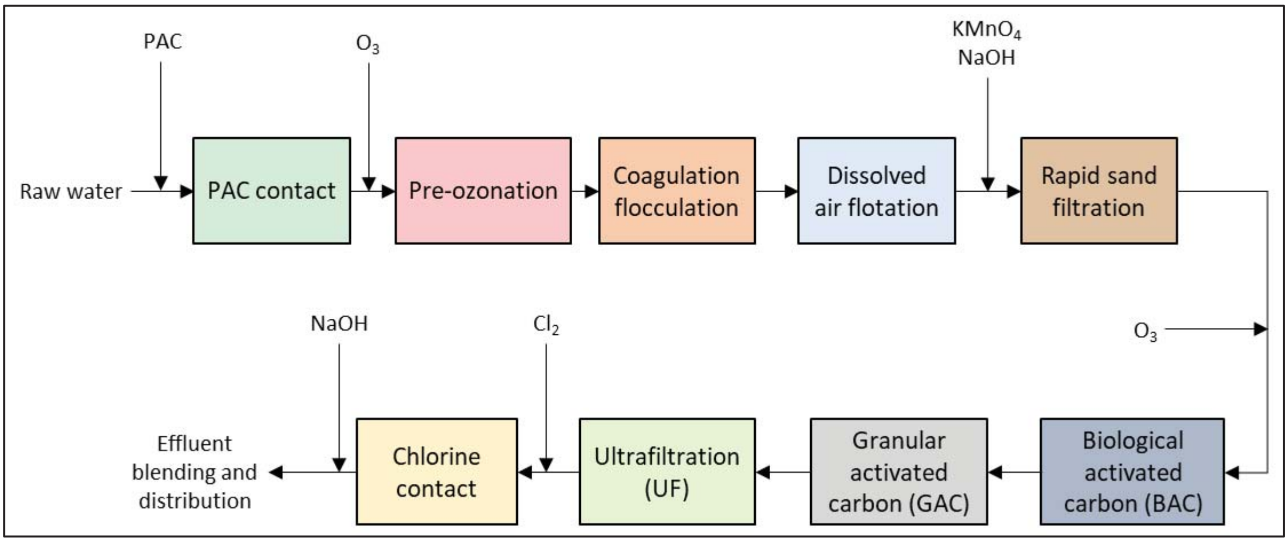
2.4.4 Process configurations used in water reclamation

Figure 2-1 shows the process configurations which are most commonly used in water reclamation and reuse plants (Swartz *et al.,* 2014).

Configuration 1	**Example: Old Goreangab Water Reclamation Plant**
Chemical treatment – Phase separation – filtration – adsorption – disinfection	

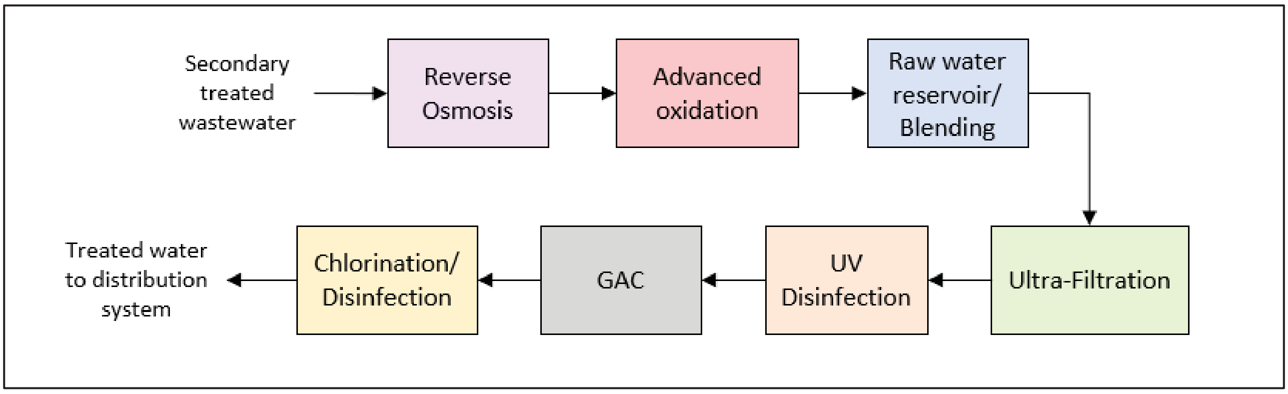


Configuration 2	**Example: New Goreangab Water Reclamation Plant (NGWRP)**
Chemical treatment – Phase separation – filtration – ozonation – BAC – GAC – UF – disinfection	



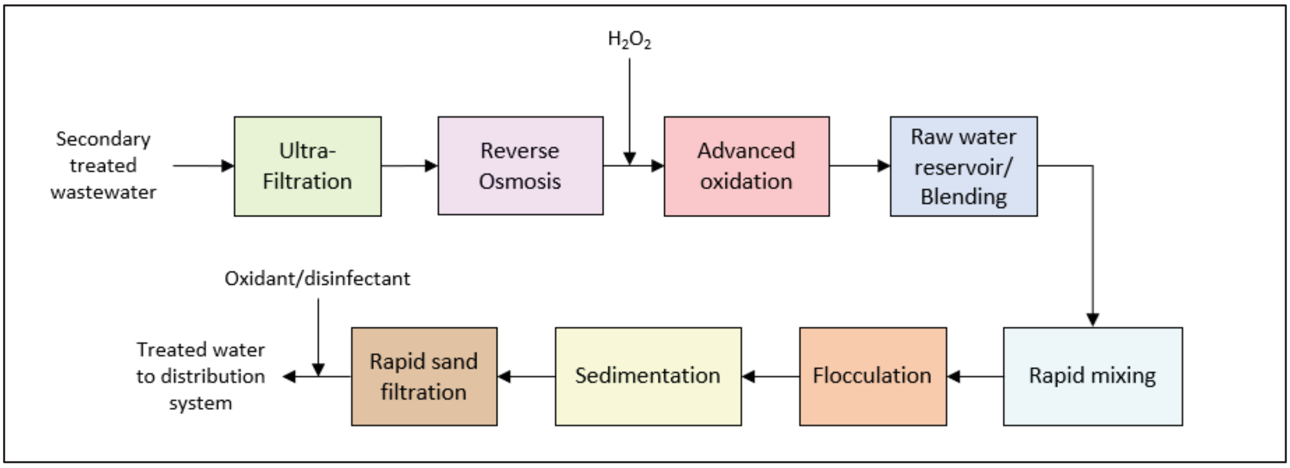
Configuration 3 | **Example: Cloudcroft, New Mexico**

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



Configuration 4 | **Example: Big Spring, Texas**

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



Configuration 5	Example: Beaufort West, South Africa
Rapid sand filtration – Membrane filtration – Reverse Osmosis – Advanced Oxidation – Disinfection	

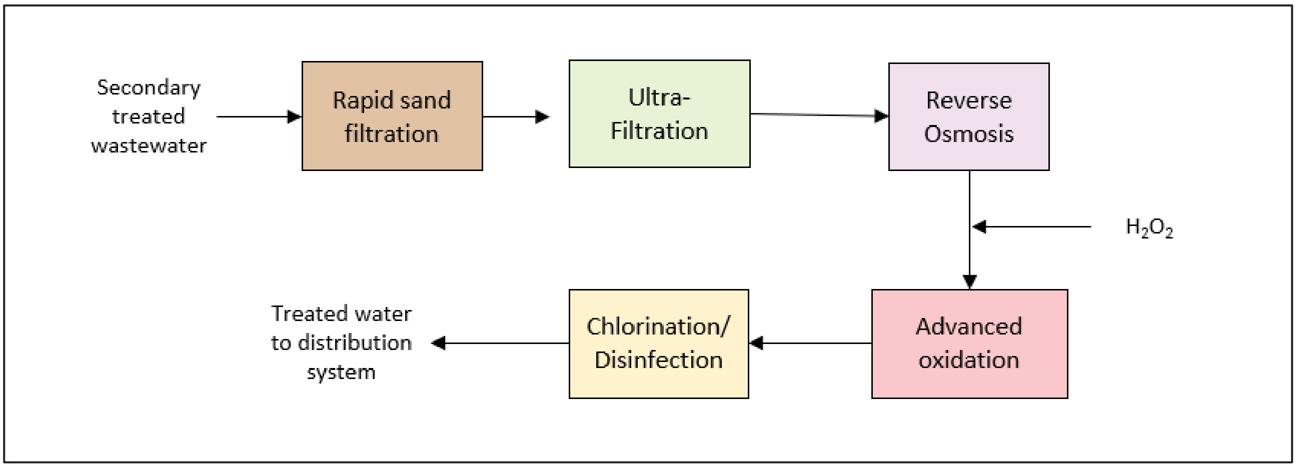


Figure 2-1: Most common process configurations used in water reclamation schemes (with examples)

2.4.5 Pathogen Removal in the Two Process Configurations

Interim information is provided in Table 2-9 on an ozone/BAF based treatment train that is being conducted at a facility in Florida. The DPR demonstration system has full-scale components. The data reflects information based on 6 months of operation.

Table 2-9: Pathogen Log Reduction Credits for an Ozone-BAF with UF Treatment Train (Mosher et al., 2016)

Pathogen	Log Reduction Credit per Treatment Process					
	Ozone[1]	BAF	UF	UV/AOP	Storage with Cl_2	Total
Virus	4	0	2	6	4	16
Cryptosporidium	0	0	4	6	0	10

Note: Both chlorine and ozone likely will achieve higher LRVs than shown if higher contact times are used.

2.4.5.1 Percentage Removal of Micro-Pollutants for the Two Process Configurations

Table 2-10 shows the removal capabilities of various unit treatment processes used in conventional water treatment plants as well as in advanced water treatment plants for the eight indicator chemicals that were studied in the de facto water reuse project (Swartz *et al.,* 2021).

No removal percentages could be found in literature for the two antiretrovirals (Efavirenz and Emtricitabine) as well as for the recreational drug (methaqualone).

Table 2-10: Removal Capabilities of Various Unit Treatment Processes for the Eight Indicator Chemicals (Swartz et al., 2021)

CEC removal capabilities by various unit treatment processes									
Chemical	**Removal by treatment process (%)(average)**								**Reference**
	Coagulation, Sedimentation, Filtration	**Chlorine Disinfection**	**Ozone**	**GAC/PAC**	**UF**	**RO**	**UV disinfection**	**UV/H2O2**	
Caffeine (Stimulant)		44	95	11		99	4.1		US EPA (2010)
	Low	Medium	High	Medium	Low		Low	Low	Snyder et al. (2007)
	<35	<20	40 - 100	> 90		> 90		>90	Olivier (2015)
Sulfamethoxazole (Antibiotic)		61	93	49		81	28		US EPA (2010)
	Low	High	High	Medium	Low		Medium	High	Snyder et al. (2007)
	<35	<20	40 - 100	> 90		> 90		>90	Olivier (2015)
Carbamazepine (Anti-epileptic)	65		88			98	2.3		US EPA (2010)
	Low	Low - Med	High	Med - High	Low		Low	Low	Snyder et al. (2007)
	<35	<20	40 - 100	> 90		> 90		>90	Olivier (2015)
Diclofenac (Anti-inflammatory)		61	100	59		98	34		US EPA (2010)
	Low	High	High	Medium	Low - Med		Medium	High	Snyder et al. (2007)
	<35	<20	40 - 100	> 90		> 90		>90	Olivier (2015)
Acetaminophen (Analgesic)		77		59		92	19		US EPA (2010)
	Low	High	High		Medium		Low	High	Snyder et al. (2007)
	<35	<20	40 - 100	> 90		> 90		>90	Olivier (2015)
Efavirenz (Antiretroviral)	No Data								
Emtricitabine (Antiretroviral)	No Data								
Methaqualone (Recreational drug)(Madrax)	No Data								
Atrazine (Pesticide)	Low	Low	Medium	Med - High	Low		Low	Med - High	Snyder et al. (2007)
			20-50	63			92		USBR (2009)

* v = variable

Table 2-11 and Table 2-12 show the results of a comprehensive summary by the U.S. Department of the Interior Bureau of Reclamation (USBR, 2009) of removal percentage ranges for a number of CECs for conventional and advanced water treatment processes. The green shading in these tables shows processes which provide good removal (80-100%), the yellow shading represents moderate removal (50-80%), and the pink shading shows poor removal (0-50%).

USBR (2009) reported that technologies that can remove CECs to a moderate extent (50-70%) included activated carbon absorption (GAC, PAC), UV Irradiation, conventional activated sludge systems, and MBR. Technologies that can remove CECs to a greater extent (>85%) include RO, ozone/AOP, UV/AOP, and BAC.

Table 2-11: Percentage Removal Ranges of Conventional and Advanced Water Treatment Processes for a Number of Chemical Compounds (CECs) (adapted from USBR, 2009)

Compound	Subcategory	Percentage Removal (%)									
		Activated Carbon Adsorption	Ozone	UV AOP	UV Irradiation	CAS	MBR	NF	RO	Biologically Active Sand	Biologically Active Carbon
1,4-Dioxane ($C_4H_8O_2$)[a]	Industrial	<20	<35	>95	<20	<20	<20	20-40	20-50	<20	<20
Acetaminophen ($C_8H_9NO_2$)	Analgesics	78	>95	>97	73	N/A[b]	>99	25-50	>90	79	95
Androstenedione ($C_{19}H_{26}O_2$)	Steroids	70	>80	96	89	N/A	>98	50-80	>61	96	97
Atrazine ($C_8H_{14}ClN_5$)	Pesticides	63	20-50	80	92	N/A	N/A	50-80	N/A	54	83
Benzon(a)pyrene ($C_{20}H_{12}$)	PAH	72	N/A	N/A	N/A	>85	N/A	>80	>90	N/A	89
Caffeine ($C_8HYN_4O_2$)	Stimulant	59	>80	89	44	>97	>85	50-80	>99	77	93
Carbamazepine ($C_{15}H_{12}N_2O$)	Analgesics, stimulant	72	>95	>88	60	N/A	20	50-80	>99	54	90
DDT ($C_{14}H_9Cl_5$)	Pesticides	70	N/A	N/A	N/A	N/A	N/A	>80	N/A	N/A	85
DEET ($C_{12}H_{17}NO$)	Pesticides	54	50-80	89	52	N/A	20	50-80	>95	37	80
Diazepam (Valium) ($C_{16}H_{13}ClN_2O$)	Anticonvulsant	67	50-80	93	52	<20	N/A	50-80	N/A	82	84
Diclofenac ($C_{14}H_{11}Cl_2NO_2$)	Analgesics	49	>95	>98	>98	N/A	>50	50-80	>97	67	75
Dilantin ($C_{15}H_{12}N_2O_2$)	Anticonvulsant	56	50-80	97	96	N/A	4	50-80	>99	77	80
Erythromycin ($C_{37}H_{67}NO_{13}$)	Antimicrobials	52	>95	50-80	39	N/A	96	>80	>98	79	78
Estradiol ($C_{18}H_{24}O_2$)	Steroids	55	>95	>98	93	60-80	N/A	50-80	N/A	85	94
Estriol ($C_{18}H_{24}O_3$)	Steroids	58	>95	>99	90	>85	>98	50-80	N/A	81	92
Estrone ($C_{18}H_{22}O_2$)	Steroids	77	>95	>99	94	80	82	50-80	>95	62	95
Ethinyl Estradiol ($C_{20}H_{24}O_2$)	Steroids	70	>95	>98	93	N/A	N/A	50-80	N/A	73	91
Fluorene ($C_{13}H_{10}$)	PAH	94	N/A	N/A	N/A	N/A	N/A	>80	N/A	N/A	>94
Fluoxetine (Prozac) ($C_{17}H_{18}F_3NO$)	Antidepressant	91	>95	>98	>98	N/A	40	>80	>96	98	>99
Gemfibrozil ($C_{15}H_{22}O_3$)	Heart Medication	38	>95	95	57	N/A	>86	50-80	>99	54	74

Table 2-12: Percentage Removal Ranges of Conventional and Advanced Water Treatment Processes for a Number of Chemical Compounds (CECs) (adapted from USBR, 2009)

Compound	Subcategory	Percentage Removal (%)									
		Activated Carbon Adsorption	Ozone	UV AOP	UV Irradiation	CAS	MBR	NF	RO	Biologically Active Sand	Biologically Active Carbon
Hydrocodone ($C_{18}H_{21}NO_3$)	Analgesics	72	>95	>98	64	N/A	>94	50-80	>98	47	92
Ibuprofen (Advil) ($C_{13}H_{18}O_2$)	Analgesics	26	50-80	94	70	>80	95	50-80	>99	66	83
Iopromide ($C_{18}H_{24}I_3N_3O_8$)	X-Ray Contrast Media	31	20-50	91	99	N/A	20	>80	>99	28	42
Lindane (a-BHC) ($C_6H_6Cl_6$)	Pesticides	70	N/A	N/A	N/A	N/A	N/A	50-80	N/A	N/A	91
Meprobamate ($C_9H_{18}N_2O_4$)	Anticonvulsant	36	20-50	75	29	N/A	<1	50-80	>99	36	71
Metolachlor ($C_{15}H_{22}ClNO_2$)	Pesticides	50	N/A	N/A	N/A	N/A	N/A	50-80	N/A	N/A	79
Musk Ketone ($C_{14}H_{18}N_2O_5$)	Fragrance	69	N/A	N/A	N/A	<20	N/A	>80	N/A	N/A	83
Naproxen ($C_{14}H_{14}O_3$)	Anti-Inflammatory Agent, Analgesics	60	>95	>99	99	N/A	>86	20-50	>99	80	82
N-Nitrosodimethylamine (NDMA) ($C_2H_6N_2O$) [a]	DBPs	<20	40-70	>95	<20	<20	<20	20-50	30-70	<20	<20
Oxybenzone ($C_{14}H_{12}O_3$)	Sunscreen	92	>95	50-80	50	>85	95	>80	>93	83	98
Pentoxifylline ($C_{13}H_{18}N_4O_3$)	Heart Medication	71	>80	90	50	N/A	85	50-80	>96	91	90
Progesterone ($C_{21}H_{30}O_2$)	Steroids	84	>80	98	92	N/A	95	50-80	N/A	N/A	99
Sulfamethoxazole ($C_{10}H_{11}N_3O_3S$)	Antimicrobials	43	>95	>99	>99	N/A	20	50-80	>99	77	63
TCEP ($C_9H_{15}O_6P$)	Flame Retardant	60	<20	16	10	<20	20	50-80	>91	53	80
Testosterone ($C_{19}H_{28}O_2$)	Androgenic Steroids	71	>80	97	91	N/A	96	50-80	N/A	92	96
Triclosan ($C_{12}H_7Cl_3O_2$)	Antimicrobials	90	>95	>97	>97	70	70	>80	>97	97	97
Trimethoprim ($C_{14}H_{18}N_4O_3$)	Antimicrobials	69	>95	94	<5	N/A	>76	50-80	>99	24	94

Legend	Good removal (80-100%)		Moderate removal (50-80%)		Poor removal (0-50%)		N/A

2.5 GUIDELINES FOR PROCESS SELECTION AND COSTING OF WATER RECLAMATION TECHNOLOGIES

2.5.1 Planning considerations

To ensure that water reuse projects culminate in successful development schemes, it is essential that careful planning is done. This chapter highlights some important planning aspects.

2.5.1.1 Key overall considerations

Turner *et al.* (2015) lists the following key planning considerations:

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

2.5.1.2 Design considerations

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

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

2.5.1.3 Funding and Institutional Considerations

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

- Accurate capital and operational expenditure estimates and detailed life cycle costing are required and should include adequate risk factors that allow for unexpected changes in water quality, demand, escalation and changes in rates and availability of consumables (especially electricity), etc.
- Clear and concrete take-off agreements (and other associated operational, maintenance and other agreements) are required for successful implementation and operation.

- Revenues from water rates should be adequate to cover annual operating, maintenance and repair costs, replacement and improvement costs, adequate working capital, and servicing of debt finance (if applicable) as well as some reserves. This should also take into consideration the cost of specialist support services.
- Budgeting of the operational phase should include sufficient allowances for asset management, preventative maintenance, and future infrastructure replacement and/or re-investment.
- Cost of quality materials, as well as training and skills development should be included in the financial and implementation models.

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

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

2.5.2 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 (Swartz *et al.,* 2014).

a. <u>Plant and technology costs</u>

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

b. <u>Energy sources</u>

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

c. <u>Feed water intake</u>

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

d. <u>Feed water quality</u>

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.

e. 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.

f. Plant life

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

g. Interest rates

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

h. 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.

i. 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.

j. 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.

k. 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.

l. 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.

m. Storage and distribution of the final water

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

2.5.3 Costing components

2.5.3.1 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:

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.

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

Land Cost

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

Land Acquisition Cost

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

Total Capital Cost

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

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

Unit Production Cost

Equivalent Annual Cost divided by total annual water production.

A typical capital cost breakdown for water treatment plants is provided below (Swartz *et al.,* 2013). The ratios will be in the same order of magnitude for water reclamation plants.

<table>
<tr><td rowspan="4">Civil
60%</td><td colspan="2">Electrical
12-15%
consisting of</td><td rowspan="4">Mechanical
25-28%</td></tr>
<tr><td>Electric
80%</td><td>Electronic
20%</td></tr>
</table>

The effect of economy of scale (higher unit treatment costs for smaller plants) is shown in Figure 2-2, which provides a graph for operating costs for three water reuse plants (Swartz et al., 2014), showing that as capacity increases, the unit cost of reclamation plants decreases. Whilst some equipment-based aspects and processes feature economy of scale benefits, this effect is more pronounced for personnel (labour), safety, health, environmental, monitoring, compliance, and laboratory expenses.

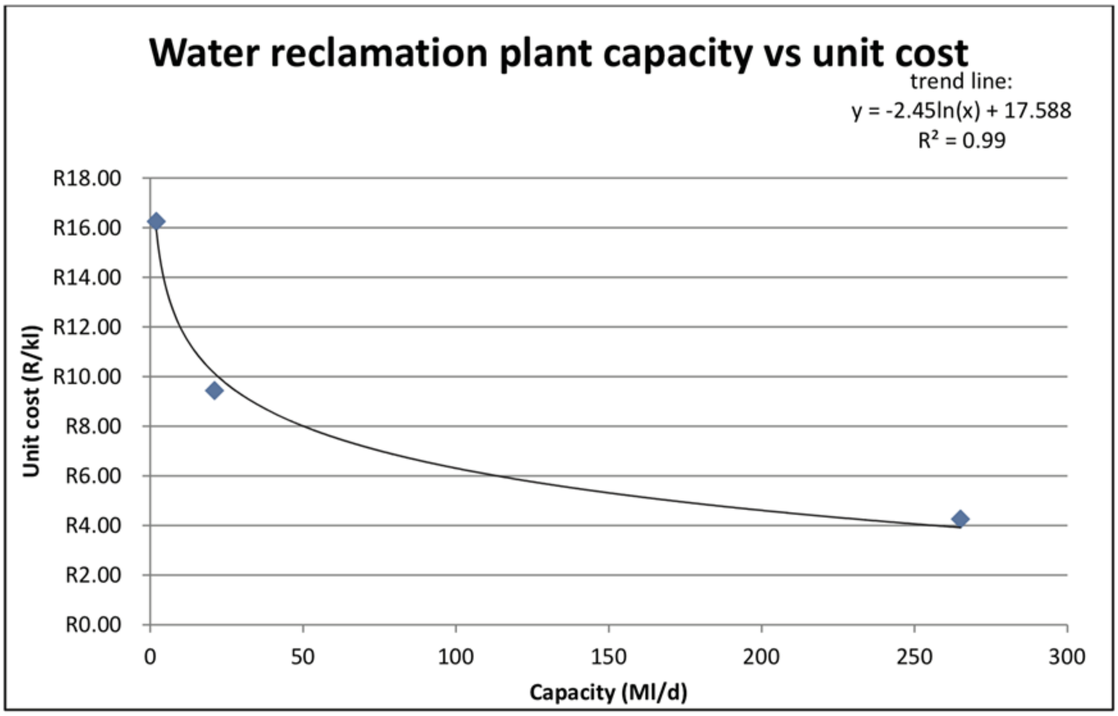


Figure 2-2: Unit Cost Graph for Water Reclamation Plants (Swartz et al., 2014)

2.5.3.2 Operating costs

Operating costs include the following (Swartz *et al.,* 2013):

- 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

From an Operation and Maintenance (O&M) cost perspective, the O&M costs for an ozone-BAF system include labour, power, chemicals (including liquid oxygen), laboratory and monitoring costs, equipment maintenance and repair, residuals management, and other minor costs. RO-based plants have significantly higher O&M costs, primarily due to significantly higher power requirements than the ozone-BAF treatment train, primarily for the high-pressure pumps needed for the RO process. RO-based treatment trains employ mechanically intensive processes, which result in 2.5 times as much electricity as the ozone-BAF plants (average of 3,867 kWh/MG [1.0 kWh/m^3] for RO-based treatment compared to approximately 1,400 kWh/MG [0.37 kWh/m^3] for ozone-BAF treatment) (WRRF, 2014).

Ozone-BAF processes are typically cheaper than RO processes, although the range of plant sizes considered is much larger than the size of typical reclamation plants in Southern Africa.

2.5.3.3 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.

2.5.3.4 General comparison of costs for the different types 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.

An assessment by Sundaram et al. (2010), found that relative to an Ozone-BAF-UV process which had the lowest capital cost, adding RO as a side stream with brine discharge to the ocean increased costs by a factor of 1.4, whilst a RO-based process, with brine discharge to the ocean increased costs by a factor of 2.5. A RO process with ZLD was the most expensive option, confirming earlier assessments that ZLD is unfeasibly expensive.

Table 2-13: Evaporation Ponds and Brine Volumes (Sundaram et al., 2010)

Treatment Process	Relative Capital Cost
Ozone-BAF-UV	1.0 X
Ozone-BAF-UV with side-stream RO and ocean discharge	1.4 X
RO-UV/AOP and ocean discharge	2.5 X
RO-UV/AOP with zero liquid discharge	3.3 X

More recently, the WateReuse Research Foundation (WRRF) conducted a comparison of costing of RO versus non-RO (ozone-BAF) process trains, in particular regarding the added cost of brine disposal required for RO systems (WRRF, 2013). The comparative costing is shown in Table 2-14. Figure 2-3 shows graphs with a comparison of capital and O&M costs for the two treatment configurations.

These assessments by the WRRF show that a RO process with evaporation ponds has a capital cost three times that of an Ozone-BAF process and more than double that of a RO process with brine discharge to the ocean. The Net Present Value (**NPV**) costs largely mirror the capital costs.

Table 2-14: Comparative costing for RO and non-RO (Ozone-BAF) Process Configurations (USEPA, 2017)

Process		Ozone-BAF	Fully advanced treatment with RO Concentrate Disposal		
Cost/Impact			Ocean Outfall	Mechanical Evaporation	Evaporation Ponds
Capital Cost (millions)		$91	$120	$172	$303
Annual O&M Cost (millions)		$4.2	$5.9	$10.9	$6.3
Annual Environmental Costs (millions)		$0.4	$16	$6.3	$2.2
Total TBL NPV (millions)		$173	$267	$533	$512
Cost of Water (including environmental costs)	$/AF	$386	$596	$1,190	$1,143
	$/1000 gal	$1.18	$1.83	$3.65	$3.51
	$/m^3	$0.31	$0.48	$0.96	$0.93
Power Consumption (MWh/year)		4,400	16,000	65,400	22,000
Chemical Consumption (dry tons/year)		1770	1,860	3,020	1,860
Air Emissions (tons/year)	CO_2	2,900	13,400	44,200	17,200
	Other	11	30	150	49

Note: TBL = Triple Bottom Line of financial, social, and environmental costs.

A RO process with evaporation ponds is the most expensive option, in terms of capital costs, and is marginally cheaper on NPV than RO with mechanical evaporation. The latter has the highest power consumption and emissions impact, providing the most expensive water. Whilst much of the energy costs and associated emissions can be attributed to the RO process, mechanical evaporation of the brine is also costly, and will contribute to the high emissions.

Overall, if RO is to be used, the cheapest and lowest-impact option is to dispose of the brine to sea, which is not an option available to Windhoek. On all measures shown, including capital cost, Tiple Bottom Line NPV, power consumption and air emissions, the Ozone-BAF option is more favourable than the RO-based process. Table 2-15 summarises the capital costs for a number of southern African reuse plants, while Table 2-16 shows the capital costs expressed as unit costs in R million per ML reuse plant capacity as well as the operating costs for the plants (R/m^3).

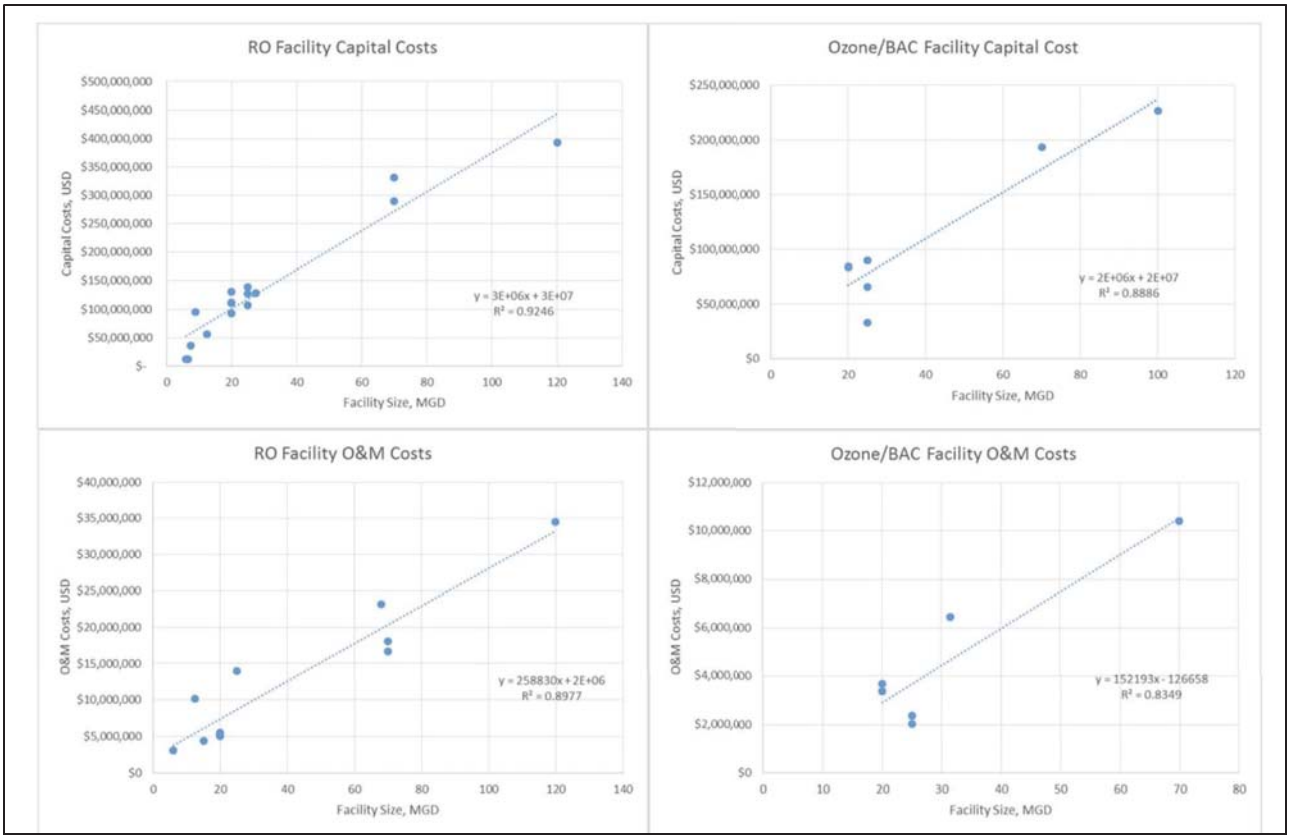


Figure 2-3: Relationship between Plant Capacity and O&M Costs for Full-Scale RO and Ozone-BAF Facilities (NMWRRI, 2017)

Table 2-15: Capital costs for potable reuse plants

Plant	Reuse Type	Process Configuration	Capacity (Mℓ/d)	Year for Costing	Total (R million)	Source / Reference
Paarl WRP (feasibility study)	DPR	UF - RO - UV/H_2O_2 - GAC	10	2017	102.8	C Davids, Lyners WISA symposium 2019
Cape Flats WRP CFA MAR	IPR	Coag - media filtration - O_3-BAF - UVAOP	40	2018	650.3	W&WE
Chapultepec, Mexico	DPR	UF - RO - UV	14.7	2019	196.1	T Fischer, EScience WISA symposium 2019
Stellenbosch DPR Modelling study	DPR		10	2019	346.0	M Raubenheimer, US Masters Thesis
Stellenbosch DPR Modelling study	DPR		20	2019	504.3	M Raubenheimer, US Masters Thesis
Beaufort West	DPR	Sedimentation - media filtration - UF - RO - UVAOP	2	2010 2019	23.7 38.4	M Raubenheimer, US Masters Thesis
New Goreangab WRP	DPR	Coag - DAF - media filtration - O_3 - BAC - GAC - UF - Cl_2	21	2001 2019	108.6 284.6	M Raubenheimer, US Masters Thesis
Zandvliet demonstration plant	DPR	Coag./sedim - media filtration - UF - RO - UVAOP	10	2019	~ 300	P Fourie, Proxa WISA mini-symp, 2019 W vd Merwe, Proxa

Notes: C/F = Coagulation, flocculation. Total costs include civils, preliminary and general costs, etc.

Table 2-16: Capital costs per ML plant capacity and operating costs for potable reuse plants

Plant	Config. Type	Process Config.	Capacity (Mℓ/d)	Year for Costing	CAPEX		OPEX	Source / Reference
					Total capital cost (Rm)	Capital cost/ML/d (Rm/ML)	O&M cost (R/kL) (incl amort)	
Paarl WRP (feasibility study)	RO	UF - RO - UV/H_2O_2 - GAC	10	2017	102.8	10.2	9.73	C Davids, Lyners WISA symposium 2019
Cape Flats WRP CFA MAR	O_3-BAF	Coag - media filtration - O_3-BAF - UVAOP	40	2018	650.3	23.65	10	W&WE
Chapultepec, Mexico	RO	UF - RO - UV	14.7	2019	196.1	13.34	7.94	T Fischer, Escience WISA symposium 2019
Stellenbosch DPR Modelling study	RO		10	2019	346	34.6		M Raubenheimer, US Masters Thesis
Stellenbosch DPR Modelling study	RO		20	2019	504.3	25.21		M Raubenheimer, US Masters Thesis
Beaufort West	RO	Sedimentation - media filtration - UF - RO - UVAOP	2	2010 2019	23.7 38.5	11.9 19.23	~ 7.78	M Raubenheimer, US Masters Thesis WRC Report TT 638/15
New Goreangab WRP	O_3-BAF	Coag - DAF - media filtration - O_3 - BAC - GAC - UF - Cl_2	21	2001 2019	108.6 284.6	13.55	5.47	M Raubenheimer, US Masters Thesis WRC Report TT 638/15
Zandvliet demonstration plant	RO	Coag./sedim - media filtration - UF - RO - UVAOP	10	2019	~ 300	30	5.00-8.00	P Fourie, Proxa WISA mini-symp, 2019 W vd Merwe, Proxa
USA comparative costing (from table and graphs above) (exchange rate distorts figures)	RO	UF-RO	20 (5.2 MGD)		725	36.25	8.94	WRRF, 2013
	O_3-BAF	O_3-BAF	20 (5.2 MGD)		667 (extra-polated)	33.35	Out of graph range, but << RO	

2.5.4 Costing models

The Water Reuse Costing Model (REUSECOST)

The WRC Water Reuse Costing Model (referred to as REUSECOST) was compiled as part of WRC project "*Guidelines for the Selection and Costing of Water Reclamation and Reuse Systems*" (WRC Report No. 2119/1/14 by Swartz *et al.,* 2014).

The overall objective of the decision-support model and costing guidelines were 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 and social and cultural aspects. More specifically, the aims of the model were to collate existing expertise and information for planning and implementation of potable water supply and direct potable re-use projects, and to provide decision-support guidelines and methodologies in the form of a spreadsheet-based, multi-criteria decision support model. The intention was that this would enable municipalities to identify, evaluate, compare, and select appropriate options for water reclamation and reuse.

2.5.4.1 Structure of REUSECOST

The structure of REUSECOST is shown in Figure 2-4.

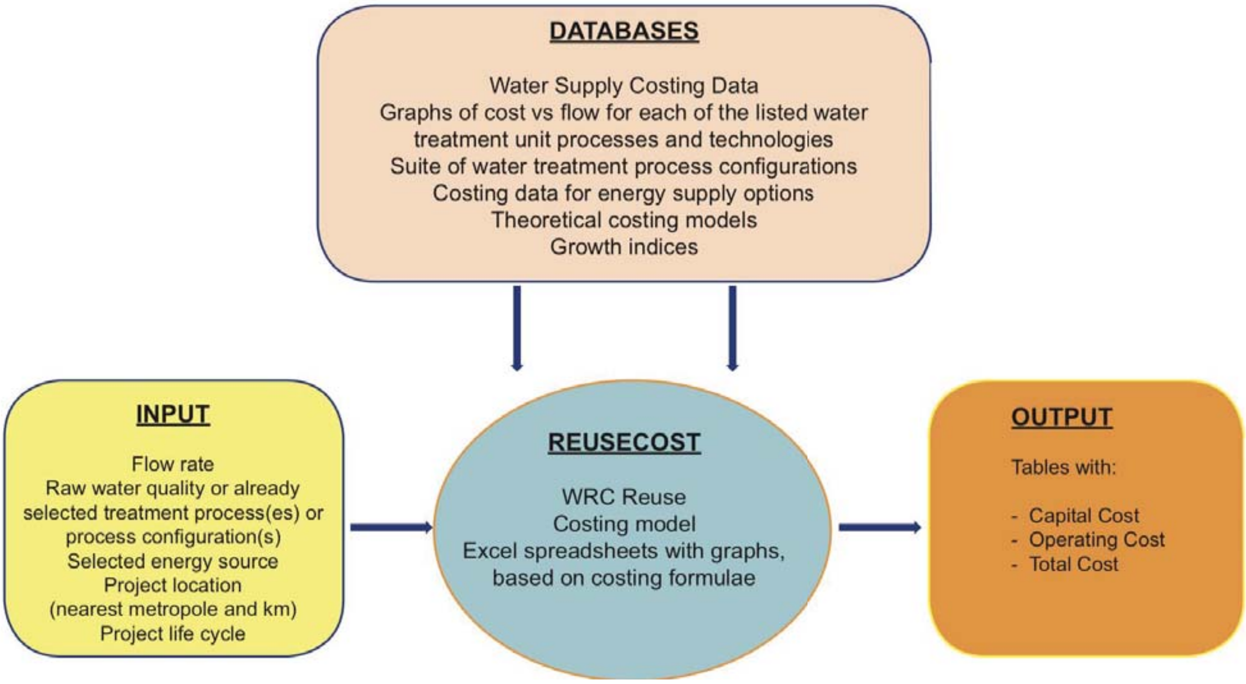


Figure 2-4: The REUSECOST decision-support and costing model

2.5.4.2 Features of the REUSECOST model

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 the WRC report.
- 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.

2.5.4.3 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 endeavoured to ensure that data-points are not centred on one size (capacity).

2.5.4.4 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.

2.5.4.5 Using the REUSECOST model

To apply the model for determining the first-order costs of a project, the municipal engineer is referred to the WRC report which contains the costing spreadsheets. The REUSECOST Costing Model is available electronically on a CD in the back-page sleeve of the report. 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).

It is important to note that all costs should be escalated to present cost, as the cost figures in the model are based on 2013/2014 costs.

2.6 POST-TREATMENT PROCESSES FOR RECLAIMED WATER

Because the main treatment barriers in water reuse plants are specifically aimed at removing or reducing the particulate and dissolved substances and chemicals to low levels to ensure that quality of the water will pose no health risk to users of the water, these processes will also remove or reduce to too low a level constituents in the water that is necessary for a healthy (for human consumption) or stable (for distribution to the users) drinking water. This is in particular the case where RO or NF are used as treatment barriers. The result is that some form of post-treatment is required to ensure that the final drinking water is chemically stable and wholesome for human consumption. The post-treatment applied therefore normally consists of chemical conditioning of the water by dosing of chemicals. Blending of the water with other water containing sufficient quantities of the necessary minerals and other constituents is also a form of post-treatment.

Some chemical treatment options for post-treatment are discussed below.

2.6.1 Stabilisation

As mentioned, in instances where RO or NF processes treat reclaimed water, it is often necessary to stabilise the water by remineralisation techniques. RO and NF remove minerals, such as calcium and magnesium, and produce a permeate water with pH often below 6 (EPA, 2017). The resulting product water is extremely corrosive and can cause severe corrosion in metal piping or concrete tanks.

Advanced treated water is stabilized through some combination of decarbonation, or addition of lime, caustic soda, and/or calcium chloride. The stabilization generally targets a Langelier Saturation Index (LSI) near or above zero through the addition of hardness and alkalinity (EPA, 2017). Other stabilization indices, such as the Ryznar Stability Index, can be used in addition to the LSI to determine stabilized water. The following paragraphs provide basic information on processes commonly used for product water stabilization in RO and NF facilities (EPA, 2017).

2.6.1.1 Decarbonation

Often after RO treatment, packed tower aerators are used to remove carbon dioxide and increase the pH of the permeate without the addition of chemicals, or in addition to other chemical usage (EPA, 2017). Decarbonation can be a low cost means of increasing the pH when sufficient carbonate alkalinity is present. However, removal of carbon dioxide does not impact the total alkalinity of the water and, in some cases, can increase the amount of chemicals required to reach a stabilised LSI value (EPA, 2017). Decarbonation can provide advantages if other dissolved gases or volatile chemicals, such as trihalomethanes, hydrogen sulfide, methane, or radon, are present in the water (EPA, 2017).

2.6.1.2 Sodium Hydroxide

Sodium hydroxide (caustic soda) is the most common chemical used for pH adjustment after RO (EPA, 2017). The addition of sodium hydroxide will increase the total alkalinity and pH of the water, increasing the LSI and producing a more stable product water. Because RO permeate is generally low in hardness as well as alkalinity, sodium hydroxide alone is rarely sufficient for producing a stable product water (EPA, 2017).

2.6.1.3 Lime Stabilization

Calcium oxide (lime) can be used for product water stabilisation, adding alkalinity, hardness, and pH to the water with a single chemical (EPA, 2017). Lime is mostly difficult to work with; this is due to clumping in the dry feed equipment, dust accumulation, and turbidity carryover in the water. While lime is often the lowest cost means of stabilizing RO product water, many utilities choose to avoid it due to its operational challenges (EPA, 2017).

2.6.1.4 Calcium Chloride

Calcium chloride can add hardness to water, but it does not impact the pH or alkalinity. For this reason, calcium chloride needs to be used in conjunction with another chemical, such as sodium hydroxide. Calcium chloride can be purchased in liquid form, and it does not cause turbidity when added to water. While it is costlier than lime, some utilities have chosen to use calcium chloride and caustic soda for stabilization to avoid the operational challenges associated with lime (EPA, 2017).

2.6.2 Blending

Blending with fresh surface waters is an additional way to stabilise water following RO or NF treatment. Mixing the treated water with water of appropriate quality can restore hardness and alkalinity levels.

In DPR schemes, blending could occur at different steps throughout the treatment process; it could occur before entry into an engineered storage buffer, after storage in the buffer, or before introduction into the potable water system (WRRF, 2011a). Blending advanced treated wastewater with conventional source water prior to consumption may or may not occur within a given DPR scheme; this depends on site-specific constraints (Khan, 2013).

2.7 NATURAL SYSTEMS FOR WATER RECLAMATION

In South Africa, where more than 60% of the population live in urban areas water scarcity is a major concern and the potential use of all water resources should be considered. These include not only conventional primary sources, but also water that has already been polluted through contact with human activity. Such polluted sources include wastewater treatment plant effluent streams as well as stormwater runoff. Effluent streams, though treated to levels acceptable for release into the natural environment, require further treatment for reclamation for direct human use. Additionally, and contrary to popular belief, rainwater can also contain many pollutants and must similarly be treated before use. Typical components of concern are pathogens, organics, nutrients (Nitrogen and Phosphorus), ammonia, heavy metals and synthetic chemicals.

Natural Systems, engineered for application to treatment plant effluent or stormwater runoff treatment, can be used to reduce components of concern. The levels of component reduction depend on the component types and concentrations, as well as the chosen treatment system. The use of water reclaimed by these means depend on the concentrations of components in the final product and include application to urban non-potable settings where access is restricted, urban non-potable settings where access is not restricted, agricultural reuse (Mihelcic & Zimmerman, 2014) as well as ground water recharge and industrial applications (Metcalf & Eddy, 2004).

Here the term "Natural System" refers to constructed structures that use living processes to treat water. This is akin to the term "Green Infrastructure" that is often used in stormwater management. For treatment plant effluent, natural systems typically refer to stabilization ponds and wetlands. These also comply with the general meaning of Green Infrastructure. Green Infrastructure is defined as "constructed features that use living, natural systems to provide environmental services, such as capturing, cleaning and infiltrating stormwater; creating wildlife habitat; shading and cooling streets and buildings; and calming traffic" (Watershed Management Group, 2012). The practice seeks to implement natural mechanisms using vegetation, filter materials and microbial processes to remediate stormwater in populated areas (Maimone et al., 2011). Natural Systems typically provide passive treatment and have the advantage of lower operating costs because they rely on natural methods for treatment features such as aeration (Mihelcic & Zimmerman, 2014). Similarly, an advantage of Green Infrastructure is that it can be applied to provide a dispersed and passive treatment response to the spatially distributed nature of polluted stormwater runoff (Brink, 2019).

Examples of Natural Systems for treatment plant effluent remediation towards reclamation include facultative lagoons, aerated lagoons, anaerobic ponds, maturation ponds, free water surface flow wetlands, subsurface water flow wetlands as well as algal ponds. Green Infrastructure for stormwater runoff quality improvement towards reclamation include wetland basins and channels, green roofs, raingardens, grass swales and strips, retention and detention ponds as well as plant biofilters. However, there is currently limited local research in this area.

The availability of public open spaces creates an attractive opportunity for municipalities to implement Green Infrastructure (Anderson et al., 2016; Armitage et al., 2014). Where the units are located on a private residence, the homeowner can incorporate the system into their landscape, adding value and diversifying the area. In South Africa, the strategies of sustainable management and Water Sensitive Urban Design (WSUD) are gaining popularity for reducing the impacts associated with polluted runoff in urban areas. This through the establishment of areas that mimic pre-development dynamics, reducing urban flood discharge, increasing infiltration, enhancing water quality and encouraging ecological improvements within urban waterways. WSUD has evolved from the initial linear stormwater management strategies and adopted a holistic management approach of the urban water cycle and its integration into urban design (Wong, 2006). The reader is referred to the Urban Water Management website for further information on South African case studies and resources (see below).

Figure 2-5: Detention Pond in residential areas, Somerset West (2021)

Figure 2-6: Retention Pond in residential area, Somerset West (2021)

Figure 2-7: Plant biofilter experiment, Stellenbosch University (2018)

Figure 2-8: Wetland in residential area, Somerset West (2021)

A possible disadvantage of Natural Systems and Green Infrastructure is that they may require regular maintenance to prevent plant overgrowth and sediment build up; especially when incorporated inside the urban area. Another disadvantage is the system's reliance on water, since the living organisms that they use require it, this within the context of South Africa being a water scarce country. This issue can however be negated by careful design especially in the case of wetlands to ensure they do not dry out and incorporating indigenous plant species that are accustomed to the climatic and weather conditions.

Numerous guidelines exist for the design and implementation of Natural Systems for treatment plant effluent remediation as well as for stormwater treatment Green Infrastructure. However, guidelines for Green Infrastructure are often broadly written without very clear explanation of underlying reasoning. Much has, however, been reported on structure performance and efficiency in removal of various pollutants. An informed trial and error approach may therefore be recommended.

The reader is referred to the following sources for more information and design guidelines:

Lagoons and wetlands for treatment plan effluent remediation

Alley, ER. 2007. Water quality control handbook 2nd edition. McGraw-Hill. pp. 10.72-10.76.

Metcalf & Eddy. 2004. Wastewater Engineering: Treatment and reuse 4rth edition. McGraw-Hill. pp. 840-854, 1345-1438.

Mihelcic RJ, Zimmerman JB. 2014. Environmental Engineering: Fundamentals, sustainability and design. John Wiley&Sons inc. pp. 440-522.

Green Infrastructure

From South Africa:

The University of Cape Town

UCT Urban Water Management: Water Sensitive Design (http://www.uwm.uct.ac.za)

From Australia

Various manuals and websites from different states. Refer to the UCT site above for general WSUD philosophy.

From the United Kingdom

Construction Industry Research Association (CIRIA)

Search "Resources" for The SuDS manual and various free publications on Green Infrastructure (ciria.org)

From the United States of America

The Water Research Foundation

The International Stormwater BMP Database (https://bmpdatabase.org)

The Environmental Protection Agency (EPA) –

National Pollutant Discharge Elimination System (NPDES) (https://www.epa.gov/npdes/national-menu-best-management-practices-bmps-stormwater)

Best Management Practices siting tool (https://www.epa.gov/water-research/best-management-practices-bmps-siting-tool)

Green Infrastructure page (https://www.epa.gov/green-infrastructure)

2.8 REUSE TREATMENT TECHNOLOGY VALIDATION

2.8.1 Validation, research, and development

Validation of treatment technologies is crucial. Schemes cannot be developed and introduced without conclusive evidence that they will provide safe drinking water. Validation involves evaluating available scientific and technical information (including historical data and operational experience) and, where necessary, undertaking investigations, including performance monitoring and water quality testing. Technology validation has the following objectives:

- Greater understanding of sources and potential hazards
- Validation of the operational effectiveness of treatment processes, including new products.
- Review of the operation of environmental barriers
- Investigation of production of chemical by-products
- Development of analytical procedures
- Development of new processes and improvement of efficiency in existing processes
- Studying emerging water-quality issues
- Understanding synergistic additive and antagonistic effects of chemicals
- Understanding interactions of recycled water with receiving waters
- Assessment of epidemiological effects of recycled water schemes

- Composition of treatment-waste streams and prevention of environmental impacts.

Partnerships and industry-wide cooperation in research and development can be a cost-effective way to address issues associated with drinking water augmentation. Opportunities for such collaboration should be identified with partnership organisations, including water (e.g. DWS), health, environment, and natural resource management agencies; industry associations; other recycled water suppliers; university departments; and other research organisations and community groups.

2.8.2 Validate processes and procedures to ensure they control hazards effectively.

Validation involves the assessment of processes as a whole, as well as the assessment of individual components, such as process-specific operational procedures, operational parameters, critical limits, target criteria and corrective actions. Validation needs to deal with selection of operational parameters, critical limits, and target criteria, to ensure that the parameters are appropriate for the hazards in question and that the limits define acceptable performance in terms of inactivation or reduction of hazards. This is particularly important where surrogates are used. For example, if total organic carbon is used as a surrogate for a membrane performance, validation is required to show that compliance with the critical limit means that the required level of hazard reduction is achieved.

Variation in performance of control measures, and of uncertainties and variations in validation testing, need to be considered. Safety margins need to be applied to account for these potential uncertainties.

2.8.3 Validate reliability and consistency.

Validation of short-term performance is not sufficient. Drinking water augmentation schemes need to maintain high levels of performance over many years. Validation needs to consider reliability and consistency of performance.

2.8.4 Revalidation of processes

Processes need to be revalidated when variations occur that may affect performance of processes, for example, if:

- hazard concentrations increase.
- an emerging hazard is identified.
- systematic failures are detected.
- catchment inputs change (e.g. increased flows)
- process configuration, operational parameters and mode of operation is varied.
- upstream treatment processes are changed (e.g. primary, or secondary treatment)
- dilution rates or detention times in receiving water and storages change (e.g. increased demand, drought, and changes to peak flows)

Any new processes need to be tested using bench-top, pilot-scale or full-scale experimental studies, to confirm that the required results are produced under conditions specific to the individual water-supply system.

2.9 EXPERT ADVISORY PANEL

It is widely recognised that the establishment of expert advisory panels for water reuse projects contributes to ensuring successful planning, implementation, and operation of these projects. The section below provides some salient points toward the establishment and management of expert advisory panels (Swartz, 2019).

2.9.1 Need for an Advisory Panel for desalination and reuse

The implementation of desalination and reuse projects is relatively new in South Africa, with no long track record of experience. Together with the fact that there is not yet a regulatory framework for reuse, there is uncertainty regarding interpretation of new and emerging water quality aspects. Should SANS 241 be used, or the WHO guidelines for water reuse, or a combination of the two (and perhaps other international guidelines and/or standards)? In addition, the responsibilities of different contractual parties for monitoring of water quality are not always clear.

2.9.2 Aims of the Panel

The main aim of the Panel will be to provide independent scientific assessment of the following:

- Available raw water quality data
- Seawater quality (salinity, turbidity, CECs, algal blooms, microbiological water quality, other)
- Contaminants of emerging concern
- Disinfection by-products
- Waste-streams (including in particular brine streams)
- Water quality monitoring requirements

This is normally achieved by consideration and/or application of:

- Water Safety Plans
- Incident Management Protocols
- Sampling programs
- Pilot-plant monitoring
- Water quality in reticulation networks
- Environmental approvals required.
- Treatment process evaluation (advisory)
- Validation of technologies

2.9.3 Proposed structure

Based on panels that have been operating successfully on a global scale, the following structural aspects are proposed:

- Panel of 8-10 independent water sector experts
- Convened and facilitated by the Desalination and Reuse Community of Practice
- Independent Chairperson
- Should have a constitution.
- Findings and recommendations should be binding and have legal status (e.g. in arbitration)
- Meets when required on project basis.
- All inputs by experts are done on a voluntary basis.

2.9.4 Tasks of the Panel

- Provide independent review and critical input on the scope and direction of desalination and reuse projects.
- Review desalination and reuse water quality programs
- Present recommendations and comments to the Project Team (client; regulators; engineers; contractors)
- Provide input on the system feasibility.
- Establish project battery limits (various responsibilities)
- Give advice on public outreach and communication.

PART 3

OPERATIONS AND MAINTENANCE ASPECTS

PART 3: OPERATIONS AND MAINTENANCE ASPECTS

3.1 INTRODUCTION

This part of the guide considers the operational and maintenance requirements of water reuse projects, and provides information and guidelines on relevant aspects in striving towards optimised treatment systems.

3.2 OPERATIONAL ASPECTS

3.2.1 Operations management

3.2.1.1 Introduction

In developing an operational monitoring program, the following are important considerations in reclamation and reuse plants (Swartz *et al.,* 2013):

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

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

Preventative and regular maintenance is critical at water reuse plants, particularly to ensure good performance of the treatment barriers. The materials of construction, preventative maintenance procedures and protocols are just as critical to the sustainable operation and maintainability of water reuse plants, as with desalination plants. A detailed operational and maintenance schedule should be put in place from plant start-up. Knowledge transfer between the plant designer and plant operator is essential.

3.2.1.2 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
- normal operating procedures (day-to-day)
- cleaning procedures (for separation processes, filters, membranes, and the plant as a whole)
- process control and quality control procedures (monitoring)
- troubleshooting
- summary of technical specifications
- drawings
- safety aspects

3.2.2 Operational skills requirements

The importance of process controller capability is often underestimated. Establishment of a drinking water augmentation scheme requires construction of recycled water systems and design of comprehensive risk management systems. However, effective ongoing implementation over the lifetime of schemes relies on the skills, awareness and commitment of operators and contractors, who need to be trained to maintain a precautionary approach. This training needs to include the need to react to any faults or changes in performance, and to report these events and any doubts about performance of any action or process that might affect recycled water quality. New employees need to receive sufficient training before being given responsibility for key processes.

Organisations that operate drinking water augmentation schemes are responsible for ensuring that all personnel with responsibilities related to the scheme have sufficient training, qualifications, and expertise to undertake their tasks. Overall operation of treatment trains — including the performance of operators and contractors — needs to be supervised by managers with appropriate engineering and quality assurance expertise.

The following essential topics for DPR process controller knowledge and training are recommended, followed by topic areas on treatment processes (adapted from CUWA, 2016):

- Wastewater treatment processes
- Water treatment processes
- Drinking water regulatory requirements
- Wastewater regulatory requirements
- Wastewater treatment plant operation and maintenance
- Laboratory procedures
- Distribution system operation and maintenance
- Source water
- Administrative duties (including reporting)
- Collection system operation and maintenance

Treatment process to be included in the process controller knowledge requirements.

- Water quality (groundwater, surface water, raw water storage)
- Coagulation, flocculation, sedimentation
- Filtration
- Disinfection
- Demineralisation (RO, NF and Ion Exchange treatment)
- Corrosion control
- Iron and manganese removal
- Softening
- Wastewater treatment technologies
- Best available technology (BAT)

Supporting skills and capabilities:

- Mathematics
- Communication
- Management of instruments and meters
- SCADA, reporting and alarm management
- Operational interfaces
- Critical control points and the HACCP Process

Process controllers need to be aware of the potential consequences of system failure, and of how decisions can affect public and environmental health. Ensure process controllers maintain appropriate experience and qualifications. All personnel involved in the operation of a recycled water system need to have the appropriate skills and training to undertake their responsibilities. Process controllers should be appropriately skilled and trained in the management and operation of recycled water supply systems because their actions can have a major impact on water quality, and on public and environmental health.

3.3 MAINTENANCE ASPECTS

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. This is of particular importance in potable reuse systems where it is crucial to maintain the treatment barriers in good and high-performance condition.

3.3.1 Maintenance programs

Proper mechanical maintenance of equipment contributes to the efficiency and life span of the equipment. The process controller should do a routine check of mechanical instruments for problems such as leaks, overheating, vibrations, noise, or any other abnormalities. The process controller should check that equipment is free of obstruction, properly aligned and moving at normal speed.

3.3.2 Preventative maintenance

In order to minimise mechanical equipment breakdowns, it is necessary to carry out preventative maintenance rather than corrective maintenance, which involves repairing and replacing damaged parts. This type of maintenance combines both the manufacturer's recommendations and the process controllers' experience acquired over a period.

The efficiency of the process controllers could be maximised by keeping charts that show equipment maintenance requirements (i.e. what and when maintenance is to be done) thereby prioritising work to be done. A copy chart can be kept at a convenient spot for the process controller and his assistants.

Process controllers should be careful not to replace parts that are in good condition, just to carry out preventative maintenance. This implies that they must avoid replacing equipment parts without proper inspection.

3.3.3 Asset management

Asset Management is an integrated process of decision-making, planning and control over the acquisition, use, safeguarding and disposal of assets to maximise their service delivery potential and benefits, and to minimise their related risks and costs over their entire life (DWAF, 2007). It includes operation and maintenance, repair, rehabilitation, and replacement of infrastructure. It involves applying the functions of management specifically to the care of assets, to ensure their optimum and sustained functioning during their design life span (or longer, if possible). These functions are planning (including budgeting), organising work activities, and controlling by monitoring, evaluating, and reporting.

Reporting ensures accountability by technical departments to municipal managers and Councils, and to relevant provincial and national departments, to ensure compliance with legislation and regulations, and that assets are properly maintained.

Asset management involves the following:

- Asset registration that provides essential information on all assets, including their condition and maintenance needs
- An asset management policy
- Planning and budgeting over the full life cycle of assets
- Asset management activities, including O&M, rehabilitation, and replacement.
- Monitoring, assessing, and reporting, which feed into the asset register/information system.
- Both the asset management information system and asset management plans need to be regularly updated in order to remain relevant and reflect current infrastructure condition
- Improvements due to maintenance, rehabilitation, or replacement
- New assets
- Disposal of assets.

3.4 GUIDELINES AND PROCEDURES FOR MONITORING AND MANAGEMENT OF WATER QUALITY IN WATER REUSE, RECLAMATION AND RECOVERY PLANTS

The exponential growth of new unknown chemicals is of great concern and needs to be addressed in the process design of a water reuse treatment plant. Most chemicals, with a few exceptions, are only a health concern after long-term exposure. The sources of the chemical constituents may be from naturally occurring geology (soil and rocks); industrial, human, and agricultural activities; products used in water treatment or by-products of water treatment; and toxins produced by blue-green algae in eutrophic dams and lakes. Guideline development for chemical contaminants normally takes one of two approaches, depending on the type of adverse health effects expected. These are classified as either threshold or non-threshold effects (Swartz *et al.,* 2015; Swartz *et al.,* 2018).

3.4.1 Monitoring programmes

3.4.1.1 Definitions of monitoring terminology

Drinking water quality monitoring

This monitoring should assure the safety of drinking water for public health protection. To achieve this, the monitoring should be strategic, system-specific, and evidence-based, having the ability to detect contaminated drinking water in order to effectively inform about risk. The collected data should increase the understanding of the entire water supply system and provide improved insight on hazards, treatment performance and the overall vulnerability of the system. It should define analytical methods, detection limits, quality assurance and control methods and frequencies of sampling.

Catchment monitoring

This monitoring aims at understanding the continuous challenge of changing water quality in the water source due to two contributing mechanisms in the catchment, namely (1) changes in the natural hydrological cycle, and (2) activities of society. It also includes the contamination challenges caused by capturing normal operation, seasonal variation, and individual events.

Operational monitoring

Operational monitoring accesses and confirms the performance of individual treatment plant barriers against specified target values. Non-compliance with target values should trigger short term corrective action to protect product water quality in order to prevent unacceptable risk to human health. It aims at understanding the treatment performance. Operational control monitoring measures a few parameters, but at a high frequency. Typical parameters that are used for operational control monitoring include functional parameters like temperature, pressure, differential pressure, and flow rate; and quality parameters like pH, turbidity, electric conductivity and UV254 (surrogate measurement for organic matter content). Ideally the operational control of water reclamation plants will make use of constant feedback from the treatment units and will require online sensor instruments that can produce parameter values at a sufficiently high frequency.

Compliance monitoring

This requires a large number of quality parameters to be measured once a week or once a month. The results are then compared with the standards, guidelines, and regulations to determine whether the water quality of the final product water comply or not.

Validation monitoring, research, and development

Validation of preventive measures (barriers) is crucial. Schemes cannot be developed and introduced without conclusive evidence that it will provide safe drinking water. Validation involves evaluating available scientific and technical information (including historical data and operational experience) and, where necessary, undertaking investigations, including performance monitoring and water quality testing.

Verification monitoring

This monitoring assesses the effectiveness of the recycled water system. It includes compliance testing of treated water end product, the mix of different water sources, and storage in reservoirs (delivery into distribution system). It judges the treated drinking water quality by capturing normal operation, individual events, and compliance to accepted guideline values or standards.

Verification provides:

- confidence for users of recycled water and regulators in the quality of the water supplied and the functionality of the system as a whole.
- confidence that environmental targets are being achieved.
- an indication of problems, and a trigger for corrective actions, or for incident and emergency responses

Water quality assurance, consumer satisfaction monitoring

It is a surveillance mechanism providing timely information on potential problems that have gone unidentified through monitoring drinking water quality. It should include a consumer complaints program which offers the opportunity for early recognition of contamination to initiate corrective action should have close links to operations for immediate response. It judges the treated drinking water quality by capturing normal operation, individual events, and compliance to accepted guideline values or standards.

3.4.1.2 Methods of monitoring

Real-time versus off-line monitoring

There are two basic methods of monitoring, namely real-time and off-line monitoring. Real-time monitoring is done on-line and typically includes for water quality parameters such as turbidity, pH, electrical conductivity (surrogate for TDS), UV absorbance and TOC, whereas off-line monitoring is conducted in laboratory to verify measurements made by real-time instruments and for detailed characterisation of individual of different classes of constituents (many of which cannot be measured in real-time).

Indicators and surrogates for monitoring

Indicator compounds are used to predict the presence or absence of other constituents provided that the indicator is removed by similar mechanisms and to the same degree as the other constituents. A surrogate compound is a bulk parameter that can serve as a measure of performance for individual processes. It is site specific and needs to be established for individual treatment options.

On-line sensors

The use of on-line sensors in order to have high parameter measurement frequencies available is essential to operational control monitoring. Unfortunately, there are many expenses that must be considered when on-line sensors are implemented at the monitoring system. Once the monitoring system starts collecting data, the data must be logged and interpreted. Based on the interpretation, decisions need to be made and actions need to be taken. In most cases, an automated computerised data collection and management system is installed with the monitoring equipment. One example is the supervisory control and data acquisition (SCADA) system that is typically integrated with the monitoring system of a plant. For more information on on-line sensors, the reader is referred to the compendium on water sensors that were compiled for the Global Water Research Collection through a Water Research Commission project (Swartz, 2014).

3.4.1.3 Raw water monitoring

Catchment monitoring and source water monitoring.

Table 3-1 shows proposed monitoring programmes for the intake water feeding the water reuse plant.

Table 3-1: Proposed water reclamation plant intake water monitoring programme (Swartz *et al.,* 2015)

Parameter group	Frequency	Sample
Physical and organoleptic: Turbidity, pH, Conductivity, Colour, Alkalinity, Hardness	Weekly	Composite
Inorganic - anions: Cl, SO_4, F, Br, NO_3, NO_2, PO_4	Monthly	Composite
Inorganic - cations non-metals: K, Na, Ca, Mg, NH_3,	Monthly	Composite
Inorganic - cations metals: Fe, Mn, Al (operational)	Weekly	Composite
Inorganic - cations metals: Ni, Cd, Hg, Pb, Zn…others	Monthly	Composite
Organics: DOC, COD, UV_{254}, Phenol, Formaldehyde	Weekly	Composite
Organics: THM, THMFP, AOX	Monthly	Composite
Nutrients: TKN, PO_4, NH_3, NO_3, NO_2	Weekly	Composite
Solids: TDS, TSS, TS, TFS, TVS, SS	Weekly	Composite
Microbiology: HPC, Total coliform, Faecal coliform, Faecal streptococci, Pseudomonas aeroginosa, Clostridium (spores, viable)	Weekly	Grab
Virology: Somatic Coliphage	Weekly	Grab
Virology: Virus CPE+PCR	Weekly	On-Line Concentration

Parameter group	Frequency	Sample
Biology: Algae, [Toxins, Geosmin, 2MIB #1]	Weekly	Grab
Biology: Chlorophyll	Weekly	Grab
Biology: *Giardia, Cryptosporidium*	Weekly	On-Line Concentration
Disinfection (residuals): Free + Total CL_2, Ozone	Weekly	Grab
Disinfection by-products: THM, BrO_3	Weekly	Composite
Toxicity (acute): Daphnia, Bacterial growth, Urease enzyme	Quarterly	Composite
Mutagenicity (chronic): Ames Salmonella (S98+S100)	Quarterly	Composite
Medical substances: PCPs, etc. #2	Quarterly	Composite
Estrogenic substances: Estrone, Estradiol	Quarterly	Composite
Organic Pollution Profile #2	Annually	Composite
Plant and system performance: Isotherms, Beaker settling tests, Sieve analysis, Lime test, Settling tests, AOC, BDOC #3		
Bio monitoring: Fish bio monitoring and others	Daily	On-Line
On-line Instrumentation: pH, Turbidity/TSS, Cond, Temp, DOC/TOC, ORP, NO3/NO2, NH4, Free Cl_2	Daily	On-Line
#1 to be tested only when incident occurs, #2 program determined by specialist team, #3 only done when required		

3.4.2 Management of incidents and emergencies

Continuous performance and compliance with targets should always be the goal of any water recycling scheme, but it is unrealistic and potentially dangerous to expect that faults and incidents will not occur. In most cases, considered, controlled and timely responses will prevent such events from posing a risk to public health or requiring public notification.

Protocols need to be established for dealing with identifiable events such as power outage, equipment breakdown, exceedance of monitoring criteria and consumer dissatisfaction. Such responses protect public and environmental health and help to maintain the supplier's reputation and confidence among users of recycled water. Some events cannot be anticipated. Therefore, utilities must 'expect the unexpected'. Where such incidents occur, the organisation must be able to adapt to the circumstances and respond constructively and efficiently.

Potential hazards and events that can lead to emergency situations or incident investigations include the following:

- Non-conformance with critical limits, guideline values and other requirements
- Accidents that increase levels of contaminants or cause failure of treatment systems (e.g. spills in catchments, illegal discharges into collection systems and incorrect dosing of chemicals)
- Equipment breakdown and mechanical failure

- Prolonged power outages
- Extreme weather events (e.g. flash flooding and cyclones)
- Natural disasters (e.g. fire, earthquakes, and lightning damage to electrical equipment)
- Human actions (e.g. serious error, sabotage and strikes)
- Cyanobacteria blooms in storages or waterways
- Illegal or accidental cross connections
- Kills of fish or other aquatic life in receiving waters.

The immediate questions asked when an incident is communicated to the public are:

- What happened?
- Why did it happen?
- What are the impacts?
- When was it detected?

These questions need to be dealt with openly and with as much clarity as possible. Gathering information to include in answers is important but cannot be allowed to delay communication. Telling stakeholders that they have been exposed to a risk that was detected days or even many hours ago is unacceptable and will immediately undermine confidence.

Incident management of drinking water quality failures

According to SANS 241 of 2015, when a result from a drinking water sample exceeds the numerical limits in tables 1 or 2 of SANS 241-1:2015, further investigation and corrective action are required. The adverse risk to consumers increases with an increased deviation of the result from the numerical limits listed in SANS 241-1. The nature and urgency of the corrective actions required shall be guided by the impact of the non-compliant determinand(s).

Microbiological determinands

Remedial action and non-routine follow-up sampling are required for any acute health determinand that exceeds the numerical limits specified in table 1 of SANS 241-1:2015. A resolution to the problem shall be implemented in the shortest time. The increased sampling frequency shall continue until such time as results are compliant. The water safety plan shall include or refer to an incident management protocol for the management of drinking water quality failures.

Chemical, physical, aesthetic, and operational determinands

Remedial action and non-routine follow-up sampling are required for any acute or chronic health chemical determinand that exceeds the numerical limits specified in table 2 of SANS 241-1:2015. While non-compliance with the physical, operational, and aesthetic numerical limits does not necessarily imply that the water is unacceptable for consumption, it does indicate potential shortcomings that require resampling and implementation of corrective action in the treatment and distribution processes.

PART 4

MANAGEMENT OF WASTES AND RESOURCE RECOVERY

PART 4: MANAGEMENT OF WASTES AND RESOURCE RECOVERY

4.1 MANAGEMENT OF PROCESS RESIDUALS (WASTE STREAMS)

4.1.1 Residuals from a reuse plant

The residuals resulting from a reuse plant treating secondary treated wastewater will depend on the combination of processes employed for treatment. Typical residuals can include:

- Screenings from pre-screening facilities
- Backwash solids from biologically active carbon filters
- Periodic backwash stream from MF and UF processes
- Backwash solids from the cartridge filters
- RO concentrate, where RO is used in the process (the brine stream).

4.1.2 Management of Non-RO Concentrate Residuals

The management of non-RO concentrate residuals is considered separately from the management of RO concentrate because these management methods differ significantly.

4.1.2.1 Filter Screenings

The most common methods of managing screenings (Tchobanoglous et al., 2014) include:

- Removal by hauling to disposal areas (i.e. landfills), including co-disposal with municipal solid wastes
- Incineration either alone or in combination with sludge and grit (for large installations only)
- Mixing and processing with thickened process solids
- Discharge to grinders or macerators, where the screenings are ground and returned to the wastewater.

4.1.2.2 Reject Streams and Backwash Water

Where the advanced water treatment or reuse plant is located near the wastewater treatment plant (WWTP), reject streams and backwash water are returned directly to the WWTP. Reject streams are often recycled to the inlet of the reuse plant for reprocessing. Where the DPR plant is located some distance away from the WWTP, these liquid streams are discharged to the wastewater collection system.

4.1.2.3 Management of RO Concentrate

Where RO is to be used, the management of the RO concentrate is a major consideration, especially for inland locations. RO concentrate treatment and disposal options are considered in the following sections.

The nature of the brine or concentrate is site- and process-specific, being directly related to the quality of the feedwater, the desalination technology used, the rate of recovery and the chemical additives used (Ahmed et al., 2000 and Mickley, 2009). Some common characteristics of the brine include (Mickley, 2009):

- A higher salinity than that of the feedwater

- A higher concentration of most of the feedwater constituents
- In addition to the (concentrated) quality of the feedwater, the brine contains chemicals added during the treatment process, including (dependant on the process) coagulants and flocculants, pH control chemicals, acid, anti-scalants, chlorine, decholorinating species, membrane cleaning compounds and other residual chemicals (also Van Niekerk, 2012).

The primary challenge associated with- and often the limiting factor on inland RO-based water treatment, is determining the best solution for brine management, given the nature of the brine and the limited options which may be available for disposal thereof (after Tinos et al., 2012 and Fergus and Page, n.d.). In particular, the environmental concerns associated with brine discharge relate to the increased salinity of the concentrate, the increased concentrations of species present in the raw water and the nature and concentrations of the process-added chemicals (Mickley, 2009).

4.2 BRINE MANAGEMENT OPTIONS

4.2.1 Types of Management or Disposal Options

There are a number of "conventional" and "newer" options available for the management or disposal of RO brine. Costs can play an important role in the selection of the brine management / disposal method (Ahmed et al., 2000), which depends on a number of factors including the following (Ahmed et al., 2000 and Mickley, 2009):

- The volume and characteristics of the brine, including the salinity thereof
- The level of treatment prior to disposal
- The nature of the receiving environment, including hydrogeology, geographics, climate and topography
- The availability and cost of land
- Conveyance requirements and costs
- Regulations and permitting requirements
- Public health and perception (concern)
- Recovery of as much water as possible
- Costs – both capital and operating.

Options for the inland management / disposal of brine can broadly be listed as follows (after Mickley, 2009, Van Niekerk, 2012 and Tinos et al., 2012):

1 Conventional disposal:
   a. Ocean outfall
   b. Surface water discharge
   c. Disposal to the sewerage network and wastewater treatment plant
   d. Deep well injection
   e. Land application (irrigation, percolation, infiltration, etc.)
   f. Evaporation ponds
   g. Landfill

2 Non-conventional disposal or management options

    a. Evaporation shed (small, covered but otherwise open-air enclosure holding the concentrate) or an advanced solar dryer
    b. Low pressure RO at a WWTP as a polishing step
    c. Wind-Aided Intensified eVaporation (**WAIV**) processes
    d. Evaporators / Crystallisers
    e. Solar gradient ponds
    f. Electrodialysis reversal
3. Beneficial use options: These include options such as solar ponds, cooling water, dust control, etc.
4. High recovery treatment of concentrate:
    a. Crystallisation to solids for landfill
    b. Solidification of high solids brine for landfill
    c. Thermal brine concentration
    d. Spray dryer
    e. Second pass and kidney systems (multi-stage RO) for higher recovery rates
    f. Forward osmosis
    g. High Efficiency Reverse Osmosis (HERO^{TM})
    h. Pulse Flow Reverse Osmosis (PFRO)
    i. Vibratory Shear Enhanced Processing (VSEP)
    j. Chemical softening and secondary desalting
5. Selective salt recovery: Harvesting individual salts for beneficial use and sale
6. Combinations of the above.

4.2.2 Conventional Brine Disposal Options

4.2.2.1 Disposal to surface water: coastal plants

For coastal and near-coastal locations, ocean disposal through deep water outfalls is the method used, which is not a possible option for Windhoek.

4.2.2.2 Disposal to surface water: inland plants

The disposal to inland surface water bodies which are not salty, such as lakes and rivers, makes use of dilution of the brine concentrate (Tinos et al., 2012) and requires a suitable receiving body of moving water with lower TDS than that of the brine relatively nearby (Mickley, 2009).

4.2.2.3 Disposal to Sewer

Small membrane desalination plants elsewhere discharge brine into the sewerage network which has the benefit of diluting the brine (Tinos et al., 2012) and lowering the BOD of the domestic sewage effluent (Mickley, 2009). This will however increase the TDS of the wastewater which may negatively impact on the microorganisms in the WWTP (Tinos et al., 2012) and may cause the resulting treated effluent to not comply with the discharge standards.

4.2.2.4 Deep Well Injection

This disposal method entails the injection of brine into deep and consolidated aquifers which contain non-drinking water where the liquid waste is ultimately stored in subsurface geological formations (Tinos et al., 2012). The deep well aquifer must be able to receive concentrate over the lifespan of the desalination plant (Mickley, 2009) and is only possible where deep aquifers exist.

4.2.2.5 *Disposal via Land Application*

The disposal of brine via land application can include irrigation spraying of lawns, parks, golf courses, etc., as well as percolation ponds and infiltration basins (Mickley, 2009). This method of disposal is considered to be not environmentally responsible.

4.2.2.6 *Evaporation Ponds*

Evaporation ponds have been used over the centuries to remove water from saline solution, using the energy of the sun and wind to evaporate the water, leaving behind deposits of salts in crystallising ponds. Such ponds are a potential option where net evaporation rates are high and inexpensive level land is available, although noting that even for small concentrate flows, the areal requirements and costs can be high. Impermeable liners are required to reduce the risk of groundwater contamination, which comprise a major component of the construction cost.

4.2.3 Non-conventional Brine Disposal Options

4.2.3.1 *Wind-Aided Intensified eVaporation (WAIV)*

Wind-Aided Intensified eVaporation (WAIV) is a relatively new process developed to increase the concentration of brine to be disposed of whilst decreasing the footprint area required to do so. This method relies on the drying power of the wind without generating small droplets which can cause salt drift.

4.2.3.2 *Evaporation or Mechanical Misting*

Mechanical misters can be used to decrease the area of evaporation ponds by spraying the brine into the atmosphere in tiny droplets, thereby substantially increasing evaporation, depending on atmospheric conditions. These mechanical units are installed at the edge of the evaporation ponds, directing their spray over the ponds so that unevaporated droplets can fall back into the ponds.

4.2.3.3 *High Recovery Membrane Systems*

The recovery rate from RO membrane systems can be increased in a number of ways, including:

- Multiple passes and kidney systems
- Precipitative softening
- High Efficiency Reverse Osmosis (HERO^{TM})
- Pulse Flow Reverse Osmosis (PFRO).

4.2.4 Costs for Different Brine Disposal Options

There is substantial literature available covering qualitative assessments and comparisons of different brine disposal options, but little in the way of direct cost comparisons between different options, most likely because the concentrate water quality, the availability of alternatives and hence costs is site-specific (Mickley, 2009 and Tinos et al., 2012).

Table 4-1: Capital Cost Estimates for Different Brine Disposal Options (Van Niekerk, 2012)

Technology	Unit Energy Use (kWh / m^3 product)	Capital Investment (N$ / R per m^3/d treated)
Conventional UF / RO	1-2	10,000
High recovery UF / RO	2-4	20,000
Evaporation ponds	< 0.1	180,000
Brine concentrators (mechanical vapour recompression)	25-45	90,000-120,000
Brine crystallisers	50-65	Included above

Van Niekerk (2012) indicates that evaporation ponds, whilst having the lowest energy consumption, feature by far the largest capital costs for brine disposal of the options considered.

PART 5

CASE STUDIES

PART 5: CASE STUDIES

5.1 INTRODUCTION

In this chapter an overview is provided of a number of case studies of water reuse in southern Africa. The case studies include direct potable reuse schemes, indirect potable reuse, mining water reuse, managed aquifer recharge and industrial reuse.

5.2 DIRECT POTABLE REUSE

5.2.1 New Goreangab Water Reclamation Plant

The Goreangab water reclamation plant in Windhoek, Namibia is a world-renowned pioneer in direct water reclamation. The first direct potable reuse plant was commissioned in 1968 and was the result of severe droughts in Namibia, with no other viable water sources for the City of Windhoek. The initial capacity of the Goreangab reclamation plant was 4.3 ML/d. During a drought in 1992 the plant was upgraded to a capacity of 14 ML/d (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 plant was developed to utilise domestic wastewater from the Gammams Wastewater Treatment Plant in Windhoek (built in 1965) and was designed based on nearly 30 years of extensive experience and research which were conducted locally. Input from international experts were also obtained to ensure compliance with the strictest water quality guidelines applied around the world.

The biggest challenge for the NGWRP consisted of the plants' ability to remove four major elements form the wastewater, which includes physical and organoleptic elements, macro elements, microbiological elements, and disinfection by-products (FRACTAL, 2017). Therefore, the NGWRP was specifically designed to implement a multiple barrier approach, which combines 9 treatment, non-treatment, and operational processes throughout the entire reclamation process. The multi-layered approach provides a redundancy throughout the system that continually protects public health in the event one of the other barriers fail (FRACTAL, 2017)l.

Three lessons emerged from the Windhoek experience. First, the project proved that augmenting drinking water supplies through direct reuse of water could be undertaken in a safe and responsible way. Second, a multi-disciplinary team approach was essential in ensuring proper installation and operation of the technologies was employed. Additionally, proper monitoring was important to ensure safety of the finished product. Third, policies and regulations at national and local levels were needed for proper support to ensure long-term safety and sustainability (FRACTAL, 2017).

Windhoek hasn't always got it right. Despite attempted public awareness and education campaigns, a major criticism has been the city's failure to sustain a public awareness and communication campaign – particularly when there isn't a perceived water crisis (Spear, 2017). This has meant that targets for water use haven't always been met. However, Windhoek is a good example of how raising awareness can play an important role in coping with water scarcity and the NGWRP is an excellent example of one of the innovations practiced in a country with few resources, either natural or financial (Spear, 2017).

5.2.2 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 built in 2010 when the town's main water supply, the Gamka Dam, dried up during a severe drought. It became operational in January 2011. The Beaufort West Water Reclamation Plant (WRP) has a capacity of 2.3 ML/d and uses wastewater from the Beaufort West Wastewater Treatment Plant as its only raw water source (Marais and Dürckheim, 2011). The plant has adopted a very conservative design with multiple treatment barriers to ensure the safety of the drinking water.

Scepticism against direct water reclamation is high, which is why communication of treatment efficiency and final water quality is important for public acceptance (Marais and Dürckheim, 2011). 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.

Beaufort West region is currently experiencing a very harsh drought, probably even worse than that in 2010. The water reclamation project is proving to be a reliable source of water for the town, albeit not sufficient on its own to meet the water demand of the community and industry.

5.2.3 Ballito Water Reclamation Plant

During the peak of the drought in KwaZulu-Natal late in September 2014, a service provider, which has a 30-year concession contract with the Ilembe District Municipality, was made aware of the critical levels of dams in the region. The service provider considered different options for augmentation of the drinking water supply, to ensure sufficient supply of water for domestic, commercial, and industrial purposes. These options included ground water development, water carting (supply using water tankers), desalination of sea water, and wastewater reuse (Swartz, 2019). The wastewater recycling option was found to be sustainable and the most cost-effective option and was chosen as the preferred option for further development. The success of the project depended on the effective communication strategy and public participation process adopted by Ilembe District and the service provider (Swartz, 2019). The recycling plant, with a capacity of 3 ML/d, was subsequently constructed and commissioned in August 2016. The plant was upgraded in 2018 to a capacity of 4 ML/d and currently supplies reuse water to communities in the Ballito area.

5.3 INDIRECT POTABLE REUSE

5.3.1 George Indirect Potable Reuse Plant

As the largest town on the Garden Route, George also faced water shortages and decided to investigate and then implement an indirect water reuse strategy (Turner et al., 2015). Final effluent from the Outeniqua Wastewater treatment Plant (WWTP) is treated to a very high quality through ultra-filtration and disinfection, prior to it being returned to the main storage facility, the Garden Route Dam (Turner et al., 2015). Consultants were appointed to undertake the necessary design, formulation of tender documents for the construction phase and overall monitoring of the construction works for the indirect re-use of the treated effluent scheme (Aurecon, 2021).

This initiative supplemented the existing supply by an additional 9 to 10 Mℓ/day which contributed approximately one third towards meeting the town's drinking water demand. Based thereon, the water from the wastewater treatment works is treated in the George water reclamation plant to a standard similar or better than the quality of the water in the Garden Route Dam (Turner et al., 2015).

From a resource perspective, the indirect re-use of treated effluent is not only environmentally sustainable, but also economically sustainable, as water that has already been collected from natural raw water resources can be safely recycled and continuously used (Aurecon, 2021).

5.4 REUSE OF MINING EFFLUENT

5.4.1 eMalahleni Water Reclamation Plant

eMalahleni (Witbank) is an industrial town surrounded by coal-producing mines, steel manufacture and Eskom coal-fired power stations. The town's water security was threatened not only by water shortages, but also low water quality due to high amounts of dissolved metals and salts accumulating in the catchment, mainly as a result of acid mine drainage (WHO, 2017).

To address these challenges, a water reclamation plant was constructed to treat mining effluent water to potable standards for use in the town. The plant has now been operational for several years and continues to produce safe, potable water to the eMalahleni community, while simultaneously reducing the risk of environmental contamination from the uncontrolled discharge of acid-mine drainage (WHO, 2017).

The eMalahleni Water Reclamation Plant was designed and built to recover potable water from acid mine drainage from several mines in the eMalahleni (Witbank) area. The Project is a joint initiative between mining companies (Anglo Coal and BECSA). The project was to be ground-breaking with the following goals (Hutton et al., 2009):

- Mine water being used to produce potable water for local municipality use.
- A plant of a significant local impact at 20 ML/day product
- Waste production at an extremely low level of less than 3% brine

- Positive waste utilization

These goals were shifted halfway through construction, after scrutinizing the design and adding clever changes to the existing over-design and allowing the plant capacity to be increased to 25 ML/day.

The plant was commissioned in September 2007 and has been operating successfully since. Production was ramped up to the design level (20 ML/d) by June 2008 (Hutton et al., 2009) .

The application of the HiPRO process for the treatment of Acid Mine Drainage is a world’s first and therefore the correct operating and maintenance of the eMalahleni Plant was a challenge and a learning experience from the very beginning.

From the outset it was clear that operating a world’s first plant would present a unique challenge. Several complex components of operations would have to be managed simultaneously, not only to ensure that the plant met its design criteria, but also making the satisfaction of all stakeholders a priority, as well as strict adherence to the Mine Health and Safety Act and the Occupational Health and Safety Act.

Operating and maintenance staff was brought in early on in commissioning, some having been involved in the demonstration plant trials. Strict operating procedures were drawn up and enforced. These procedures have undergone several iterations over the past two years, as the plant created many “teething” challenges whilst it began to live up to its full potential.

The plant was the first of its kind in the world, and as such, there were many unforeseen situations, or challenges, which had to be overcome (Gunther & Mey, 2006). Fortunately, the challenges now serve as valuable lessons learned by those involved in the project, as well as those that study it.

5.5 WATER RECLAMATION AND DESALINATION INTEGRATIONS

5.5.1 Durban Remix

A study by the eThekwini Water Services (EWS) to assess the Inner-City Water Demands indicated the water demand will exceed the water supply by 2020 (Masha, 2019). In response to this demand, EWS has investigated desalination technologies available to implement in the city, one of them being the Remix Water™ System. A water remix system consists of a combination of seawater desalination and reuse of effluent from a wastewater treatment plant, that is treated with membrane bioreactor technology (MBR) and brackish water reverse osmosis (BWRO) (Masha, 2019).

In line with eThekwini Municipality’s long-term strategy to investigate the feasibility of implementing a large-scale desalination plant to further supplement the water supply, the Municipality partnered with the New Energy and Industrial Technology Development Organisation (NEDO) for a demonstration project (Masha, 2019). The purpose of the demonstration project was to test the Remix Water technology to assess whether it can reliably produce potable water and to optimise the design and operation in order for the technology to be considered for a large-scale desalination scheme.

The proposed Remix Water demonstration project required a combination of seawater desalination and wastewater reuse. As a result, the demonstration plant had to be located within a reasonable distance from the sea. Based on various criteria, the Central Wastewater Treatment Plant (WWTP) was identified as the ideal location for the implementation of a Remix Water Plant. The construction of the demonstration plant commenced in October 2018 and was commissioned in November 2019. The demonstration plant comprised of a 3 ML/d containerized unit and a 6.25 ML/d demonstration plant (Masha, 2019).

It is envisaged that a proposed 100 ML/d Remix Plant would be commissioned towards the end of 2023. The plant would be based on 50% seawater mixed with 50% treated wastewater. The lessons learnt from the demonstration plant will guide the implementation of the larger-scale project (eThekwini Water Services, 2015).

The Remix system has been shown to have major benefits as compared to desalination without the use of wastewater, or a conventional treatment (i.e. activated sludge process) alone. These benefits are a reduction in energy needed, due to a reduction in the power needed for filtration and a reduction in aeration volume, and a reduction in costs. Lower environmental impacts, due to a 30% decrease in energy requirements, and the lower salinity of the resulting brine, and stable operation and product water quality (Freidrich et al., 2017).

5.6 MANAGED AQUIFER RECHARGE

5.6.1 Atlantis

Atlantis was a planned town from its planning inception in the late 1960s (Nathan and Scobell, 2012). Initially the water supply was provided from a single borehole and later a local spring, the Silwerstroom. However, there was a general recognition that these sources would not be sufficient over the long-term (Nathan and Scobell, 2012). The challenge was that Atlantis was located far from most other feasible sources. A plan was put forward to use surface water from the Berg River about 70 km away. Despite the high cost of this plan, the Withoogte Water Treatment Plant (WTP) was designed with sufficient capacity for supplying water to Atlantis. This was however a very long-term plan and town planners had to think of other solutions and turned their attention to groundwater resources (Kotzé, 2019).

The town of Atlantis rest on the Atlantis aquifer, a groundwater system that covers an area of about 130 km² inland from the Atlantic Ocean to the town itself. The groundwater enters the aquifers through the sandy surface, in particular, at the bare sand dunes, and then flows towards the coast down a relatively steep gradient (Kotzé, 2019). Initially prompted by the need to find an alternative to marine wastewater discharge, Atlantis began recharging its storm water and treated wastewater into its sandy soils in 1979 (Nathan and Scobell, 2012). Town planners and engineers recognised that the natural groundwater yield of the aquifer was not sufficient to meet the long-term needs of the town and shifted their focus to recharging the aquifer and recycling water (Nathan and Scobell, 2012).

This decision resulted in major developments, which included the addition of storm water to recharge the system and the eventual separation of domestic and industrial effluent. This allowed recharge of the aquafer with the highest quality water in the areas of greatest importance (Nathan and Scobell, 2012). Subsequently, the Atlantis Water Resource Management Scheme (AWRMS) now uses treated domestic effluent, all of the domestic storm water and most of the industrial storm water to recharge the aquifer.

The AWRMS is a complex, large-scale system that depends on specialised management. Long-term sustainability of the system depends on proper maintenance of all components, requiring a multidisciplinary approach (Kotzé, 2019). The system faces many challenges to the sustainability of the water supply. These challenges include basin-clogging, groundwater pollution, uncontrolled abstraction, emerging pollutant and varying quality of the groundwater throughout the system (Nathan and Scobell, 2012; Kotzé, 2019).

The AWRMS provides a local South African example of a cost-effective artificial recharge solution and has successfully recharged and recycled water for more than four decades (Nathan and Scobell, 2012). The AWRMS has proven that these types of recharge schemes are feasible: that they can be managed; that it is possible to integrate storm water; and that it is possible to separate different types of wastewater and storm water and manage them all (Nathan and Scobell, 2012).

5.7 INDUSTRIAL REUSE

5.7.1 Durban Water Recycle

In the 1990s Durban was facing sewerage capacity constraints, as the existing infrastructure could not cope with the growing population as well as economic development (World Bank, 2018). Around the same time, Mondi Paper approached eThekwini Water Services (EWS) to investigate the possibility of increasing Mondi's intake of reclaimed water to a substantially higher volume and quality (Gisclon et al., 2002). Given these developments, the municipality had to develop a plan for a wastewater treatment plant that was able to cater for the increased demand. The solution was for EWS to upgrade the existing activated sludge process and to construct a new tertiary treatment plant. One complexity of the project was that Mondi required high-quality water, given that it is used to produce fine paper (World Bank, 2018). Despite the proven technical feasibility of the reclamation project, the economic feasibility remained in doubt. The costs, technical complexity and the risks associated with the project were considered to be beyond the normal functions of EWS, which therefore lead to the water utility to propose a public-private partnership (PPP) (Gisclon et al., 2002).

After an international bidding phase, a 20-year concession contract was implemented. The contract is a Build-Own-Operate-Transfer (BOOT) contract, valid until 2021 (World Bank, 2018) making it the first PPP of its kind in South Africa (EU-SA Partners for Growth, 2019).

Construction commenced in 2000, which included the upgrading of the existing activated sludge process from 50 to 77 ML/day, the construction of the new tertiary wastewater treatment plant (WWTP) with a design capacity of 45 ML/day, tying in with pre-existing and decommissioned assets, refurbishment of storage tanks and installation of the reclaimed water reticulation system (Gisclon et al., 2002). The first water sales were made in 2001 to the clients, Mondi Paper and the South African Petroleum Refineries (SAPREF), with 85% of the treated water going to Mondi Paper and 15% to SAPREF (Durban Water Recycling Project, 2019).

The case of Durban is an example of a successful and innovative PPP to improve the sustainability of wastewater management, minimizing environmental impact and having multiple benefits for the community. The city was able to convert a challenging situation into an opportunity, leveraging the local conditions and innovative thinking that resulted into a win-win solution for all stakeholders. The project shows that if the right stakeholders are involved and committed, it is possible to achieve the principles of circular economy (World Bank, 2018).

5.7.2 Mossel Bay Water Reuse Plant

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

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