DIRECT RECLAMATION OF MUNICIPAL WASTEWATER FOR DRINKING PURPOSES

Volume 1: Guidance on Monitoring, Management and Communication of Water Quality

Report to the
Water Research Commission

by

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WRC Report No. TT 641/15

October 2015

Obtainable from

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The publication of this report emanates from a project entitled *Monitoring, Management, and Communication of Water Quality in the Direct Reclamation of Municipal Wastewater for Drinking Purposes* (WRC Project No. K5/2212).

This report will form part of a series of two reports. Volume 2 was still in preparation at the time of publication of this report (Volume 1).

ISBN 978-1-4312-0709-1

Printed in the Republic of South Africa

EXECUTIVE SUMMARY

BACKGROUND

Water scarcity is recognized as a major challenge for countries on a world-wide basis in their endeavour towards sustainable life for humankind and the environment. This has become as widely a discussion point as the challenges posed by sustainable energy supply. According to Lazarova *et al.* (2013), by 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under water-stress conditions. Existing water sources are increasingly coming under stress due to growing water demand on a global scale. Water resource managers and planners are forced to look at other, unconventional water sources such as desalination (of seawater and brackish groundwater), water reuse and rainwater harvesting. Water 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. The most important drivers for water reuse are rapid population growth, urbanization and unpredictability of conventional water source sustainability (due to climate change and source pollution).

In South Africa, there has also been a lot of interest recently in direct water reclamation (direct potable reuse), for a number of reasons. Being an arid region, southern Africa faces serious challenges with availability of conventional water sources. Already the effects of prolonged droughts in the sub-continent are evident, necessitating the implementation of contingency plans in the short term, and the 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 of wastewater as alternative water supply sources to sustain development and economic growth in the region. Water reclamation plants that have been constructed as a result of this water shortage include: Beaufort West (direct potable reuse (DPR)), George (indirect potable reuse (IPR)) and Mossel Bay (reuse for industrial purposes). Direct potable reuse options in Durban (eThekwini Municipality), Port Elizabeth, Cape Town and Hermanus are at an advanced planning stage. In this regard, water reuse for potable purposes involves the reclamation of wastewater for drinking purposes after it has been extensively treated by a number of treatment processes to produce water that is safe for human consumption and human use. Direct water reuse involves the reuse of treated wastewater or effluent by direct transfer from the site where it was produced, to the site of the new or different beneficial application, whereas indirect water reuse comprises the reuse of treated wastewater from a surface water or groundwater body where it was discharged to with the intention of reuse, before being abstracted for reuse at a new or different site of beneficial application.

AIMS

The project had the following aims:

- Document the status of water reuse for potable purposes (direct and indirect) for planning and regulatory purposes.
- Compile a database of direct and indirect potable reuse potential of towns in South Africa.
- Develop standardised terminology for water reuse including direct potable reuse as well as indirect potable reuse that are understandable by stakeholders and the public to instil credibility and confidence. Use the outcome of the terminology and public perception research to develop effective messaging and communications materials for different stakeholders and the general public.
- Develop proposed water quality monitoring programmes and guidelines consisting of constituents and parameters that will require monitoring, including analytical methods, time to obtain results, reliability of method, detection limits, frequency and costs of analyses. The focus should be on on-line (real-time) measurements to ensure that all the required process barriers are intact.
- Produce a concise guideline document for use by municipalities and water professionals incorporating all of the above aims.

METHODOLOGY

- An identification and selection was performed of all the water quality constituents and other aspects to be included in the guidelines document. The status of water reuse for potable purposes (direct and indirect) for planning and regulatory purposes was determined from various sources implementing or planning the implementation of water reuse. This was followed by the development of baseline sources and concentrations of selected critical constituents (key parameters), focussing on any improvements that may be necessary to reduce the risk of raw water source quality deterioration and quantity problems, *e.g.* the use of reliable on-line measurements as early warning systems. Standardised terminology for water reuse including direct potable reuse as well as indirect potable reuse was developed in conjunction with the relevant stakeholders.
- Influent monitoring systems were considered, which include constituents, parameters, and monitoring systems. The focus was in particular on the potential benefits of various influent monitoring schemes that may be used for early detection of constituents.
- Key factors were considered on how monitoring systems should be designed in relation to process design for the various unit treatment processes in direct and indirect potable reuse to maintain the treatment barriers, *i.e.* prevention of break-through by pathogens, organic substances and other micro-pollutants.
- A selection of constituents and parameters that require monitoring in the final water (in particular those known to be harmful to humans) was done, which included parameter details, health impacts, analytical methods and detection limits.

- The "minimum" monitoring programmes developed in the project was also coordinated with the Blue Drop programmes (for the water reclamation plants), and the Green Drop programmes (for the wastewater treatment plants feeding the water reclamation plants).
- A database was compiled of towns in South Africa having direct and indirect potable water reuse potential. A database was further compiled of South African laboratories that can perform the various physical, chemical and microbiological analyses required for water reclamation compliance measurements and research purposes. This was done in cooperation with DWA's (currently DWS's) Regulation Directorate, who has already developed databases with information on available laboratories and accreditation status thereof.
- Utilising all of the information gathered during the project, and incorporating existing knowledge elsewhere, a concise guideline document was compiled for use by municipalities, water professionals and other stakeholders.

OUTCOMES AND FINDINGS

Water sustains life and it is in public interest that the water supplied by the public utility conforms to required water quality guidelines. These are determined by specialist teams and according to the raw water supply the treatment process is designed. Regular monitoring of the raw water source, the treatment process steps themselves and the final water quality produced, are the only items of evidence that the utility can produce to ensure the consumers that the water treatment process indeed met all the required targets that have been set.

When dealing with DPR there is a major risk that the utility should keep in mind and that is: one incident, which can be proven to stem from the DPR, where people in the community have been severely compromised (death or serious suffering, mostly caused by acute infection) will lead to a high probability that the treatment unit may be closed in the extreme or that financial losses will occur due to law suits. During periods of investigation the treatment unit will most probably not be allowed to operate. With all this said, it is in the interest of the owner and operator of the DPR to ensure that, at all times, good data are produced from a robust monitoring program. The higher cost of monitoring can be compared to an insurance policy, once any doubt occurs, it will prove its value to ensure to the public as well as any panel of judges (either in court or the media) that the treatment unit complied with all set guidelines and regulations.

This policy is a proven one practiced in Windhoek since the first DPR came into operation in 1968. With the upgrades and extensions of capacity of the DPR scheme in Windhoek, monitoring was intensified. With numerous water quality issues mainly caused by natural sources not complying, the public could be convinced that DPR technology (monitoring is an integral part of it) is functioning well and is not causing any threat. As with an insurance policy, it provides peace of mind to the operational staff component, because it proves their commitment. This is one of the reasons ensuring that both the citizens of Windhoek, as well as the owner and operator of the DPR are proud of their reclamation scheme.

Guidelines

Monitoring systems are proposed for the three key components of a potable reuse plant, namely raw water monitoring, operational and control monitoring and compliance monitoring. The monitoring makes provision for early detection of deteriorating incoming raw water quality, rapid changes in the raw water quality, maintenance of treatment barriers in the plant through setting of operational alert levels for the various unit treatment processes in the plant, and compliance of the final water quality with adopted local and international norms and standards. Because the final water at issue in this study is produced from reclaimed wastewater, the focus was on health-related constituents and parameters, which, for the larger part, have not yet been included in local water quality standards. The intended testing of the proposed monitoring systems at full-scale reuse plants was not performed in this project due to the fact that the high cost of such work would have exceeded the resources of the project. The following guidelines were drawn up based on the research that was done for this project, and are applicable to the water quality monitoring and management of direct and indirect potable reuse schemes in Southern Africa.

Scheme feasibility:

- Political will is an important factor in determining whether the reclamation plant project will be a success
- A steering committee should be established before a Water Reclamation Plant (WRP) is constructed. It should review the different catchments and sources to the plant and establish proper monitoring protocols
- Thorough Environmental Impact Assessment (EIA) studies should be completed and the reduced return flow factored into the feasibility of the WRP. A minimum return flow to the environment can compete against upgrading the WRP in the future
- Financial feasibility must be established. It is also important to take into consideration that many WRP's are built during extreme droughts and that the production capacity of the plant may reduce significantly once conventional water sources are no longer depleted

Raw water:

- A steering committee should be established to review water quality results on an annual basis
- Catchments should be reviewed and verified annually to see if the monitoring programme addresses all water quality aspects
- A catchment (including all the sources to the Waste Water Treatment Works (WWTW) and WRP) status should be completed once a year to identify parameters of concern and ensure that the plants are prepared to treat the influent they receive to the required standard
- Ammonia is not effectively removed by reverse osmosis (RO); this should be kept in mind. Ammonia should preferably be removed at the source or by the wastewater treatment processes.
- The design of maturation ponds is critical; if the pond is too shallow (or has large open surface areas), the wind will stir the water and rise the sediments at the bottom of the pond, increasing the turbidity.

Water reuse plant:

- Proper operation and maintenance is very important to ensure the required water quality over time.
- Treatment process units must be thoroughly monitored. The monitoring data should be stored and reviewed in order to ensure that each of the treatment units performs as intended. Impromptu

maintenance should also be carried out based on the monitoring results. (However, risk-based maintenance is still the most important tool to properly maintain the plant).

- Filters should have a filter-to-waste option to ensure low turbidity (i.e. it should prevent particle breakthrough) after backwashing to ensure proper removal of *Giardia* and *Cryptosporidium.*
- If a unit process is out of a target specification it should automatically go into bypass or recycle mode, providing that the final water quality can still be attained. (If not, the plant should be shut down and the problems fixed).

Monitoring instruments:

- On-line monitoring, using high quality instrumentation, is not optional for direct and indirect potable reuse plants because of the high demands placed on treatment efficiency and water qualities.
- The feed and final water of each of the treatment units should further be measured at a high frequency in order to detect treatment failures.

Plant operators/process controllers:

- The process controllers of WRPs should have a sufficient skills level to understand each of the treatment processes on the plant.
- Sufficient guidelines or operational manuals should be available on-site at each of the applicable treatment process units that can guide a process controller, especially during emergencies.
- All process controllers must be able to use and calibrate hand-held sampling and measuring devices.

Public participation:

- Good analytical results and data management (archiving) is a very important aspect for public participation and motivating the use of certain technologies. The laboratory should also set high standards and be promoted to set the minds of the public at ease. Open communication channels with the public, will further enhance public participation in, and acceptance of, water reuse schemes.

CONCLUSIONS

It is emphasised in the report that the success of a DPR scheme depends on five important elements, namely:

- A reputable specialist team to accompany the project from design to implementation
- A robust treatment training
- A proven treatment technology with a good track record elsewhere. (Pilot plant studies will further prove a technology)
- Water quality monitoring
- Good communication at all levels and between all stakeholders
- Continued training and research

The guidelines provided here have focused on water quality monitoring as an important link in the various potable reuse chains. Important conclusions drawn from the development and public presentation of the guidelines are summarised below.

1. With good technologies, personnel and communication protocols, barriers and monitoring systems in place, direct and indirect potable reuse is becoming increasingly attractive as a water source.

2. Although the technological development and analytical and engineering procedures for monitoring are well advanced and potable water quality can be ensured, there are still a few challenges and issues that are receiving attention and which are currently studied further at research centres across the world.

3. The successful implementation of IPR and DPR schemes depends strongly on the expertise of design and monitoring teams and the availability thereof in the particular region. A good example is the management of brine streams, and addressing the technological and economic challenges that are evident in this regard.

4. In the design of DPR monitoring programs, information about the water quality should be clearly communicated to the consumer as well as within the water service provider. Negative communication should be avoided at all cost (without distorting facts), because any negative information and publicity about a water quality event at the consumer point will be blamed on DPR. A good monitoring program will allow the water quality manager to convince all stakeholders about the true reflection of water quality in the system.

5. The most common and widespread health risk associated with drinking water is microbial contamination and therefore the control of microbial contamination must always be of primary importance. Ensuring the chemical safety of water requires a different approach as not all the chemicals specified in most guidelines and standards for drinking water will occur in all locations, and if they do exist, they may be present below levels of concern. However, the importance of chemicals in drinking water should not be underestimated, and it is therefore imperative that chemical contaminants be prioritised so that the most important ones are included in monitoring programmes.

6. For the optimisation of the performance of unit treatment processes, it is important to note that the measurement of control parameters should not aim at concentrations of zero, but rather an indication of the removal percentage or log removal. This is an important feature of measured parameters since it would be impossible to determine the performance of a treatment process of the measured parameter that indicates the performance of the treatment process is zero at the inlet of the treatment unit. When the operational control of a water reclamation plant is performed correctly, each of the treatment units of the plant will operate at its optimal conditions.

7. Monitoring a water distribution system requires advanced and expensive monitoring systems if it is to be done automatically, which is the situation that is strived towards. Even then, at some point manual samples will have to be taken to check on the monitoring system and to calibrate the sensors that are used. Good protocols will ensure that this can be achieved in an efficient manner.

8. Community size should be taken into account when it comes to monitoring. Currently the tendency is to have a more extensive monitoring system with larger communities since the risk is higher. However, monitoring should be extensive, irrespective of the number of users. This is a very important point, as it is often considered that smaller communities using IPR or DPR may have a scaled-down version of a monitoring program. For obvious reasons, this should never be allowed.

9. Effective communications of data or results is all about building trust relationships. Data without good communication are worthless and will not serve any purpose, should an incident occur where the health of the public is at risk.

10. *Professionalism and care*! Trust from the public in drinking water provision is paramount. Internal lines should be open, the public happy and the critics (newspapers or specialists) convinced that they can trust the water service provider to rectify a situation, should something go wrong.

RECOMMENDATIONS

1. The Department of Water and Sanitation (DWS) should use the information provided in this report to adopt and implement standards for direct and indirect potable reuse in South Africa as a high priority.
2. DWS should also assist water service providers (municipalities and water boards) to have access to proficient scheme and plant managers, and skilled process controllers, by funding training programmes for scarce skills (such as membrane treatment plant operation).
3. Standards for drinking water quality from IPR and DPR plants should be included in the SANS 241 as a separate section for water reclamation plants for producing drinking water.
4. Regulation of IPR and DPR plants should be given specific attention, and included in, the Blue Drop program, as well as in the Green Drop program (for wastewater treatment plants supplying reuse plants with secondary or tertiary treated wastewater).

ACKNOWLEDGEMENTS

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

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The funding of the project by the Water Research Commission and the contributions of the members of the Reference Group are acknowledged gratefully.

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ACRONYMS AND ABBREVIATIONS

ADI	acceptable daily intake
AOP	advanced oxidation process
AOX	adsorbable organic halogens
ASP	activated sludge process
AWT	advanced water treatment
AWTP	advanced water treatment plant
BAC	biological activated carbon
BW	body weight
CCP	critical control point
CEC	chemical of emerging concern
COD	chemical oxygen demand
CSIR	Council for Scientific and Industrial Research
DAF	dissolved air flotation
DOC	dissolved organic carbon
DoH	Department of Health
DPR	direct potable reuse
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EC	electrical conductivity
ED	exposure duration
EDCs	endocrine disrupting compounds
EDP	endocrine disruptors and pharmaceuticals
EDSTAC	Endocrine Disruptor Screening and Testing Advisory Committee
EEQ	estradiol equivalents
EIA	environmental impact assessment
EPA	Environmental Protection Agency
ETEM	events triggered enhanced monitoring
GAC	granular activated carbon
GWRC	Global Water Research Coalition
GWRS	groundwater replenishing system
HPC	heterotrophic plate count

IPR	indirect potable reuse
IR	intake rate
IWA	International Water Association
IX	ion exchange
Lft	lifetime
LRV	log removal value
MF	microfiltration
NF	nanofiltration
NGWRP	New Goreangab Water Reclamation Plant
NOEL	no-observed-effect-level
NPR	non-potable reuse
O_3	ozone
OGWRP	Old Goreangab Water Reclamation Plant
PAC	powder activated carbon
PBT	persistence, bioaccumulation and toxicity
PI	performance indicator
POP	persistent organic pollutants
PPCPs	pharmaceuticals and personal care products
QMRA	quantitative microbial risk assessment
REACH	regulation, evaluation, authorisation and restriction of chemicals
RO	reverse osmosis
SANS	South African National Standards
SCADA	supervisory control and data acquisition
TDI	tolerable daily intake
TDS	total dissolved solids
TECHNEAU	EU FP6 project
TOC	total organic carbon
TRI	toxic release inventory
TSS	total suspended solids
TTC	thresholds of toxicological concern
UF	ultrafiltration
USEPA	United States Environmental Protection Agency
UV	ultraviolet irradiation
UV254	UV absorbance at 254 nm

WQG	water quality guidelines
WHO	World Health Organisation
WRC	Water Research Commission
WRP	water reclamation plant
WSP	water safety plan
WWTW	waste water treatment works

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CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

Water scarcity is recognized as a major challenge for countries on a world-wide basis in their endeavour towards sustainable life for humankind and the environment. This has become as widely a discussion point as the challenges posed by sustainable energy supply. According to Lazarova *et al.* (2013), by 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under water-stress conditions. Existing water sources are increasingly coming under stress due to growing water demand on a global scale. Water resource managers and planners are forced to look at other, unconventional water sources such as desalination (of seawater and brackish groundwater), water reuse and rainwater harvesting. Water 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. The most important drivers for water reuse are rapid population growth, urbanization and unpredictability of conventional water source sustainability (due to climate change and source pollution).

In South Africa, there has also been a lot of interest recently in direct water reclamation (direct potable reuse), for a number of reasons. Being an arid region, southern Africa faces serious challenges with 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 of wastewater 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; Beaufort West (direct potable reuse (DPR)), George (indirect potable reuse (IPR)) and Mossel Bay (reuse for industrial purposes), while direct potable reuse initiatives in Durban (eThekwini Municipality), Port Elizabeth, Cape Town and Hermanus are at an advanced planning stage.

1.2 PROJECT AIMS

The aims of the project are the following:

1. Document the status of water reuse for potable purposes (direct and indirect) for planning and regulatory purposes.
2. Compile a database of direct and indirect potable reuse potential of towns in South Africa.
3. Develop standardised terminology for water reuse including direct potable reuse as well as indirect potable reuse that are understandable by stakeholders and the public to instil credibility and

confidence. Use the outcome of the terminology and public perception research to develop effective messaging and communications materials for different stakeholders and the general public.

4. Develop proposed water quality monitoring programmes and guidelines consisting of constituents and parameters that will require monitoring, including analytical methods, time to obtain results, reliability of methods, detection limits, frequency and costs of analyses. The focus should be on on-line (real-time) measurements to ensure that all the required process barriers are intact.
5. Produce a concise guideline document for use by municipalities and water professionals incorporating all of the above aims.

1.3 SCOPE AND LIMITATIONS

Monitoring systems are proposed for the three key components of a direct potable water reuse plant, namely raw water monitoring, operational and control monitoring and compliance monitoring. The monitoring makes provision for early detection of deteriorating incoming raw water quality, rapid changes in the raw water quality, maintenance of treatment barriers in the plant through setting of operational alert levels for the various unit treatment processes in the plant, and compliance of the final water quality with adopted local and international norms and standards. Since the final water studied here is produced from wastewater, the focus was on health-related constituents and parameters, for which have mostly not yet been included in local water quality standards.

1.4 APPROACH

a. An identification and selection was performed of all the water quality constituents and other aspects to be included in the guidelines document. The status of water reuse for potable purposes (direct and indirect) for planning and regulatory purposes was determined from various sources implementing or planning the implementation of water reuse. This was followed by the development of baseline sources and concentrations of selected critical constituents (key parameters), focussing on any improvements that may be necessary to reduce the risk of raw water source quality deterioration and quantity problems, e.g. the use of reliable on-line measurements as early warning systems. Standardised terminology for water reuse including direct potable reuse as well as indirect potable reuse was developed in conjunction with the relevant stakeholders.
b. Influent monitoring systems were considered, which include constituents, parameters, and monitoring systems. The focus was in particular on the potential benefits of various influent monitoring schemes that may be used for early detection of constituents.
c. Key factors were considered on how monitoring systems should be designed in relation to process design for the various unit treatment processes in direct and indirect potable reuse to maintain the treatment barriers, *i.e.* prevention of break-through by pathogens, organic substances and other micro-pollutants.

d. A selection of constituents and parameters that require monitoring in the final water (in particular those known to be harmful to humans) was done, which included parameter details, health impacts, analytical methods and detection limits.

e. The "minimum" monitoring programmes developed in the project were also coordinated with the Blue Drop programmes (for the water reclamation plants), and the Green Drop programmes (for the wastewater treatment plants feeding the water reclamation plants).

f. A database was compiled of towns in South Africa having direct and indirect potable reuse potential. A database was further compiled of South African laboratories that can perform the various physical, chemical and microbiological analyses required for water reclamation compliance measurements and research purposes. This was done in cooperation with DWA's (currently DWS's) Regulation Branch, which has already developed databases with information on available laboratories and accreditation status thereof.

g. Utilising all of the information gathered during the project, and incorporating existing knowledge elsewhere, a concise guideline document was compiled for use by municipalities, water professionals and other stakeholders.

1.5 TERMINOLOGY AND DEFINITIONS IN WATER RECLAMATION AND REUSE

The following terminology is suggested for future use:

- **Wastewater**

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

- **Return flows**

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

- **Water reuse**

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

- **Potable reuse**

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

- **Non-potable reuse**

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

- **Direct reuse**

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

- **Indirect reuse**

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

- **Planned reuse (intentional reuse)**

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

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

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

DPR = Direct Potable Reuse **IPR** = Indirect Potable Reuse **NPR** = Non-Potable Reuse
WTW = Water Treatment Works **WWTW** = Wastewater Treatment Works

Figure 1.1: Schematic diagram showing different types of water reuse

CHAPTER 2: DIRECT AND INDIRECT POTABLE WATER REUSE REVIEW

2.1 GLOBAL STATUS OF DIRECT AND INDIRECT POTABLE REUSE

2.1.1 Overview

A detailed survey was done of the current international status of direct and indirect potable reuse, consisting of technical details of water reclamation plants that have been constructed and are in operation, motivation for these projects, and reclamation projects currently in the planning stages.

2.1.2 Current direct and indirect potable water reuse types, applications, experiences and challenges

It is critically important for the successful application and sustainability of water reuse as a water source to alleviate water scarcity situations, that there is a common understanding of the concepts and terminology used in planning and, especially, public outreach processes. It is also important that the definitions and terminology be updated on a regular basis as development of planning and implementation processes develop, which is currently in an accelerated stage. New approaches and concepts should be taken up in the international and local literature and clearly explained, not only to the water reuse stakeholders and role-players, but also the public at large. One such a new concept in water reuse is the “fit-to-purpose” approach (Lazarova *et al.,* 2013), which entails the production of reuse water of such a quality that it meets the needs of end-users. Many new water reuse projects have also adopted new terminology to improve the image of these projects with the public, notably names such as new water (or NEWater), processed water, purified water and eco- water. At both the IWA World Water Congress in Busan, Korea in 2012, and the IWA Water Reuse Specialist Group Conference in Windhoek, Namibia in 2013, considerable time was devoted to discussions on this important topic. Although development of treatment technologies, barriers and monitoring systems is making direct and indirect potable reuse increasingly attractive as a water source, there are still a number of challenges and issues that are receiving attention and which are currently studied further at research centres across the world. The most important issues and constraints are summarized in Table 2.1

Table 2.1: Direct and indirect potable reuse applications, experience and challenges (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 modeling 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 waste water 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

2.1.3 Current Direct and Indirect Potable Reuse Plants

A number of developments in both direct and indirect water reuse have taken place during the last two decades, of which the more important developments are listed below:

- Implementation of a number of full-scale direct and indirect water reuse plants worldwide, of which the most important ones are listed in Table 2.2 and 2.3 below.
- A gradual increase in the concern regarding emerging contaminants of concern (ECCs) in reuse water, which have accelerated during the past three years. These contaminants and chemicals include endocrine disrupting compounds (EDCs), and pharmaceuticals and personal care products (PPCPs).
- Advancements in membrane and advanced oxidation technologies. In the field of advanced oxidation, ultraviolet radiation (UV) technology has progressed to such an extent that it has become more economic than ozone, and also does not form disinfection by-products as is the case with chlorine-based systems or ozone. UV is also used more effectively for the destruction of parasites such as *Cryptosporidium*.
- UV and hydrogen peroxide in combination is now recognised as the best available technology for destruction of N-Nitrosodimethylamine (NDMA) and other organic compounds present in reclaimed water.

As can be seen from Table 2.2 and Table 2.3, there are a number of treatment processes that are commonly used at water reclamation plants. The following list of treatment processes have been identified as potential processes for the reclamation of wastewater for potable purposes:

- Coagulation/Flocculation
- Clarification
- DAF (dissolved air flotation)
- Media Filtration
- BAC (biologically activated carbon)
- GAC (granular activated carbon)
- PAC (powder activated carbon)
- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)
- Reverse Osmosis (RO)
- Ozonation
- UV/H_2O_2

Table 2.2: List of direct potable reclamation plants across the world

Plant Name	State/ Province	Country	ML/d	Commissioned	Status	Treatment train	System
'Old' Goreangab Water Reclamation Plant	Windhoek	Namibia	7	1968	Superseded 2002	Clarification - DAF - SF - GAC -> Cl	DPR: Blending prior to treatment
'New' Goreangab Water Reclamation Plant	Windhoek	Namibia	21	2002	Operational	PAC - O3 - Clarification - DAF - SF - O3 - BAC - GAC - UF - Cl	DPR: Blending prior to treatment
eMalahleni Water Reclamation Plant	Mpumalanga	South Africa	30	2007	Operational	Neutralisation - Clarification - UF - RO - Cl	DPR: Direct injection into distribution system.
Optimum Coal Water Reclamation Plant	Mpumalanga	South Africa	15	2009	Operational	Neutralisation - Clarification - UF - RO - Cl	DPR: Direct injection into distribution 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
Beaufort West Municipality	Western Cape	South Africa	1	2011	Operational	SF - UF - RO - UV/AOP Cl	DPR: Blending with conventionally treated sources
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 = Ultra Violet, ASR = Aquifer Storage Recovery, BAC = Biological Activated Carbon, GAC = Granular Activated Carbon, PAC = Powder Activated Carbon, MBR = Membrane Bio-Reactor, SAT = Soil Aquifer Treatment, O3 = Ozonation, IX = Ion Exchange, LC = Lime Clarification, SF = Sand Filter, ConvWTP = Conventional water treatment plant

Table 2.3: List of indirect potable reclamation plants across the world

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
Hueco Bolson Recharge Project	Texas	USA	38	1985	Operational	LC - media filtration - O_3 - GAC - O_3 - Cl	IPR: Groundwater recharge via direct injection
Clayton County	Georgia	USA	66	1985	Operational	Cl - UV	IPR: Surface water augmentation via land application/wetlands
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
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

Plant Name	State/ Province	Country	ML/d	Commissioned	Status	Treatment train	System
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
Prairie Waters Project	Aurora	USA	190	2010	Operational	Riverbank filtration - ASR - softening - UV/AOP - BAC - GAC - Cl	IPR: Groundwater recharge via riverbank filtration (note: the environmental buffer is used early in the treatment process).
NEWater	Changi	Singapore	228	2010	Operational	UF - RO - UV	IPR: Surface water augmentation
Outeniqua WWTP	Western Cape	South Africa	10	2010	Operational	Screening - UF - Disinfection	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 = Ultra Violet, ASR = Aquifer Storage Recovery, BAC = Biological Activated Carbon, GAC = Granular Activated Carbon, PAC = Powder Activated Carbon, MBR = Membrane Bio-Reactor, 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 Tables 2.2 and 2.3 are either arid or semi-arid areas, characterized 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. Most notable of these is Singapore. The projects that are reported on in this report consist of direct and indirect potable reuse plants, either direct potable reuse schemes or planned indirect potable reuse schemes. Unplanned or *de facto* indirect potable reuse is therefore not included (e.g. water treatment plants abstracting water downstream of the Hartbeespoort Dam or in the Middle Vaal River). While unplanned reuse will not be discussed in this overview, the importance of this type of water reuse should be recognised, for two main reasons, namely to reduce fears of reusing water on the one hand, and to be able to control and manage any undesirable effects that may arise. Reducing fears of water reuse as a result of uninformed constituents remains a challenge, especially in developing countries. The plants that are included in this overview are listed in Table 2.2 and Table 2.3.

General comment

The design of IPR and DPR plants hinges heavily on the expert and design teams and the available technology in that region. Where membrane manufacturers have captured a considerable part of the market in a region there is a tendency to use membrane barriers for suspended and dissolved solids removal. It seems that there is a re-evaluation of the use of membrane plants, as NF and RO processes have a considerable cost to get rid of the brine, which render them unfeasible in an inland application.

2.2 DIRECT AND INDIRECT POTABLE WATER REUSE IN SOUTH AFRICA

2.2.1 Review of direct and indirect potable water reuse

The main outcome of the project is the development of a framework for direct potable reuse in southern Africa, consisting of public acceptance, health-based monitoring programmes (for compliance and operational barriers, including engineered buffers), funding sources and regulatory approval. The main impacts of implementation of the direct and indirect potable reuse framework will be improved sustainability of supplementary and alternative drinking water supply to towns and cities in Southern Africa to alleviate water scarcity, to empower communities to take part in the decision making processes, to improve health and to stimulate economic development.

In Southern Africa (and now also worldwide after the recent IWA Water Reuse Specialist Group conference in Windhoek), the City of Windhoek (CoW) and the original planners and researchers of the Windhoek water reclamation project, are considered pioneers in direct potable reuse (DPR). The first direct potable reuse plant was commissioned in 1968 and was the result of severe droughts in the regions, with no other viable water sources for the city. This has remained unchanged up to the present time. As the first, and until very recently the only, 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 in 2002. After more than 40 years of operation of direct potable reuse in Windhoek, no adverse health effects have been experienced.

During a similar, severe, drought experienced during 2008/2009 in the southern coastal zones of South Africa and in the semi- arid Great Karoo region bordering this area to the north, the second Southern African direct potable reuse plant was constructed in the small town of Beaufort West in South Africa in 2010. This plant uses advanced water reclamation technologies of ultrafiltration, reverse osmosis and UV/hydrogen peroxide, providing a multi-barrier approach. In George in the Southern Cape, an indirect potable reuse plant was built to replenish the surface water in the Garden Route Dam during this drought period. Feasibility studies for potable reuse (both direct and indirect) have also recently been undertaken, or will soon be performed, for the City of eThekwini (Durban), Hermanus and Cape Town. Planning is further underway for potable reuse in Botswana.

2.2.2 Direct and indirect potable water reuse potential in South Africa

Reuse of wastewater for potable use, either directly or indirectly, constitutes an attractive option since the generally poor management of discharge of treated wastewater in South Africa forms a threat to downstream surface water and groundwater quality. The development of surface water and groundwater sources are the most feasible options to meet any current or projected future water-supply shortfalls. However, these options are becoming increasingly limited, resulting in a current focus on desalination and water reuse as supplementary water supply options. A database was compiled of water reclamation potential of towns in South Africa, in which information was captured on the type of wastewater treatment plant(s) (WWTWs) of the towns and other (known) alternative water sources for drinking water supply to the towns (e.g. borehole schemes, desalination, cross-boundary water transfer schemes). The information was obtained from the All Town Study that was commissioned by the Department of Water and Sanitation's Water Resources Planning Directorate (which is responsible for the compilation of the National Water Reuse Strategy). Details of the database and its intended use is provided in Appendix A and B.

2.2.3 Review of South African Water Quality Targets

With regards to water quality monitoring, there are at least three different organisations or government departments in South Africa that provide water quality guidelines, namely DWS, WRC (Water Research Commission), and the South African Bureau of Standards (SABS), responsible for publishing all South African National Standards(SANS).

2.2.3.1 *South African National Standards for Drinking Water*

The SANS 241 water quality standard is referenced in the Water Services Act, 1997 (Act No. 108 of 1997). SANS 241 (2011) specifies the quality of acceptable drinking water defined in terms of microbiological, physical, aesthetic, and chemical determinants at the point of delivery. Water that complies with the specified parameters in SANS 241 is considered to present an acceptable health risk for lifetime consumption. A risk assessment index is calculated according to a two tiered system. Risk defined tier 1 is required for health effects and tier 2 determinands are used for operational efficiency determination. The proportion of compliant samples is specified in SANS-241 based on whether the population size the water supply system serves is greater than or less than 100 000 individuals. For risk-defined performance indicators if the population size served is greater than 100 000 an excellent water quality is defined where at least 97% compliance occurred, whereas for a smaller population size at least 95% compliance is necessary for a water to be classified as excellent.

In addition to specifying *E. coli* (or faecal coliforms) as microbiological determinands, cytopathogenic viruses and protozoan parasites are specified for "Acute health – 2" determinands and should be absent in a 10 litre sample size. The volume specified is based on a matter of convenience and not as a protection of public health. Using a quantitative microbial risk assessment approach, a volume of at least 1000 litres should be sampled to ensure that the probability of infection is as low as that described in the US EPA and WHO guidelines (Probability of infection of 1 in 10 000 per annum or the equivalent 1 in 100 000 disability adjusted life years or DALYs described in the WHO drinking water quality guidelines (WHO, 2011)).

2.2.3.2 *The DWAF Water Quality Guidelines (1996)*

The South African Water Quality Guidelines developed by the Department of Water Affairs and Forestry (now DWS) 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 possible 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 briefly described in Table 2.4. (Additional metal determinands and latest limits were also added from SANS241:2015). No attempt was made to prioritise the various parameters that should be assessed.

Table 2.4: 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	max mg/L	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 (recoverable) 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	6	10	50

Parameter	Source	DWA WQG for Domestic Use (1996)		SANS 241: 2015
		Target in mg/L unless otherwise stated	max mg/L	Target (max) µg/L unless stated
	faecal pollution			
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

* SANS 241:2005

Due to the dynamic nature of nitrite-nitrate conversion in distribution systems it is prudent to include both ions for regulation

2.2.3.3 *The DWAF, DoH and WRC (1998) Assessment Guide*

A guideline series to provide water supply agencies and water resource managers and other stakeholders with information to sample, analyse, assess and interpret the quality of domestic water supplies was developed and are available from the Water Research Commission website (www.wrc.org.za)

- Quality of domestic water supplies Volume 1: Assessment Guide
- Quality of domestic water supplies Volume 2: Sampling Guide
- Quality of domestic water supplies: Volume 3: Analysis guide
- Quality of domestic water supplies Volume 4: Treatment guide
- Quality of domestic water supplies Volume 5: Management Guide

The Assessment Guide is a user-friendly guide designed for assessing water supplied for domestic use. It involves a simple colour-coded classification system and information is presented in a simplified format so that a wide spectrum of users will be able to understand the underlying concepts of water quality as it affects the domestic user.

This guideline prioritises the substances according to four different groups (Group A-D substances, Table 2.5). The Group A substances are the general indicators of water quality and potential problems within the water supply system. These substances (electrical conductivity (EC), faecal coliforms, pH, turbidity and free residual chlorine) require continuous monitoring (sampling and analysis) at all points within the water supply system (e.g. from source (river), through treatment facility, bulk water supply, the reservoir, to the point-of-use where the end-user will access the water). Group B substances should be determined before the water is supplied (depending on the source and treatment applied), Group C substances require testing at the point-of-use where soft water of a low pH value is used and Group D substances should at least be analysed for when assessing the quality of water for the first time.

The Assessment Guide makes use of a classification system where water is classified into one of 5 classes, as follows:

Table 2.5: Colour-coded classification of water for domestic use

Class / Colour	Description
Class 0 (Blue)	***Ideal*** water quality – Safe for domestic water use
Class 1 (Green)	***Good*** water quality – Safe for domestic use
Class 2 (Yellow)	***Marginal*** water quality – Safe for use, but may affect certain sensitive groups
Class 3 (Red)	***Poor*** water quality – May be used for short-term emergency use where no other supply is available
Class 4 (Purple)	***Unacceptable*** water quality – Water is unsafe without treatment

2.3 APPROACHES FOR DIRECT POTABLE REUSE WATER QUALITY MANAGEMENT

2.3.1 World Health Organisation, California and Australia

First International Guideline for DPR

An international approach to reuse monitoring was officially formulated in a publication titled: "Health effects relating to direct and indirect re-use of wastewater for human consumption" (WHO, 1975). The main approach recommended by an international team of experts was to apply the multiple barrier principle, with main considerations to include:

- There should be more than one line of defence (barrier) against the break-through of pollutants and pathogens for wastewater treatment for reuse.
- Each pollutant should be reduced in concentration by at least two processes and preferably by three or more.
- An essential pre-condition for any reuse of waste water is the control of industrial waste to the maximum degree, so as to remove at source as many potentially toxic chemicals as possible."
- As rapid changes in water quality can be expected a systematic water quality monitoring is needed for both chemical and microbial parameters.
- Continuous monitoring systems and the development of toxicity monitoring systems using living organisms is recommended.
- It was stated that "because of the time required for a full examination a retention time of about 48 hours prior to distribution of the treated water should be strived after.
- Similarly retention for a period of 7 days between the point at which the waste water quality is measured and the treatment plant is advantageous.

Over the years many reports have been published dealing with water reuse but none dealt explicitly with guidelines for DPR. As a result, various schemes developed their own approaches and guidelines, many in line with both international code of practice and according to their national guidelines. A comprehensive manual on water reuse, containing international reuse guidelines applied in various countries was published by Crook et al. in 1992. However, information on DPR was limited. For that reason Windhoek adopted its own guidelines when designing the New Goreangab Water Reclamation Plant (NGWRP). The same was done in Singapore. After publication of the WHO guidelines of 2004 (WHO, World Health Organization, 2004), the emphasis was on risk assessment. It recommended the implementation of water safety plans (WSP). These recommendations were extended in subsequent publications (WHO, 2009) and are adopted by many countries.

In California, the Groundwater Replenishing System (GWRS) in Orange County is considered the world leader in groundwater recharge using reclaimed water for indirect potable reuse (IPR), but considerable work on artificial recharge is also currently being done (and further extensions planned for the near future) at Windhoek, Namibia, where water banking takes place to store the excess reclaimed water for future use. In the case of replenishment of surface water for indirect potable reuse, the Upper Occoquan Service

Authority in Virginia, USA is considered to be doing pioneering work (Lazarova et al., 2013). They have gained long-term experience in this type of indirect reuse.

After a series of severe droughts and water shortages, Australia published an extensive range of guidelines for reuse, including DPR (Australian WQG, 2011). Recently the EPA has also published a manual containing guidelines for water reuse (USEPA, 2012).

Measures to enhance reliability

- Source control: Substances that are not compatible with recycled water systems. Enhance source control programs, including tools to identify and rapidly address contaminants of concern and outreach programs to manage and minimize the discharge of contaminants of concern at source. Ensure regulatory authority and management actions.
- Enhanced fine screening: Fine screens to enhance performance of membrane bioreactors. Also to be used in conventional activated sludge processes (ASPs).
- Elimination of untreated return flows: Return flows contain constituents that deteriorate overall plant performance. Presence of N-compounds in return flows impacts the ability of biological treatment process to achieve low levels of N-removal. Install separate systems which treat N-containing return flows.
- Flow equalisation: To improve performance and variability of downstream treatment processes and to reduce size and cost of treatment facilities.
- Operational mode for biological treatment: Include nitrification-de-nitrification in ASP membrane bioreactors also employing RO should be operated to nitrify completely. Potential to form disinfection by-products and N-nitrosodimethylamine (NDMA) when ASP is operated in either nitrification or nitrification/ denitrification mode, process must be operated and controlled properly.
- Enhanced performance monitoring: HACCP (1992) and WHO-WSP (2004, 2008) should be implemented as a tool to be used for performance evaluation in DPR.
- Ongoing pilot testing: Permanent pilot-scale facilities are incorporated into the design of advanced treatment processes for DPR. These should be used to investigate operational and reliability issues that arise during full scale operation.

Monitoring and constituent detection

On-line monitoring should be done to provide real-time data. Identify surrogate and indicator constituents to assess performance of key unit processes.

- Types of monitoring: Two basic types: real-time and off-line. Real-time on-line monitoring include: TDS, UVA, TOC, Off-line monitoring are conducted in laboratory to verify measurements made by real-time instruments and for detailed characterisation of individual of different classes of constituents.
- Monitoring strategies: Indicator compounds used to predict the presence or absence of other constituents provided that indicator is removed by similar mechanisms and to the same degree as the other constituents. 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.

- Monitoring locations: (a) To assess process performance, (b) process control and (c) verify compliance with public health and other regulatory requirements.
- Catchment monitoring: know what goes on in the catchment. On-line real-time surrogate parameters to determine off-limit changes in the incoming water. (Recommended to use flow-equalisation)
- Process performance and reliability: Monitoring of critical treatment processes or barriers by online real-time surrogate parameters to comply with regulatory or operational target values. Parameters are process specific. Define off-site parameters to validate treatment performance and final water quality.
- Water quality assurance: Full off-site (grab as well as composite and on-line samples) to be analysed for full spectrum of parameters of health concern. Use of qualified accredited labs. Define analytical methods, detection limits, quality assurance and control methods and frequency.

Monitoring at engineered buffer: All constituents of importance can be assessed in the product water with sufficient speed and accuracy within the time limit allowed by the size and design of the buffer facilities. Out-of specification water needs to be diverted to an alternative location.

Future developments in DPR

The question that must be asked is what constitutes an acceptable treatment process train and identifying the corresponding knowledge gaps. There is a need to maintain flexibility in the development of DPR regulations to accommodate the coming technology breakthroughs.

These include: new WWTP processes, blending with natural waters, new AWT technologies, redundant RO (where two RO steps in sequence are included in a treatment train, following USA philosophy). AWT can be with or without demineralisation (with or without RO).

Other concerns may, among other, include the following:

- Balancing of the water supply mineral content.
- Impact of various water chemistries from different sources on infrastructure or health quality when mixed.
- What should the level of blending be? (What will determine this level? Defining a rationale for blending levels).
- Potential impact of purified water on drinking water distribution system: corrosion, water quality impacts.
- Emergency and standby power, equipment, process redundancy.
- Bypass and discharges when quality goes out of specification.
- The requirement to have a review panel for pilot testing and for advice and recommendations on the design, operation and monitoring plans.
- Monitoring protocol for collection of baseline data (raw water) to the AWTP.

- Pilot testing needs to be designed in a way that data can be used to assess the reliability of treatment processes as applied to the proposed source water.

2.3.2 Examples of water quality management strategies in selected DPR schemes

2.3.2.1 *Old/New Goreangab Water Reclamation Plant, Windhoek*

DPR has been practised in Windhoek since 1968, thus there is a firm foundation of experience and an extensive database about the performance of treatment train units to remove various suspended and dissolved organics. Guidelines were developed for the Old Goreangab Water Reclamation Plant (OGWRP) by the National Institute for Water Research (NIWR, CSIR). Between 1992 and 1998 a new set of guidelines was developed for the New Goreangab Water Reclamation Plant (NGWRP). These guidelines were based on the history of the raw water quality, the treatment plant capacity to treat such water to a specific quality, a guide for the planning, design and implementation of a water reclamation scheme (Meiring & Partners, 1982), and a number of international drinking water quality guidelines, such as WHO Drinking Water Guidelines (WHO, 1993), the National Drinking Water Standards and Health Advisories USEPA (USEPA, 1996), the European Community Guidelines for the use of water for human consumption (80/778/EWG) (1980 and 1994 draft) (EC, 1980), Guidelines for the Evaluation of Drinking water for Human Consumption (1991) Department of Water Affairs, Namibia (Namibian Guidelines, 1991) and Rand Water, Potable Water Quality Criteria (Rand Water, 1994).

2.3.2.2 *United States of America (USA)*

Due to increasing water scarcity, conventional water supplies are becoming limited in the USA and as technology improves and the public becomes better informed, increased emphasis will be placed on planned augmentation of drinking water supplies with highly treated water. As a result of the development and demonstration of full scale advanced treatment processes, the use of purified water recovered from municipal wastewater for potable uses is receiving increased interest. Therefore, water agencies and interested parties are defining guidelines and criteria needed for direct potable reuse (DPR). In their report “Direct Potable Reuse, A Path Foreward”, Tchabanoglous and others (Tchabanoglous et al., 2011) draw the following conclusions from reports published in 1975, 1980, 2010, which reflect current academic thinking about DPR at the time and an evaluation of current international DPR plants:

- Advanced treatment steps to be employed, RO, advanced oxidation and others, which will reduce unregulated chemicals that are known or suspected to be of health concern to non-measureable levels to render the product water safe for human consumption.
- Intermediate treated water criteria should apply to ensure best operation of individual treatment units. Failure to meet the intermediate criteria will automatically put the non-complying water into a bypass mode, or even shut the plant down if required.
- During pilot studies or commissioning, no adverse health effects (toxicity, carcinogenicity, reproductive and other effects) are to be detected.

- Comprehensive operation, extensive ongoing monitoring and reporting requirements need to be applied which comply with applied local standards, ISO 9000, HACCP, etc., meeting all intermediate quality target values and applicable numeric drinking water guidelines and standards. Compiled reports need to be evaluated by a steering committee with the necessary knowledge and background of DPR principles and technical knowledge of advanced treatment technology.
- Product water quality needs to be equal or better than conventional supply sources in the drinking water system. It needs to meet or exceed available conventional drinking water requirements as well as all international Drinking Water Guidelines.
- The product water needs to be blended with a conventional water source at a determined level. It can be used via a ground water replenishment system.
- Extensive, ongoing public education needs to be conducted to demonstrate the safety of the DPR and to ensure public participation and acceptance of the project.

The authors recommend:

- There is a distinction between DPR and IPR, which points out the need to investigate the relevance of an engineered storage buffer.
- The need for and its size for an engineered storage buffer should be researched and determined.
- DPR System reliability cannot be compromised.
- Appropriate monitoring techniques should apply for a treatment plant, which are specific for the treatment train implemented.

2.3.2.3 *Australia*

Australia is a country which built up considerable experience in (mostly indirect) water reuse. Some of their experience and recommendations are summarised below:

Multiple barriers

Recycled water systems need to include and continuously maintain robust and reliable multiple barriers. The multiple barrier approach is the foundation for ensuring safe drinking water. The approach applies no matter what the initial source of water. The need for highly reliable barriers is essential for both microbial and chemical hazards. No single barrier is effective against all conceivable hazards or is completely effective all of the time. Multiple barriers protect against variations in performance of individual barriers. Every effort should be taken to ensure that barriers operate within acceptable ranges.

Skills and training

Designers, operators and managers of schemes must have appropriate skills and training. Everyone involved in the design, management, operation and audit of recycled water systems needs to have sufficient and appropriate knowledge and skills for their role. They also need to be aware of the consequences of failure or poor performance. Responsibilities and accountabilities need to be identified, communicated, understood and supervised. Overall operation of the treatment process needs to be supervised by managers with appropriate expertise in engineering and quality assurance. System operators must be able to respond quickly and effectively to adverse monitoring signals.

Management of industrial waste

Industrial waste management programs need to be established and maintained. Risk management plans are predicated on prevention and on dealing with contamination as close to the source as possible. However, chemical quality depends on inputs and can therefore be influenced by trade-waste control programs. Trade-waste programs are essential for preventing or minimising contamination of source waters before treatment.

Regulatory surveillance

All schemes must be subject to regulatory surveillance. Independent regulatory surveillance and auditing needs to be applied to drinking water augmentation, and needs to include involvement of public health agencies. The public has a reasonable expectation that such schemes will be subject to rigorous regulatory oversight. Surveillance and auditing verify that recycled water systems are being managed and operated correctly and at a high standard, and that public health is being protected. Outcomes should be published in publicly available reports.

Operational monitoring

Operational monitoring is used to assess and confirm the performance of individual preventative measures through a planned sequence of observations and measurements. It is the means of providing proof and ongoing assurance that performance requirements and water quality criteria are being met. In this context, operational monitoring includes observational monitoring and testing of parameters at critical control points. These data can be used to trigger short-term corrective actions to protect recycled water quality and to prevent unacceptable risk to human or environmental health.

Verification monitoring of recycled water quality and environmental performance

Verification ('Did it work?') assesses the effectiveness of the recycled water system in delivering safe drinking water to consumers. Verification includes compliance testing of the end product, and testing of environmental buffers and receiving waters. Unlike operational monitoring, verification is not used as a continuous or day-to-day management tool. However, successful verification provides:

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

Verification may be conducted more frequently during the first weeks and months of operation, to demonstrate that water-quality targets are being achieved, and to provide confidence to operators and consumers that target criteria for water quality can be reliably achieved.

Verification monitoring should include chemicals detected in high concentrations in source waters, particularly those that have either exceeded drinking water guideline values or have been detected in concentrations close to guideline values.

Availability of analytical capability is an important issue. Many of the compounds listed in the Australian and USEPA DPR/IPR guidelines are not typically included in drinking water quality monitoring programs. It is important to establish whether there is access to laboratories accredited to perform the required tests and able to detect concentrations below guideline values. Where analytical procedures are not available to detect parameters below guideline values, it will instead be necessary to rely on validation to demonstrate that treatment processes are capable of removing the parameter of concern. Verification will typically include a broad range of parameters during commissioning and in the initial months of operation. Once sufficient data has been collected to confirm that water of the desired quality is being reliably produced, the list of parameters and monitoring frequencies can be reviewed and refined.

Biological screening assays

In vitro tests have been used to measure chemical quality of Australian sewage (Leusch et al., 2005 and 2006, Muller et al., 2007), and a similar approach could be used to monitor the quality of source waters, and of partially and completely treated recycled water. Detection of biological activity should lead to further investigations into the cause of that activity. Biological tests can be used as a screening and prioritisation tool for subsequent chemical analysis. Biological screening can include both in vivo and in vitro assays. Selection of tests will be influenced by a range of factors, including the end point of interest and availability and accessibility to laboratories able to undertake testing.

Establish a sampling plan and ensure monitoring is reliable

Once parameters and sampling locations have been identified, these need to be documented in a consolidated monitoring plan. Monitoring programs need to provide data that is representative, reliable and fully validated. This means that:

- approved sampling methods and techniques need to be applied
- analyses need to be performed by laboratories accredited for the purpose (where accredited methods have been established)
- field and laboratory equipment need to be maintained and calibrated
- limits of detection and characteristics measured need to be appropriate (limits of detection need to be below concentrations representing potential health risks)
- all procedures need to be performed by qualified personnel and be subject to quality-assurance and quality-control procedures.

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 include:

- 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

Communication

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.

Operator and contractor awareness and training

The importance of operator 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.

Operator and contractor awareness, training and involvement

Operators and contractors need to be aware of the potential consequences of system failure, and of how decisions can affect public and environmental health. Ensure operators and contractors 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. Operators and contractors 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.

Contractors

Contractors are increasingly used to undertake work associated with recycled and drinking water schemes. In some cases, more than one contractor might be involved. For example, separate contractors might be involved in construction, operation of treatment processes, operation of distribution systems, and sampling and analytical work. Requirements for contractor acceptability need to be established, and contractors need to be evaluated and selected on the basis of their ability to meet the specified requirements.

Conditions of the contract under which a contractor operates need to be clear, accurate and achievable, with scope for ongoing review and improvement. Partnerships will be more successful where the recycled water supplier retains sufficient knowledge and technical expertise to manage the contract efficiently.

Community involvement and awareness

Consultation with the community is a vital element in developing recycled water schemes, particularly those involving drinking water augmentations. Surveys have indicated that community concerns increase as the degree and likelihood of personal contact with recycled water rises. For example, use of recycled water for urban or agricultural irrigation has high levels of acceptance (Po et al., 2004), whereas closer contact, including consumption of recycled water, has lower levels of support. 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.

Validation, research and development

Validation of preventive measures (‘‘Will they work?’) 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. Possible areas for applied research and development are the following:

- 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
- Emerging water-quality issues
- Synergistic, additive and antagonistic effects of chemicals
- 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.

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.

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.

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.

Documentation and reporting

Documentation provides a basis for effective communication within the organisation, as well as with the community and various stakeholders. A system of regular reporting, both internal and external, is important to ensure that the relevant people receive the information needed to make informed decisions about the management or regulation of recycled water quality and the system (from source to consumer). Documentation needs to be visible, and readily available to operators and contractors, as required. Mechanisms need to be established to ensure that operators read, understand and adhere to the appropriate documents.

Monitoring

General principles

Monitoring can be undertaken for a range of purposes; for example, monitoring may be used to:

- obtain baseline information (to underpin the risk assessment process)
- Determine whether recycled water systems will be safe and not represent a risk to human health or have detrimental effects on the environment (validation, i.e. 'Will it work?')
- Ensure that preventive measures are working (operational monitoring, i.e. 'Is it working now?')
- Determine whether the recycled water system has operated effectively, achieved compliance with management requirements and has not represented a risk to public health or had detrimental effects on the environment (verification, 'Did it work?')
- provide information needed for investigation, follow-up and research

Monitoring may also form part of the surveillance undertaken as a statutory requirement under licence or approval from a regulatory authority. The main functions of each of these types of monitoring are given in Table 2.6 below.

Table 2.6: Purpose of main types of monitoring

Type of monitoring	Main functions
Baseline	Gather information that will underpin the risk assessment process, and provide a basis for assessing potential impacts of the use of recycled water on the environment
Validation	Obtain evidence that the elements of the recycled water quality management plan will achieve performance requirements
Operational	Conduct a planned sequence of observations or measurements of control parameters to assess whether a preventive measure is operating within design specifications and is under control
Verification	Apply methods, procedures, tests and other evaluations (in addition to those used in operational monitoring), to determine compliance with the management plan for recycled water quality, and to determine whether the plan needs to be modified.

Baseline monitoring is undertaken before establishing a recycled water system, whereas validation, operational and verification monitoring are undertaken in establishing and running such a system. These latter forms of monitoring are common to risk management systems such as the hazard analysis critical control point (HACCP) approach.

Validation monitoring is an intensive activity used to prove that preventive measures are capable of adequately controlling recycled water quality within the bounds required to achieve health and environmental target criteria. As far as practicable, validation monitoring should be completed before recycled water is supplied for use, although it may continue into a pilot-testing period. Validation needs to be performed, or at least overseen in detail, by an independent and appropriately qualified professional or group of professionals. For example, validation of a disinfection system would require expertise in microbiology. The work would need to be overseen by someone independent of any organisation with a stake in the system, and independent of the laboratory that undertakes the microbial validation testing. Validation of reverse osmosis and advanced oxidation processes would require expertise in chemical testing. Such oversight provides independent assurance that the system being validated, and the sampling strategies and laboratory techniques being applied, are sound. One of the objectives of validation monitoring is to prove that the system delivers the expected water quality when operational monitoring results are specified. Therefore, operational monitoring, discussed below, is generally performed at the same time as validation monitoring, to provide a point of comparison.

Operational monitoring is the routine monitoring of preventive measures such as trade-waste control programs and treatment processes. It provides generally rapid assessment of performance of individual preventive measures. A properly designed operational monitoring program should provide a timely warning to the manager of a recycled water scheme, allowing corrective action to be taken before unsafe recycled water is supplied. Operational monitoring is required for all preventive measures, but is particularly important for critical control points. The intensity of operational monitoring needs to be commensurate with the variability and criticality of the specific preventive measure. Drinking water augmentation will typically incorporate online monitoring for a number of critical processes.

Online monitoring devices must be reliable; they should also be properly and regularly calibrated, and compared with laboratory determinations of reference meters. Online systems can produce false alarms caused by factors such as instrument errors, blockages and air bubbles. However, all alarms must be treated as real unless or until it becomes clear that a false alarm has occurred. If excessive false alarms are happening, then improved instrumentation and control algorithms are needed, rather than less urgent responses.

The purpose of **verification monitoring** is to confirm compliance with the recycled water quality management plan. Verification of recycled water quality assesses the overall performance of the recycled water system, the ultimate quality of recycled water being supplied or discharged, and the quality of the receiving environment. Verification includes monitoring for compliance with criteria associated with:

- drinking water quality
- environmental values, including recreational use of receiving waters and ecological values

Verification monitoring is often conducted more frequently during the first weeks and months of operation, to demonstrate that water quality and receiving environment targets are being achieved, and to provide confidence that the target criteria for water quality will be reliably achieved in the future. 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

Verification testing should only be undertaken by laboratories accredited for the specific tests. Laboratories need to provide evidence that test results have been conducted in accordance with accredited techniques, and that appropriate quality control procedures have been applied, including the use of analytical standards.
Table 2.7 provides an overview of indicative monitoring requirements for public health aspects of drinking water augmentation.

Table 2.7: Indicative monitoring requirements – public health aspects

Type of monitoring	Where	Parameters	Frequency
Baseline	Source of receiving water	**Pathogens or indicators:** *Cryptosporidium, Campylobacter, Escherichia coli, Clostridium perfringens*, enteric viruses, coliphage, etc. **Inorganic chemicals:** As specified in the *Australian Drinking Water Guidelines* (see ADWG) **Organic chemicals:** Health-related chemicals (see ADWG), pesticides, hormones, pharmaceuticals, personal-care products, fire retardants, dioxins, etc.[a]	Source waters and receiving waters to be monitored on a weekly basis for pathogens or indicators and on a monthly basis for chemicals, for at least 12 months, to establish the range of hazards and seasonal variations
Validation	Pilot plants (laboratory and on-site, after process being validated), pre- commissioning and commissioning trials (on-site, after process being validated)	**Target parameters** that are meant to be removed or inactivated by the process (e.g. pathogens for disinfection, chemicals and pathogens for reverse osmosis, NDMA for advance oxidation). **Operational monitoring indicators and surrogates** (see below).	Sufficient frequency to prove effectiveness of the process against target compounds, in a statistically valid manner
Operational	On-site	Process specific monitoring of activity, surrogates and indicators. **Activity:** Transmembrane pressure, flow rates, dose rates, ultraviolet light transmission, chlorine residual **Surrogates:** Turbidity, total organic carbon, conductivity	**Activity and surrogates** Most monitoring will be continuous but pressure-based testing of membranes daily **Indicators** Tested weekly

Type of monitoring	Where	Parameters	Frequency
		Indicators: Boron, NDMA, chloroform, DEET, caffeine, estrone, meprobromate, heterotrophic plate count, coliphage, *Clostridium perfringens*	
Verification	At entry into receiving waters and end point of supply[b] Biological monitoring form locations within treatment train	**Microbial indicators:** (*E. coli, Clostridium perfringens*, coliphage) **Inorganic chemicals:** (see ADWG) **Organic chemicals:** Health related chemicals (see ADWG), pesticides, hormones, pharmaceuticals, personal-care products, fire retardants, dioxins etc. **Disinfection by-products** **Biological monitoring**	**Microbial indicators** Tested three times/week **Inorganic chemicals** Monthly **Organic chemicals** Key parameters monitored monthly, other compounds monitored quarterly or annually based on likelihood of occurrence (from baseline monitoring and catchment surveys) **Disinfection by-products** Monthly **Biological monitoring** Monthly

ADWG = Australian Drinking Water Guidelines (NHMRC-NRMMC 2004); DEET = N,N-diethyltoluamide (N,N-diethyl-3-methylbenzamide); NDMA = N-nitrosodimethylamine

a Range of parameters based on existing system specific data, catchment surveys, published data, consumers perceptions,

b Design of point of supply monitoring program should consider program and results from receiving water input.

2.3.2.4 *Singapore, NEWater*

Introduction

Wastewater from domestic, commercial and industrial sectors is collected via a comprehensive sewer reticulation system and treated at six wastewater treatment plants to secondary standards. This treated effluent is a strategic alternative water resource. By using the latest proven membrane technology, a new source of high quality water can be produced. An expert panel consisting of both local and foreign experts in: engineering, biomedical science, chemistry and water technology was formed in January 1999, and oversaw the NEWater study. After evaluating plant performance and extensive testing of final water quality (including physical / chemical analyses; pesticide/herbicide analyses; radionuclides; synthetic and natural hormones; microbiological testing; and toxicology testing on fish and mice) for a period of two years, the expert panel concluded:

- NEWater is considered safe for potable use (and meets the latest requirements of the US EPA's National Primary and Secondary Drinking Water Standards and WHO's Drinking Water guidelines; and
- Singapore should adopt the approach of indirect potable reuse.

As drinking treatment from traditional water supplies become more expensive and source waters become more scarce, water recycling increases in importance. The Singapore Government is actively developing, testing and installing new approaches for drinking water treatment and supply. In particular, wastewater reuse for indirect potable reuse with the installation of the 40,000 m^3/day Kranji NEWater plant. The Kranji NEWater plant is a prime example of how wastewater reuse can be employed to produce high grade water for industrial use. This has the benefit of both providing industry with higher quality water and reducing potable water usage in industry by replacing it with NEWater.

Reliability and Safety of Plant Design and Operation

Potable reuse projects require more robust multiple barriers to chemical contaminants and microbial pathogens than conventional water treatment systems *(NRC, 1998).* For water systems, the systematic reduction of risk to human health to waterborne contaminants is comprehensively known as "multiple barriers". The provision of independent multiple barriers, or redundant safety measures, as well as a continuous, vigilant monitoring and surveillance programme will ensure the greatest level of safe, reliable operation of a potable reuse water system. The NEWater Factory is designed with a number of failsafe features to ensure the NEWater produced is of high quality, as well as protect the plant equipment from adverse operating conditions. Some of the fail-safe features are as follows:

- Routine membrane integrity testing;
- Standby units are provided for all critical equipment;
- Routine calibration and verification of the on-line monitoring instrumentation;
- Provision of automatic warning systems to alert the operator of abnormal plant conditions;
- Automatic shutdown of the plant in the event of adverse operating conditions; and
- Computerised data acquisition and trending of the operational data in real-time.

Plant Production

The NEWater Factory has been challenge-tested to prove that the constructed plant could meet or better all design specification requirements. The trials proved that the plant is capable of a production capacity of 10,000 CMD (m^3/d), while meeting all the water quality criteria.

Sampling and monitoring programme: overview

The Sampling and Monitoring Programme (SAMP) involves a comprehensive set of physical, chemical and microbiological tests. The water samples are analysed for all drinking water parameters listed in the current USEPA National Primary and Secondary Drinking Water Standards and WHO Guidelines for Drinking Water Quality, in total some 190 physical, chemical and microbiological parameters related to water quality have been measured.

Table 2.8 summarises the number of physical, chemical and microbiological parameters related to water quality with the sampling location.

Outcome of comprehensive testing

The physical, chemical and microbiological data for NEWater are well within the latest requirements of the *USEPA National Primary and Secondary Drinking Water Standards and WHO Drinking Water Quality Guidelines*.

Health effects study

The Health Effects Testing Programme (HETP) involves the evaluation of the long-term chronic toxicity and estrogenic effects of the NEWater product in comparison to PUB (Singapore National Water Agency) Raw Water (reservoir water); the latter is drawn from the Bedok Reservoir. The HETP complements the comprehensive physical, chemical and microbiological SAMP and is ongoing. The ongoing HETP will provide further information on the safety of NEWater. The parallel use of mice and fish in long-term (carcinogenic and estrogenic potential) testing is unique and more sophisticated than previously reported health effects studies of water reclamation.

To date, the findings of the NEWater Study's HETP show that exposure to or consumption of NEWater does not have a carcinogenic (cancer causing) effect on the mice and fish, or an estrogenic (reproductive or developmental interference) effect on the fish.

Table 2.8: Summary of physical, chemical and microbial parameters sampled

Water Quality Parameter	**Sample Location**						
	Plant Feedwater (1)	**MF Filtrate (2)**	**RO Permeate (3)**	**UV Effluent (4)**	**NEWater (5)**	**PUB Raw Water**	**PUB Drinking Water**
Physical	9	3	3	2	8	8	7
Inorganic							
Disinfection by-products	6	1	2	1	6	6	6
Inorganic-other	39	2	32		39	38	39
Organic							
Disinfection byproducts	22		22		22	22	22
Other compounds	42				41	41	37
Pesticides/Herbicides	50				50	50	50
Radionuclides	6				6	6	6
Water Signature Compounds	4				4	4	4
Synthetic & Natural Hormones	3	3	3		3	3	3
Microbiological	10	9	7		10	9	3
Totals	191	18	69	3	189	187	177

*PUB: Singapore National Water Agency

Expert panel findings and recommendations

After evaluating the data and reports presented during the reviews, the Expert Panel arrived at the following conclusions:

a) NEWater is considered safe for potable use, based on the comprehensive physical, chemical and microbiological analysis of NEWater conducted over two years. The quality of NEWater consistently meets the latest requirements of the U.S. Environmental Protection Agency's National Primary and Secondary Drinking Water Standards and World Health Organisation's Drinking Water Quality Guidelines

b) Singapore should adopt the approach of indirect potable reuse (IPR) based on the following reasons:

    i. Blending with reservoir water will provide trace minerals, which have been removed in the reverse osmosis process, necessary for health and taste;

    ii. Storage provides additional safety beyond the advanced .technologies used to produce safe high quality NEWater,

    iii. Public acceptance.

   This approach is similar to the precedent practice in the U.S. with planned indirect potable reuse;

c) The Singapore Government should consider the use of NEWater for indirect potable reuse, as it is a safe supplement to the existing water supply; and

d) A vigilant and continuous monitoring and testing programme be carried out if a Planned IPR scheme is implemented.

2.3.2.5 *Israel*

Israel utilises the majority of their reclaimed water for agricultural activities or IPR. In order to enable the use of reclaimed wastewater for agricultural irrigation, it has to comply with agrotechnic, environmental and sanitary quality requirements. These requirements do not always coincide, as in the case of nutrients, where from the environmental point of view the concentration in the effluents should be as low as possible, while from the agrotechnic point of view a certain level of nutrients is desirable since it obviates the need for addition of costly fertilizers. The agrotechnic requirements are low salt concentration and of heavy metals and xenobiotic compounds, controlled level of nutrients and salts, and no malodors and storage capacity in order to regulate between sewage production and demand of treated wastewater for irrigation (which occurs only in certain hours/days/seasons). When drip irrigation is practised, relatively low clogging potential is essential in order to prevent clogging of the irrigation system.

The sanitary requirements mainly refer to the pathogens present in domestic sewage (viruses, bacteria and parasites). One of the main concerns related to wastewater reuse is the potential transmission of diseases. Long-term experience in numerous countries shows that wastewater irrigation with properly treated effluents does not endanger public health. Thus, controlled reuse of wastewater may improve public health (directly or indirectly) instead of endangering it. What quality should be met? There are two different guidelines, namely: The Californian Guidelines (State of California, 1978) and the World Health Organization Guidelines (WHO, 1989; Blumenthal, Mara, Peasey, Ruiz-Palacios, & Stott, 2000).

The degree of sewage treatment required for wastewater reuse is not necessarily better and more expensive than the degree required for the release of effluents into water bodies. On the contrary, in some cases it may be cheaper. Nevertheless, it is important to stress that the quality of wastewater required for wastewater irrigation is different from the quality required for the release of wastewater in water bodies (e.g. regarding nutrient removal). Most indirect reuse schemes inject treated wastewater treated to a high degree into the underground aquifer, often using the natural filtration through layers of sand. This water is collected and then treated again to drinking water standards.

2.4 INTAKE WATER QUALITY MONITORING PROGRAMS FOR DPR

Strategic Water Quality Monitoring and Management are done to assure the safety of drinking water for public health protection. It is a holistic and comprehensive approach to risk management. Adequate resources must be supplied by the operator of the water treatment and distribution system to implement a strategic, system-specific and evidence based monitoring system which effectively informs about risk. The data must be collected in a meaningful way to understand the entire water supply system, provide improved insight on hazards, treatment performance and overall vulnerability of the system. Effectively designed monitoring programs support the collecting of data that increase the understanding of an individual water supply system, the risks present in normal operating conditions or during events.

2.4.1 Definitions and descriptions of monitoring terminology

Drinking water quality monitoring*:* It should assure the safety of drinking water for public health protection. To achieve this, it 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: Understanding the continuous challenge of changing water quality in the water source due to two contributing mechanisms in the catchment, namely changes in the natural hydrological cycle and activities of society. It aims to understand the contamination challenge by capturing normal operation, seasonal variation and individual events.

Operational monitoring: Accesses and confirms the performance of individual treatment plant barriers against specified target values. Non-compliance should trigger short term corrective action to protect product water quality in order to prevent unacceptable risk to human health. It aims to understand the treatment performance.

Validation monitoring, research and development: “Will they work?” Validation of preventive measures 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.

Verification monitoring: "Did it work?" 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.

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.

2.4.2 Risk, HACCP and Water Safety Plans (WSP) in IPR and DPR

The main thrust of HACCP (Hazard Analysis & Critical Control Points) and a Water Safety Program (WSP) is to understand the risks associated with the process and in order 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.

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 adopting and publishing 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.

2.4.3 Catchment monitoring or source water monitoring

It is important to understand what activities, urban, rural, agriculture, industrial, mining or recreational are going on in the catchment. How is the climate, wind, rain, droughts affecting the water source? Understanding the potential hazards that could arise from the natural hydrological cycle or human activities is the foundation of strategic evidence based monitoring. Source water monitoring is preventative and therefore real-time or on-line monitoring measurements should be done, which would trigger a warning when target levels are exceeded, which in turn will trigger a preventative measure in the operation of the treatment and storage processes. Where direct potable drinking water reclamation (DPR) is practised, there will be a primary and a secondary catchment. See Figure 2.1. The primary catchment covering the natural water sources and the secondary catchment covering the domestic and industrial effluents is controlled by a pollution monitoring and management program. Appropriate legislation and bylaws should regulate and determine control measures in the area. Measures that should be considered by the water authority to minimize the risk within the catchment are re-zoning, promulgation of by-laws; awareness campaigns and regular inspections.

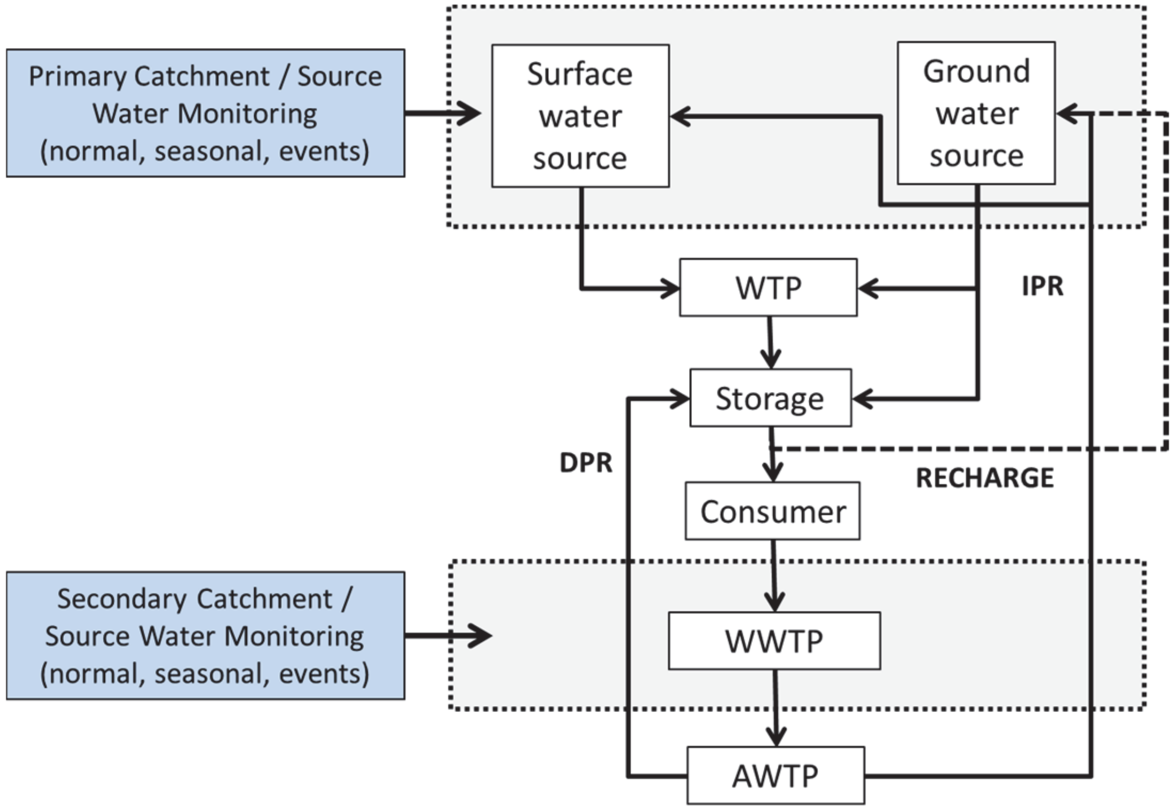

Figure 2.1: Primary and secondary catchment where either direct (DPR) or indirect (IPR) potable drinking water reclamation is practiced, further indicating aquifer recharge.

Substances of concern that could enter the water cycle include the flowing:

- NOM (Natural Organic Matter)
- Nutrients
- Viruses and other microorganisms

- Algae
- Inorganic pollutants (toxic anions and cations from mining activity and industry)
- Organic micro pollutants (including persistent organic pollutants, or POPs)
- Pharmaceuticals & endocrine disruptors (EDP's)
- Residuals from treatment chemicals including: DBP's (Disinfection By-products); corrosion; bacterial regrowth; undesirable tastes and odours.

It is helpful to compile a Risk Table for each water source in the catchment, with the possible expected water quality problems that could occur in the water cycle. Table 2.9 is an example from Windhoek's monitoring program. Each risk is rated and given a frequency of possible occurrence, which is reviewed every year. The table supports the drawing up of a comprehensive monitoring program. It is recommended that the Water Safety Plan (WSP) from the WHO, 2009 be followed.

Table 2.9: Risk table showing human activity in each catchment area that could cause water quality problems

ACTIVITY	WATER SOURCE #1	WATER SOURCE #2	WATER SOURCE #3	EXPECTED WATER QUALITY PROBLEMS (no order or priority)
Live stock	YES		YES	Taste & Odour Dissolved Metals Algae Toxins Corrosion Filter clogging DBPs Eutrophication Toxicity, Mutagenicity Water difficult to Treat AOX, other Higher treatment cost Toxic inorganics High chlorine demand Pathogens
Mining	YES			
Settlements (urban, rural)	YES	YES	YES	
Recreational boating	YES			
Evaporation	YES			
High temperature fluctuations	YES			
Treatment chemicals	YES	YES		
Industrial pollution		YES	YES	

Continuous monitoring, either by on-line instrumentation or by regular sampling of either composite or grab samples, will inform the quality manager of any events that occur in the water cycle or failures of treatment units to perform to the required guideline level. Such a program will trigger an alarm and further investigation. Table 2.10 shows water quality data for the intake water entering the NGWRP. From this table it can be seen that the quality of the intake water deteriorated significantly. It is important to understand why the water quality is changing and how this will affect the WRP. Examples of events in the primary catchment where the natural supply sources are situated can be a heavy rainfall, which can raise the turbidity, ammonia levels, DOC levels, metal levels, algae growth and raised pH levels. Although this does not influence the Advanced Water Treatment Plant (AWTP), it will affect the primary water quality in the distribution system.

Long term droughts and low water levels in the water source (dam or river), will raise the Total Dissolved Solids (TDS) and Dissolved Organic Carbon (DOC) levels. These will influence the treatment of the AWTP and add additional load on the treatment unit. Examples of an event in the secondary catchment can be an oil spill, which will effect biological treatment, and any spill from an industrial site into the sewer either directly or through the storm water system. Such events need to be transmitted correctly to take necessary precautions. Events during treatment can be the failure of a treatment unit to meet the required target guideline. This should trigger the control centre of the AWTP to go into recycle mode.

Table 2.10: Windhoek Reclamation Raw Water Values: Raw Maturation Pond and Raw Mix (Raw Maturation Pond and Return Flow)

Windhoek Reclamation Raw Water Values (95th percentiles)			
Parameter	Unit	Raw Mat	Raw Mix
		1995-1999	2006-2007
Chlorophyll A	µg/l	35.38	55.93
pH	-	8.40	8.25
Conductivity	mS/m 25°C	115	145
TDS calculated	mg/l	772	972
Turbidity	NTU	15.000	5.454
Colour	mg/l Pt	5.00	101.00
Total alkalinity	mg/l CaCO3	265.39	250.91
Total hardness	mg/l CaCO3	191.19	238.75
Calcium hardness	mg/l CaCO3	132.77	156.50
Magnesium hardness	mg/l CaCO3	62.23	88.50
K	mg/l	63.46	39.66
Na	mg/l	165.23	219.77
Cl	mg/l	138.59	247.86
SO4	mg/l	115.63	185.50
F	mg/l	0.61	0.61
Nitrate (NO3-N)	mg/l as N	16.65	20.00
Nitrite (NO2-N)	mg/l as N	0.51	0.57
Br	mg/l	0.31	0.39
THMFP	µg/l	191	182
CHCL3	µg/l	133	117
CHCL2Br	µg/l	48	37
CHCLBr2	µg/l	24	27
CHBr3	µg/l	1	1
TKN	mg/l as N	3.31	5.80
Ammonia (NH3-N)	mg/l as N	1.98	1.96
Ortho phosphate (P)	mg/l	7.78	11.00
TSS:105°GF	mg/l	12.00	23.30
FSS:500°GF	mg/l	5.38	11.80
VSS:500°GF	mg/l	6.10	13.90
DOC	mg/l	16.08	10.68
COD	mg/l	42.60	37.75
UV 254	abs/cm	0.3100	0.2239
Temperature	°C	25.30	25.07

Windhoek Reclamation Raw Water Values (95th percentiles)			
Parameter	Unit	Raw Mat	Raw Mix
		1995-1999	2006-2007
HPC	per 1 ml	262 075	520 500
Total coliform	per 100 ml	40 300	18 385
Faecal coliform	per 100 ml	9 500	2 088
E Coli	per 100 ml	6 217	1 865
Faecal streptococci	per 100 ml	200	464
Pseudomonas	per 100 ml	--	72
Clostridium spores	cfu/100 ml	4 000	8 810
Clostridium viable	cfu/100 ml	5 518	25 100
Som. coliphage 100 ml	PFU/100 ml	3 700	4 800

2.4.4 Distribution system monitoring

Distribution system contamination is a significant problem and is a major cause of waterborne disease. Having a good quality water supply and failing to protect it in the storage and distribution system is a source of many disease outbreaks. The monitoring is limited in its ability to provide real time operational information necessary to prevent potential contamination from reaching the consumer. Monitoring strategies should be included to detect changes within the distribution system or potential contamination more effectively. Parameters measured by online real-time instruments are turbidity, chlorine residual, pH, and pressure changes. These provide timely information of potential changes that are out of the normal range. These should be installed at points where the water source enters the distribution system, as well as at storage reservoirs or pump stations where water mixes are pumped into the distribution system. Preventative measures will include a cross-connection control program, approved backflow prevention devices, maintaining adequate pressure and chlorine residual levels, leak detection programs, protection of storage facilities and efforts to control corrosion.

When to monitor

Most drinking waterborne disease outbreaks are linked to some significant change in conditions in the environment that have challenged the capacity of the water treatment system. In addition to monitor the source, treatment and distribution, it is necessary to document information on events, whether seasonal or sporadic to understand unusual weather or environmental conditions on the source water quality and subsequent treatment to inform on its vulnerability. Any extreme change in water quality, flow due to rain or flooding, treatment variations, maintenance and repairs, power outages, should heighten awareness and increased monitoring to re-evaluate the system. The information will help to develop or improve early warning systems.

What to monitor

Microbiological pathogens represent the clearest and most acute risk in DPR. Waterborne disease outbreaks caused by chemicals arise from specific natural local conditions or from contamination due to illegal or unauthorised dumping either into the sewer or environment in the catchment of the AWT. Treatment chemicals may also pose a significant risk if applied outside their recommended concentration or dosage. Disinfection by-products that are formed due to oxidation and disinfection may also pose adverse health effects.

The following is a monitoring approach that was adopted by the City of Windhoek, for monitoring (a) the supply from the direct potable reclamation (DPR) plant, (b) the surface and groundwater sources and (c) the distribution system. Figure 2.2 is a Diagram of the complexity of Windhoek's distribution system. Five mixtures from five different water sources enter the distribution system. Because Windhoek is surrounded by hills, there are 17 pressure zones, which cover the complete area. Plant operation and maintenance play an important role. Equally important or even more so is the monitoring of substances which are removed by the different process steps. A comprehensive monitoring program (seen in Table 2.11) was established to cover the entry points, the storage and distribution points in the drinking water cycle in Windhoek (Liputa, 2008).
The focus of Table 2.11 is, to detect possible pollutants emanating from catchment activities and geography, treatment processes or during transport and storage entering the water cycle or being generated in the water cycle. Selection of sample points is determined by the history of the water sources, the reliability of treatment processes and the characteristics of the distribution network like pressure zones, mixing zones, low flow, population densities served.

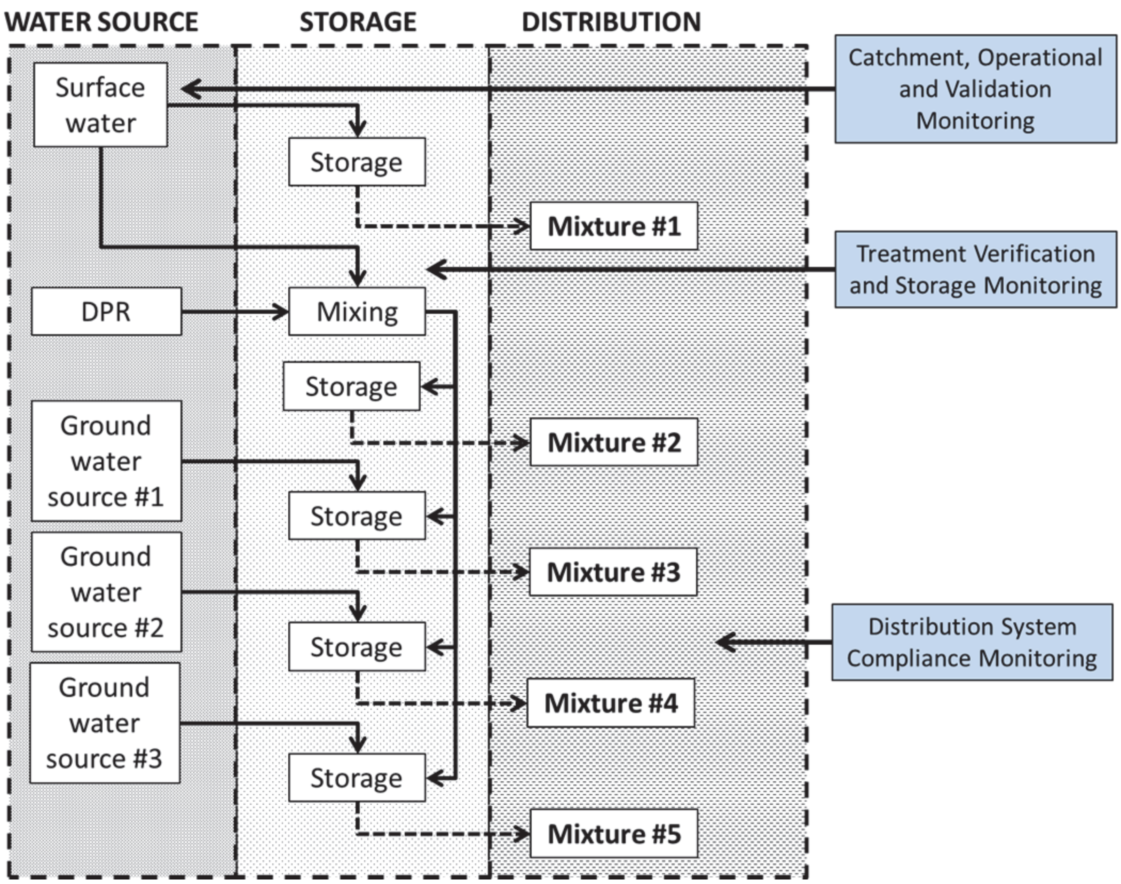

Figure 2.2: Diagram to demonstrate the complexity of the monitoring program in Windhoek, Namibia.

Table 2.11: Example of Treatment / Storage and Distribution Monitoring for Windhoek's drinking water system

	SOURCE A SURFACE & DPR	**STORAGE A** RESERVOIRS	**SOURCE B** GROUND WATER	**STORAGE B** RESERVOIRS	**DISTRIBUTION** GROUP A	**DISTRIBUTION** GROUP B	**DISTRIBUTION** GROUP C
	SOURCE #1 AND SOURCE #2	RESERVOIR #1 TO RESERVOIR #6	SOURCE #3 TO SOURCE #5	RESERVOIR #7 TO RESERVOIR #15	CRITICAL SAMPLE POINTS	IMPORTANT SAMPLE POINTS	PLACES OF PUBLIC INTEREST
AMOUNT OF SAMPLE POINTS	2	6	3	9	28	40	150
SAMP-FLD	2xw	2xw	1xd	1xw	1xw	1xm	1xa
MICR-BACT	2xw	1xw	1xd	1xw	1xw	1xm	1xa
MICR-BIOL	1xw						
CHEM-PHYS	2xw	1xw	1xd	1xw	1xw	1xm	1xa
CHEM-STAB	1xw	1xw	1xw	1xw	1xm	6xa	1xa
CHEM-ORG	2xw	1xm	2xw	1xm	1xm	6xa	1xa
CHEM-MET-1	1xw	1xm	1xw	1xm	1xm	6xa	1xa
CHEM-INORG (IC)	1xw	1xm	1xw	1xm	1xm	6xa	1xa
CHEM-SMELL:	<wn>	<wn>	<wn>	<wn>	<wn>	<wn>	<wn>
HEALTH-THM	1xm	6xa	1xm	6xa	3xa	3xa	
HEALTH-TOX	1xm	1xa	6xa				
HEALTH-MET-2	1xm		1xa				
HEALTH-GIARDIA	1xw						
HEALTH-VIRUS	1xw		1xa				
HEALTH-ENDOCRINE	3xa	2xa	1xa				
OPERATIONAL – ONLINE	ol	ol	ol	ol			

SAMP-FLD: pH, Turb, Free+Total Chlorine, Temp
MICR-BACT: HPC, TC > EC
MICR-BIOL: Chlorophyll
CHEM-PHYS: pH, Turb, Cond
CHEM-STAB: Ca, Mg, Tot-Hard, Tot Alk, CCPP
CHEM-INORG (IC): K, Na, Cl, PO4, SO4, F, Br , NH4, NO3, NO2 (BrO4)
CHEM-ORG: DOC, UV254
CHEM-MET-1: Fe, Mn, Al

CHEM-SMELL: Geosmin, 2MIB, H2S, Chloramines, Chlorine demand
HEALTH-THM: THM (CHCL3, CHCL2Br, CHCLBr2, CHBr3)
HEALTH-TOX: Urease, Bact growth, Daphn Leth, Ames
HEALTH-GIARDIA: on-line Giardia + Cryptosporidium
HEALTH-MET-2: Heavy metals by ICP
HEALTH-VIRUS: PCR
HEALTH-ENDOCRINE: 1xa (chem-Overseas) 2xa (Elisa)
OPERATIONAL ON-LINE: Turbidity, pH, Conductivity, Free Chlorine, DOC, UV254, NO3

xw = per week
xm = per month
xa = per year
<wn> = during a smell problem
ol = on-line / real time monitoring
#1 sampled once in a three year cycle

(Note: The table excludes the operational and verification monitoring done on the treatment plants)

2.4.5 Industrial pollution monitoring

Because domestic waste effluent is reused, industrial pollution monitoring is seen as part of the holistic monitoring program. This program must be driven by the local authority. As mentioned above, legislation and bylaws should regulate and determine control measures in the area. The Water Basin Management Committee should actively support measures to safeguard the natural water supply and reuse schemes in their catchment. Where the resource is of a critical nature, re-zoning should be considered. The pollution team is responsible for monitoring, inspections and holding of awareness campaigns. Public meetings should be held to inform the public and industry of their obligation towards protection of the water sources.

2.4.6 Routine monitoring and health research monitoring

The monitoring program is divided into operational routine and a health research monitoring program. The operational routine monitoring program covers the process control and final water compliance monitoring. The laboratory which is analysing the water samples, should be using state-of-the-art analytical equipment, standardised methods applying ISO 17025 guidelines to verify the test work. A range of bioassays can be applied to test for end points such as genotoxicity, mutagenicity, tumor induction, whole-animal toxicity, estrogenicity and androgenicity. Detection of biological activity should lead to further investigations into the cause of that activity. Biological tests can be used as a screening and prioritisation tool for subsequent chemical analysis.

The health research program covers parameters which are very expensive and are mostly contracted out to overseas laboratories because of the sophisticated nature of the tests. It also includes the development of new test methods, sampling approaches and pilot experimentation to monitor new process concepts and applications. Due to a limitation of having advanced water research or testing equipment available in Namibia, such tests are contracted out to South African or European laboratories as part of cooperation programs.

2.4.7 Consumer satisfaction monitoring

An effective consumer complaint and response system, linked to operations, monitoring consumer satisfaction, will be an important surveillance mechanism that can provide valuable and timely information on potential problems in the distribution system. It provides opportunity for early recognition of contamination and for initiating corrective actions.

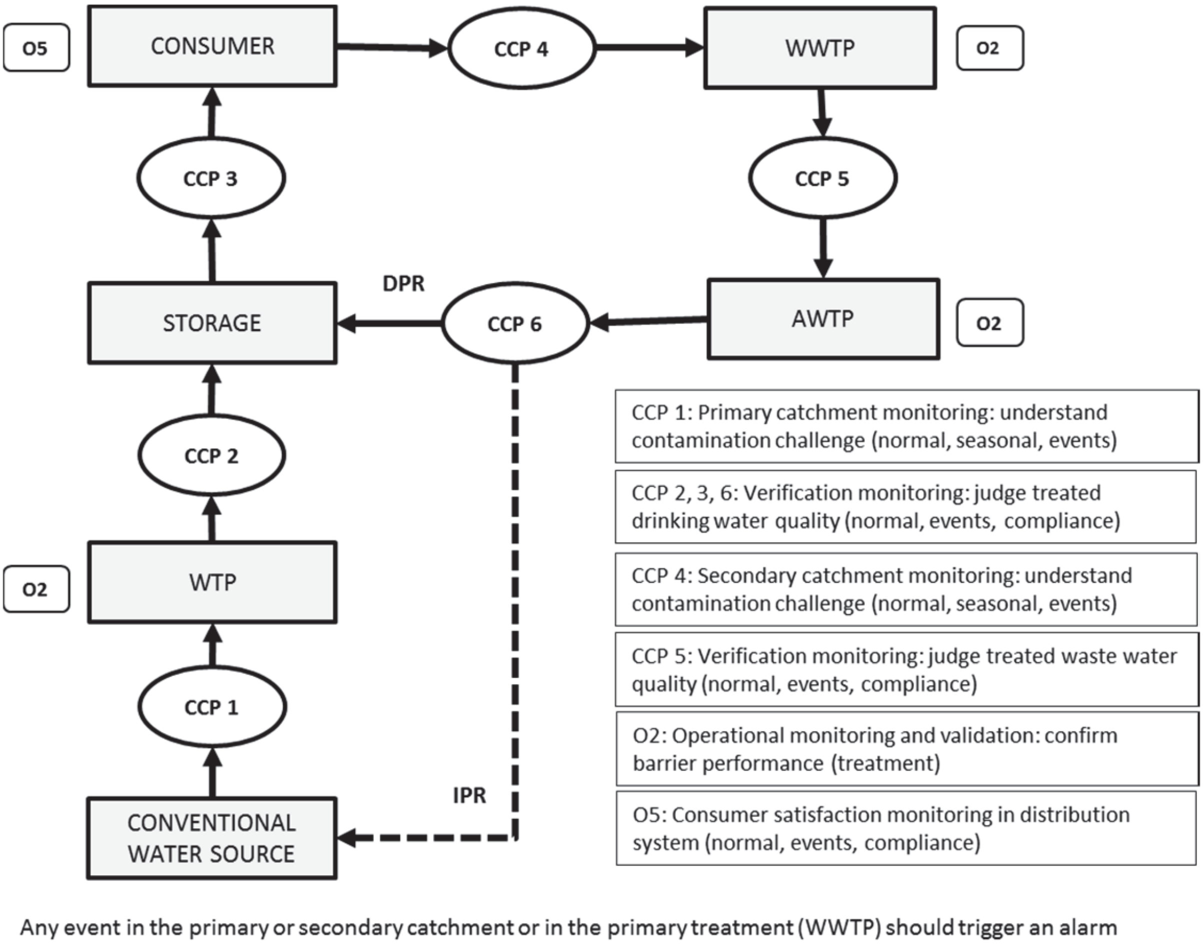

Figure 2.3: Risk-based monitoring program that covers the water treatment, distribution, collection and treatment of waste water, advanced water treatment supply to distribution network

2.4.8 Parameters not yet included in guidelines

Drinking water treatment has three goals: (1) to provide safe water, (2) to provide aesthetically pleasing water (odour, taste, colour, turbidity), and (3) to ensure that the technology applied does not create further problems such as disinfection by-products (DBPs) such as tri-halo methane's (THMs) and bromate or assimilable organic carbon (AOC) causing regrowth in distribution networks; corrosion and hardness relating to economic considerations (Bursill, 2000). When applying this concept to the water reclamation process, one has to deal with a considerable higher risk profile. The following are parameters and proposed guidelines which do not have a direct health effect, however cause secondary bacterial regrowth. It was proven that pathogenic bacteria are able to survive and even multiply with low assimilable organic carbon concentrations. Organic Carbon is either called Natural Organic Matter (NOM) found in surface waters and rivers or Effluent Organic Matter (EfOM) found in the effluent from wastewater treatment plants. In a Direct Potable Reuse (DPR), Indirect Reuse (IPR) and in Unplanned Reuse (UR) either NOM or EfOM or both can be present. Proposed guidelines for a stable water in a distribution system:

a. Chemical and biological stability guaranteed when turbidity is ≤ 0.2 NTU
b. Dissolved Organic Carbon (DOC) content is ≤ 4.0 mg/L

c. Assimilable Organic Carbon (AOC) content is ≤ 10 µg ac-Ceq/L
d. Biological Dissolved Organic Carbon (BDOC) content is ≤ 0.20 mg/L

Various international studies have proven that under the above conditions, secondary growth of microorganisms in a distribution system is greatly reduced. The monitoring program of Windhoek, Namibia shows that the temperature in the distribution system can be as high as 30°C. Under such temperature conditions it is difficult to control secondary growth other than maintaining higher dosages of free chlorine residual under current guidelines which allow higher Total Organic Carbon (TOC) of ≤ 10 mg/L. This is not always appreciated by the consumers and does lead to raised THM levels as well as odour levels in distribution systems with longer retention times.

2.5 FINAL WATER QUALITY TARGETS FOR DPR

Water quality guidelines and health-based targets have been developed in a number of countries where water reclamation and reuse is practised. The most prominent guidelines are shown below.

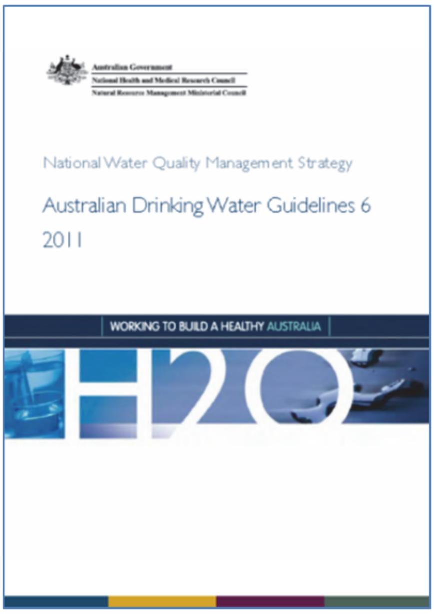

Figure 2.4: Australian Drinking Water Guidelines (NHMRC, 2011)

Figure 2.5: WHO 2012 State of the Science of Endocrine Disrupting Chemicals. An assessment of the state of the science of endocrine disruptors prepared by a group of experts for the United Nations Environment Programme and World Health Organization (Ed Bergman A, Heindel JJ, Jobling S, Kidd KA and Zoeller RT).

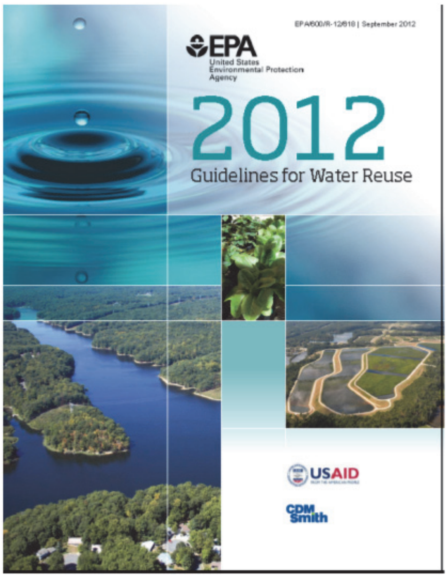

Figure 2.6: Guidelines for Water Reuse
(EPA, 2012)

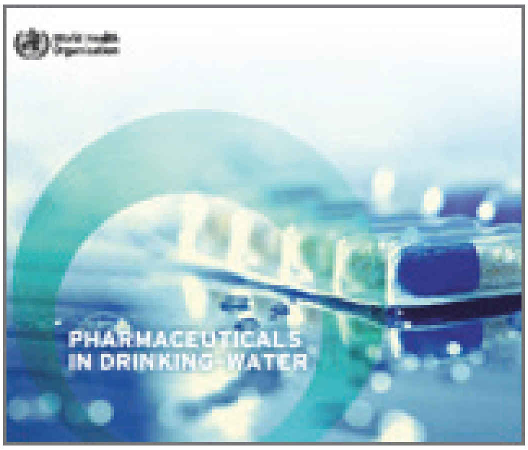

Figure 2.7: Pharmaceuticals in drinking
water
(WHO, 2012)

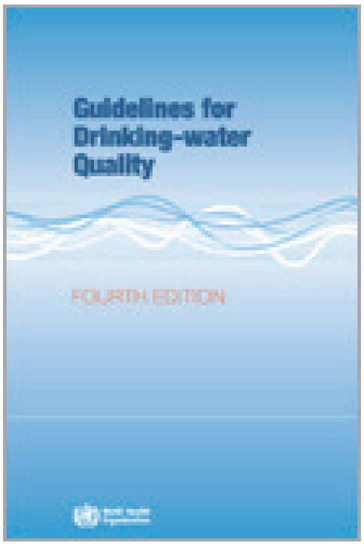

Figure 2.8: Guidelines for drinking
water quality
(WHO, 2011)

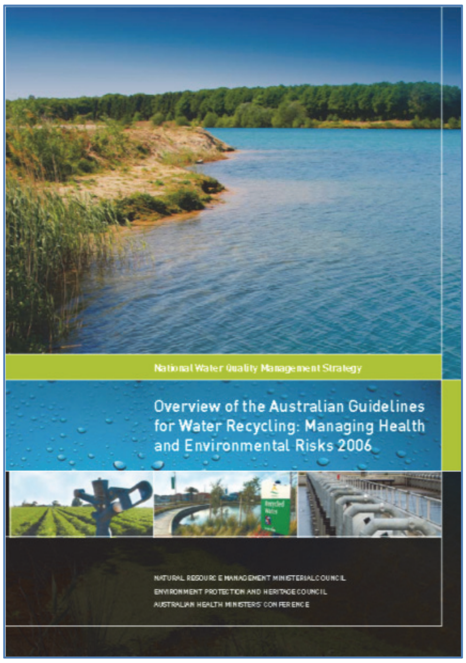

Figure 2.9: Overview of the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks 2006 (Environment Protection and Heritage Council, March 2008)

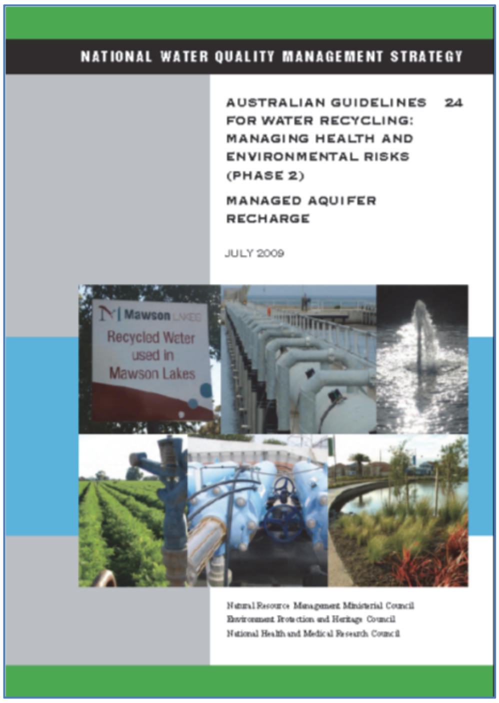

Figure 2.10: Australian Guidelines for Water Recycling: Managing Health and Environmental Risks Phase 2 Managed Aquifer Recharge (National Water Quality Management Strategy Document No 24 July 2009)

2.5.1 Health-based water quality guidelines

The World Health Organisation first developed drinking water quality guidelines in 1984 which have been revised and updated over the years resulting in the 4th edition which became available in 2011. The Guidelines describe reasonable minimum requirements of safe practice to protect the health of consumers and derive numerical “guideline values” for constituents of water or indicators of water quality (WHO, 2011). They specify that the basic and crucial requirements to ensure the safety of drinking-water are a “framework” for safe drinking-water, including health-based targets, adequate infrastructure, proper monitoring and independent surveillance. Important in ensuring a safe drinking water, a number of aspects need to be assessed, including microbial, chemical, radiological and acceptability aspects. The most important consideration is to ensure the microbial safety of the water. The greatest microbial risks are associated with ingestion of water that is contaminated with faeces from humans or animals (including birds). Faeces can be a source of numerous pathogenic bacteria, viruses, protozoa and helminths. The health concerns associated with chemical parameters of drinking water differ from those associated with microbial contamination in that chemical parameters leading to adverse chronic health effects normally result after long-term exposure to low concentrations (with a few exceptions).

The most common and widespread health risk associated with drinking water is microbial contamination and therefore the control of microbial (microbiology and virus) contamination must always be of primary importance. After 1970 the importance of DBP's and chemicals monitoring increased. Ensuring the chemical safety of water requires a different approach as not all the chemicals specified in most guidelines and standards for drinking water will occur in all locations, and if they do exist, they may be present below levels of detection. The reverse may also hold where some chemicals that do not have guideline values may nevertheless be of concern under certain circumstances. The chemicals of emerging concern (CECs) fall within this scenario and include a variety of constituents as a result of water reuse. It is important that chemical contaminants be prioritised so that the most important are included in monitoring programmes.

2.5.2 Control of microbial contamination

The protection of public health from microbial contamination may involve a quantified risk assessment. The pathogens that may cause waterborne infections are many and diverse and involve not only ingestion of contaminated water, but may also be contracted through inhalation of water droplets. In addition to specifying that no faecal indicator bacteria such as *E. coli* may be present in drinking water, most microbial guideline values for drinking water specify that no faecally transmitted pathogens may be detected within a specific volume of water. Examples include *Shigella, Salmonella, Vibrio cholera*, Adenovirus, Rotavirus, Hepatitis A & E, Norovirus, *Cryptosporidium, Giardia* and numerous others. As it is impractical to test for the absence of the large number of possible microbial pathogens, a risk assessment approach is often used.

The quantitative microbial risk assessment, or QMRA, is becoming the norm to estimate the disease burden associated with exposure to pathogens. The risk assessment paradigm involves a 4-step approach which is described in detail in the WHO (2011) drinking water quality guidelines. The four steps include the following:

1. Problem formulation and hazard identification
2. Exposure assessment
3. Dose-response assessment
4. Risk characterisation.

Making use of QMRA, risk-based performance targets may be set to ensure a locally relevant "tolerable risk". Performance targets are usually applied to treatment performance to calculate the microbial reduction needed to ensure a safe water supply. For example, a performance target of 4 log removal for parasites and a 6 log removal of viruses might be necessary, depending on the quality of the source water. For the purpose of wastewater reuse, the performance-targets should be calculated on a case-by-case basis, depending on the catchment and system where the wastewater is produced.

Most microbial drinking water guidelines specify the absence of a few specific groups of faecal indicator microorganisms such as *E. coli*, coliphage, Clostridium and occasionally specific pathogens such as cytopathogenic viruses and protozoan parasites (SANS-241, the WHO drinking water quality guidelines, Australian drinking water quality guidelines).

2.5.3 Control of chemical contamination

The exponential growth of new unknown chemicals is of great concern and needs to be addressed in the process design of a new 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.

2.5.3.1 *Development of Guidelines for Chemicals with a Threshold Effect*

If a chemical has a threshold affect it is considered to have a 'safe' dose where no adverse effects will occur. For these chemicals, a reference dose is derived or calculated based on tolerable daily intakes from which a guideline value will be derived as follows:

$$Guideline\ Value = \frac{TDI \text{ x } BW \text{ x } P}{IR}$$

where TDI = tolerable daily intake(mg/kg/d)
BW = body weight (65-70 kg)
P = portion of the TDI allocated to drinking water (normally 10%)
IR = intake rate (1-2 litres)

2.5.3.2 *Development of guidelines for chemicals without a threshold effect (carcinogens)*

When developing guidelines for carcinogens it is assumed that the carcinogenic effect may be induced at any level of exposure and therefore no threshold exists below which it is considered 'safe'. The *slope factor* or *potency factor (β)* of a chemical considered to cause cancer is derived from epidemiological and animal studies. Depending on its potency, a guideline value can be derived based on an "acceptable risk". The WHO (WHO, 2003) and other countries world-wide have set their acceptable risk level at an "excess lifetime cancer risk of one additional cancer per 100 000 of the population ingesting drinking water containing the substance at the set guideline value for 70 years " (WHO, 2003). This can be presented as a risk of 1 in 100 000, or 0.00001 or 10^{-5}. The guideline value for the specific carcinogen will be derived using the following equation:

$$Guideline\ Value = \frac{\left(\frac{R}{\beta}\right) \text{ x } BW \text{ x } P \text{ x } Lft}{IR \text{ x } ED}$$

where R = acceptable risk

β = potency of chemical

BW = body weight (65-70 kg)

P = portion of the TDI allocated to drinking water (normally 10%)

Lft = lifetime (70 years)

IR = intake rate (litres)

ED = exposure duration (30 years)

2.5.3.3 *Developing guideline values for chemicals where no health data exists.*

Internationally many studies have looked at the removal of chemicals and endocrine disrupting activities in drinking water and wastewater treatment processes. It has been shown that these compounds are not entirely removed and that additional advanced treatment processes are often needed (Kirk et al., 2001; US EPA, 2001; Snyder et al., 2003).

Different approaches have been used in countries throughout the world to address this constraint.

Thresholds of Toxicological Concern (TTC)

Thresholds of toxicological concern (TTCs) represent screening guideline values for chemicals where no health data exists. This approach has been used by the FAO/WHO and the FDA. The approach is based on structural data of the chemical and is used to determine a proposed guideline value. If a chemical is not classified using structural-toxicity, a generic threshold is employed making use of a carcinogenic potency database of over 500 chemicals.The approach has been validated comparing values in the Australian drinking water guidelines with values using this TTC approach (David, 2013). This approach making use of structural classes is illustrated in Table 2.12 below using the equation provided below.

Table 2.12: Illustration of chemical class approach

Chemical class	TTC (µg/kg/d)	Guideline value (µg/L)
Structural Class I	30	7 or 14
Structural Class II	9	2 or 4
Structural Class III	1.5	0.35 or 0.7
Neurotoxicity (Cholinesterase inhibitors)	0.3	1 or 2
Generic TTC	0.02	0.07 or 0.14
Genotoxic carcinogenicity	0.002	0.007 or 0.014

$$Guideline\ value = \frac{\text{TTC x BW x P}}{\beta\ \text{ x IR}}$$

where TTC ≡ Threshold of Toxicological concern≡Acceptable Daily Intake (ADI)

BW = body weight (65-70 kg)

P = proportion from water (10%)

β = potency

IR = Intake Rate (1-2 L)

This allows a water service provider to deal with chemicals that do not have clear guideline values and has been included in the Australian drinking water quality guidelines.

2.5.3.4 *The US EPA PBT Profiler Approach*

The PBT Profiler is an online risk-screening tool that predicts a chemical's potential to persist in the environment, bio-concentrate in animals, and be toxic, properties which cause concern for human health and the environment. PBT stands for Persistence, Bioaccumulation and Toxicity. Basing its assessment on a chemical's structure, the PBT Profiler determines whether a chemical is expected to exceed the PBT criteria under EPA's New Chemicals Program and/or Toxic Release Inventory (TRI). The PBT Profiler can also tell whether the chemical belongs to a category that is known to present human health concerns. If data is required on a chemical for which there is no guideline value, the PBT profiler database can be accessed at http://www.epa.gov/oppt/sf/tools/pbtprofiler.htm

2.5.3.5 *Estrogenic activity – target value*

In order to assess whether endocrine disruptors are present in water one can:

- carry out targeted chemical analyses for each of the chemicals thought to have endocrine disruption capabilities as well as the potential to occur in a particular area under investigation, or;
- analyse the water sample for endocrine disrupting activity using one or more of the available bioassays

The former option is not practical, as there are potentially hundreds of endocrine disruptors that might be present in water. The latter option is a more feasible option where one obtains biological measures of exposure or biomarkers. This option is also in line with the DEEEP approach (2003) followed by the National Toxicity Monitoring Programme that was initiated by DWA. Bioassays are valuable tools to measure total oestrogenic and androgenic activity resulting from all endocrine disrupting chemicals present in a water body, including unknowns. Both biological (*in vivo* and *in vitro*) and biochemical (*in vitro*) methods are used to determine endocrine disrupting chemicals activity and effects.

The proposed South African target value for oestrogen activity in drinking water (Genthe and Steyn, 2008) was derived consistent with the precautionary principle. The proposed framework derived a trigger value for oestrogenic activity similar to the TTC values described in the section above. The proposed framework makes use of an oestrogenic activity trigger value, with oestrogenic activity being determined by means of bio-assays. Estrogenic activity in water is measured in terms of estradiol equivalents (EEQ) per litre (ng/L). Estradiol is the most potent of compounds in terms of oestrogenic activity and also the standard against which oestrogenic activity of all other compounds is measured. The equation used to calculate the trigger value is as follows (WHO, 2004):

$$Guideline\ value = \frac{(ADI \text{ x } BW \text{ x } P)}{IR}$$

where: ADI = acceptable daily intake (mg/kg/d);
BW = body weight (65 -70 kg);
P = portion of exposure allocated to water (10%);
IR = intake rate of water (1-2 L)

The trigger value of 0.7 ng EEQ/L is based on the World Health Organisation's value for an acceptable daily estradiol equivalent intake of 50 ng/kg of body mass, also taking into consideration that exposure through water intake probably accounts for only about 10% of the total exposure to oestrogenic activity. Furthermore, in calculating the trigger value, an average body mass of 65 kg and daily water intake of 2 L were assumed with allowance made for a safety factor of 1 000 to compensate, among others, for sensitive populations. Making use of a Monte Carlo probabilistic assessment, considering the ranges of human body mass and daily water intake that could realistically be encountered; the trigger value is expected to vary, with 90% certainty, between 0.14 ng EEQ /L and 3.44 ng EEQ /L.

Internationally, countries are in agreement that precautionary action should be taken. As part of the precautionary action in the EU, a group has been set up for the Regulation, Evaluation, Authorisation and Restriction of Chemicals (REACH) (http://ec.europa.eu/enterprise/sectors/chemicals/reach/index_en.htm) when chemicals are produced in excess of 1 tonne per annum. The US EPA established an Endocrine Disruptor Screening and Testing Advisory Committee (EDSTAC) (http://www.epa.gov/endo/pubs/edspoverview/edstac.htm) and recommends a tiered approach to screening of target chemicals for endocrine disrupting properties. US Congress amended the Safe Drinking Water Act in 1996 and require screening of drinking water sources for endocrine disruptors (http://www.epa.gov/endo/pubs/edspoverview/primer.htm). Similarly, Environment Canada in 2003 (Hull and Swanson, 2006) adopted the weight-of evidence approach which relies on the most reliable information and recommends a tiered-testing approach. Australia proposed the use of the precautionary principle based on a no-observed-effect-level or NOEL (Stauber, 2002).

Methods to detect oestrogenic activity are described in the Global Water Research Coalition (GWRC) toolbox project "In vitro bio-assays to detect oestrogenic activity in environmental waters" (2006) and WRC 1816/1/10 "The Compilation of a Toolbox of Bio-assays for Detection of Oestrogenic Activity in Water",

(2010) are projects that have looked at the various options available to recommend the most suitable test methods for assessing oestrogenic activity in water and includes both *in vitro* and *in vivo* bio assays.

Thyroid activity testing is far enough advanced to recommend. The Organisation for Economic Co-operation and Development (OECD) validated the thyroid activity test and this test can therefore be recommended to be included in a battery of tests for endocrine disrupting activity (OECD, 2006).

2.5.3.6 *Pharmaceuticals and other Chemicals of Concern (CECs)*

Reports of trace concentrations of pharmaceuticals and other chemicals of concern in the water cycle have raised concerns over potential human health risks from exposure to very low levels of these contaminants in drinking-water. Increasingly, national and international studies are showing that a wide variety of chemicals of emerging concern are present in wastewater effluents, surface waters, and groundwater. The understanding of chemicals of emerging concern (CEC) is covered in the all-encompassing definition provided by the US Geological Society (2014), namely:
"*Any synthetic or naturally occurring chemical or any microorganism that is not commonly monitored in the environment but has the potential to enter the environment and cause known or suspected adverse ecological and/or human health effects. In some cases, release of emerging chemical or microbial contaminants to the environment has likely occurred for a long time, but may not have been recognized until new detection methods were developed. In other cases, synthesis of new chemicals or changes in use and disposal of existing chemicals can create new sources of emerging contaminants." (definition from the US Geological Survey, 2014).*

From this definition, the different types of chemicals of emerging concern groups or types are given in Table 2.13 (NRC, 2012).

Table 2.13: Types of Chemicals of Emerging Concern with Examples (NRC, 2012)

Type	Examples
Industrial chemicals	1,4-Dioxane, perflurooctanoic acid, methyl tertiary butyl ether, tetrachloroethane
Pesticides, biocides, and herbicides	Atrazine, lindane, diuron, fipronil
Natural chemicals	Hormones (17β-estradiol), phytoestrogens, geosmin, 2-methylisoborneol
Pharmaceuticals and metabolites	Antibacterials (sulfamethoxazole), analgesics (acetominophen, ibuprofen), beta-blockers (atenolol), antiepileptics (phenytoin, carbamazepine), veterinary and human antibiotics (azithromycin), oral contraceptives (ethinyl estradiol)
Personal care products	Triclosan, sunscreen ingredients, fragrances, pigments
Household chemicals and food additives	Sucralose, bisphenol A (BPA), dibutyl phthalate, alkylphenol polyethoxylates, flame retardants (perfluorooctanoic acid, perfluorooctane sulfonate)
Transformation products	N-Nitrosodimethylamine, bromoform, chloroform and trihalomethanes

High priority pharmaceuticals were identified by the GWRC 2008, (Development of an International Priority List of Pharmaceuticals Relevant for the Water Cycle) which include; carbamazepine, sulfamethoxazole, diclofenac, ibuprofen, naproxen, bezafibrate, erythromycin, ciprofloxacin, atenolol and gemfibrozil. Four of these chemicals listed were also identified in an EU funded international wastewater reuse research project (EU RECLAIM, 2008) as being of potential interest with respect to being detected in final treated drinking water, although at levels thought to be insignificant in terms of human health. In 2010 the Californian State Water Resources Control Board convened a panel of experts to address the monitoring strategies for chemicals of emerging concern (CECs) in recycled water providing recommendations for monitoring reclaimed water (Anderson et al., 2010). The panel provided a conceptual framework for assessing potential CEC targets for monitoring and used the framework to identify a list of chemicals that should be monitored. The chemicals the panel recommended for monitoring are risk-based priority chemicals, as well as CEC treatment performance indicators. Surrogates or performance indicators include turbidity, DOC, and conductivity. Health-based CECs selected for monitoring included caffeine, 17β-estradiol, NDMA, and triclosan. Performance-based indicator CECs were selected by the panel, each representing a group of CECs: caffeine, gemfibrozil, n,n-diethyl-meta-toluamide (DEET), iopromide, NDMA, and sucralose. Caffeine and NDMA serve as both health and performance-based indicator CECs.

Using international water reuse guidelines, priority chemical lists and monitoring data, a spread sheet was created to list those chemicals included; US-EPA (112 compounds), the EU (58 compounds), the NRC potential organic indicator compounds (52 compounds), the Australian drinking water quality guideline compounds (129 compounds) and relevant South African chemical compounds derived from prescription drugs and pesticide use data.

From this list, the health and environmental risk for individual CECs was assessed to prioritise chemicals which should be included in monitoring programs. A risk-based screening framework was used, which includes a few principal steps:

- Establishing which chemicals of emerging concern have been detected in either environmental and drinking waters from international literature
- Establishing which chemicals have been detected in either environmental and drinking waters in South Africa (prevalence)
- Quantity of drugs prescribed in South Africa – to represent exposure potential
- Identifying those chemicals known to be persistent and not easily removed in treatment processes
- Identifying those chemicals with an established analytical detection method as well as relevant detection limit.

A preliminary priority list representing the different groups of chemicals of emerging concern based on best-available knowledge, South African prevalence, potential for exposure and other criteria such as analytical detection ability is presented in Table 2.14 and currently forms a framework for discussion for potential monitoring for reclaimed potable water.

Table 2.14: Recommended priority list of chemicals of concern to be included in water quality assessment with direct reuse

Type	Examples
Industrial chemicals	Flame retardants, TDCPP and TCEP X-ray contract fluid, Iopromide PAH, Benzo(a)pyrene
Pesticides, biocides and herbicides	Atrazine, Terbutylazine, Imidacloprid and Simazine
Natural chemicals	Caffeine, 17 beta estradiol
Pharmaceuticals and metabolites	Antiretroviral drugs Lamivudine and Stavudine Anti-epileptic, Carbamazepine Anti-malarial drugs Cinchonidine and 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)

2.6 WATER RECLAMATION PLANT OPERATIONAL MONITORING AND CONTROL

2.6.1 Operational control monitoring

Operational control monitoring programmes are usually different from quality control and compliance monitoring programs since it focuses on the different treatment units and not only the final treated water. Therefore any given treatment unit should be monitored and controlled relative to the performance standards for that specific treatment unit and not the performance of the plant. Another difference between operational control monitoring and other forms of plant monitoring is the amount and type of parameters involved and the frequency of analysis required.

Typical compliance monitoring, for instance, requires a large number of quality parameters to be measured once a week or once a month. Operational control monitoring, in contrast, measures a few parameters but at a much higher 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 and electric conductivity; although it depends on the different treatment units and will likely also include TOC, DOC, COD and colour. This is much fewer parameters than the typical compliance monitoring parameters that include a multitude of micro and macro pollutants, organic compounds and microbiological parameters. 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.

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 taken into account when on-line sensors are implemented at the monitoring system. Once the monitoring system starts collecting data, the data must to 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.

When it comes to operational control monitoring, it should be understood that the operational control of a water reclamation plant is in no way regulated or audited by any external authorities. This is the case in South Africa, as well as the rest of the world, and makes it difficult to obtain information about the operational control monitoring being done at water reclamation plants. The companies that own and operate water reclamation plants will not likely publish this information since it can be considered proprietary information which these companies use to remain competitive in their industries.

Another problem when it comes to obtaining information about operational control monitoring systems is the fact that they are mostly plant specific. Water quality targets are affected by several factors for each of the treatment processes and in many cases, also depend on the configuration of the treatment processes. For instance, the target residual ozone coming from an ozonation treatment step will be different if the ozonation is followed by a BAC treatment process rather than a GAC treatment process. It should also be noted that, in most cases, the performance indicator (PI) used to evaluate the performance of a process unit is the parameter that indicates the treatment effectiveness at that process unit. This means that the performance indicator of a process unit depends on the design criteria of the process unit and not just the type of process unit. For instance, the performance indicator used to evaluate a DAF responsible to remove algae from water will not be the same if the DAF was responsible for iron removal after a coagulation/flocculation process.

A detailed list of water reclamation plants, with their process configurations can be seen in Table 2.2 and Table 2.3. The information from these plants can be used to develop a guideline document for the operational control monitoring of water reclamation plants for South Africa.

2.6.1.1 *Lessons learned from Windhoek, NGWRP*

Windhoek has since 1968 reclaimed wastewater to produce potable water for the inhabitants. In 2011 the proportion of reclaimed water represented 22%, ground water 5% and surface water 73% of the total drinking water production in Windhoek. There are obvious health risks involved and this study aimed at assessing microbiological health risk using a combination of quantitative microbiological risk assessment and fault tree analysis methodologies. This study was performed to evaluate if the extensive treatment is sufficient even under severe conditions. Periods of sub optimal performance for the barriers were derived from workshops with the staff and structured into a fault tree model. The normally occurring raw water levels of the index pathogens *Norovirus, Giardia and Cryptosporidium* were derived from historical data and literature. The result indicated that the health based target was exceeded for Cryptosporidium, only in the epidemic scenarios on the 95th percentile. Furthermore, the result showed that adding UV light to the process train would improve the treatment Also, power supply and good routines for operational verification of removal in the ultrafiltration step was identified as important to evaluate as a potential improvement that would lower the total risk for the plant. The plausibility of the epidemical scenario is critical to the validity of the results. The estimated *Cryptosporidium* count of 2 510 oocysts per litre (5th percentile: 972 – 95th percentile: 26 000) can be compared to the contents of untreated and treated sewage in Östersund, Sweden, during a waterborne disease outbreak affecting half the population. The maximum counts where 16 000, of which a count of 1 000 oocysts per litre of sewage was confirmed during the outbreak.

The results from the FTA showed that power failure is the major event of concern causing longest annual failure time. The other process failure times were quite similar; however ozonation failures are likely to occur more often but during shorter periods of time.

The result from the QMRA showed that the major risk for infection is highest for *Cryptosporidium* and exceeding the health based target for the 95th percentile of the scenario with epidemic raw water levels. For *Norovirus* and *Giardia* all scenarios showed very low likelihood of infection. The uncertainties that mainly affected the result were raw water data and the process data for sub optimal operation.

In order to decrease risks identified in the study the suggestion was to evaluate and improve the local power supply and develop the ozonation process to decrease the failure rate. In order to decrease the risk of infection the results indicated that UV light would be an appropriate and efficient risk reduction measure.

2.6.1.2 *Operational monitoring adapting to changing technologies*

From Tables 2.2 and 2.3 it can be seen that water reclamation plants have been constructed over a long period of time, from the late 1960s all the way to the first decade of the 21st century, and many plants are still being constructed and planned. It can also be clearly seen how the plant configurations and treatment trains have changed. It is important that operational monitoring programmes be flexible in order to remain relevant even after making changes to the treatment train.

From Figure 2.11 it can be seen that the New Goreangab Water Reclamation Plant (NGWRP) makes use of several treatment processes, some of which can be considered partial barriers and some that are considered complete barriers for various aesthetic, operational and health parameters. It should be noted that the original Goreangab Reclamation Plant was commissioned in 1968 when membrane treatment systems were not considered feasible due to the high cost of membranes at that time. Each of the different treatment units are monitored separately with the exception of the DAF. The DAF and coagulation/flocculation is monitored as one whole unit. Sampling points are located at the outflow side of each of the treatment units.

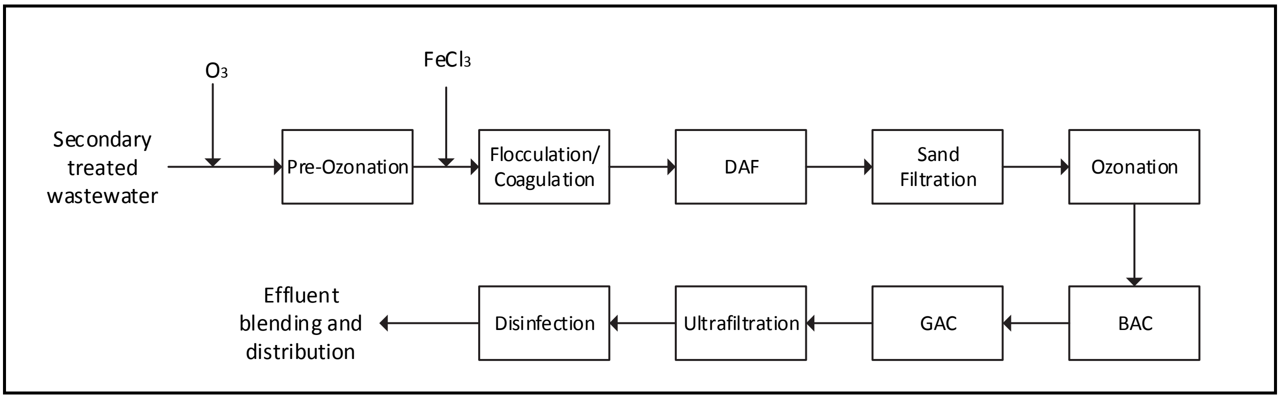

Figure 2.11: New Goreangab Water Reclamation Plant diagram

Controlling a plant and ensuring optimal performance can become a burden when so many treatment units are involved. The NGWRP has two parallel sections for pre-ozonation, coagulation/flocculation and DAF. The DAF consists of two vessels per train. The sand filter consists of five filter beds. The ozonation takes place in three dosing chambers that are in series. The BAC treatment consists of seven (five duty, two stand-by) filter beds and the GAC is also made up of seven (five duty, two stand-by) filter beds, but are two stages in series, therefore 14 beds in total. The ultrafiltration step consists of 6 parallel trains. The operational monitoring of this plant is a major burden and has severe implications on the cost of the water as well as the performance of the plant.

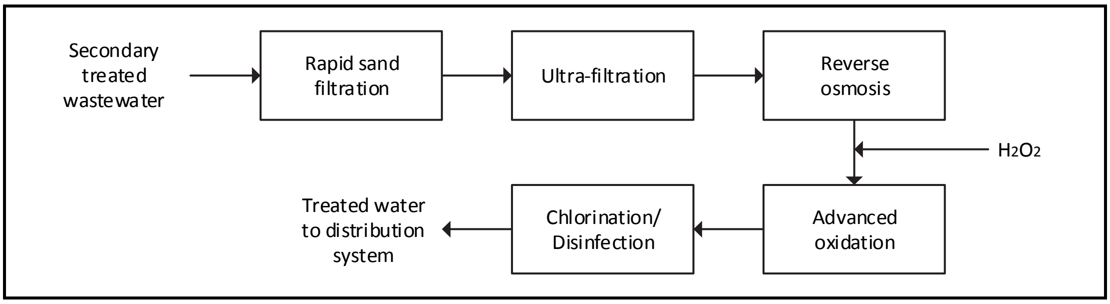

Figure 2.12: Beaufort West Water Reclamation Plant diagram

From Figure 2.12 it can be seen that there is a major difference between the NGWRP and Beaufort West WRP. First of all it should be noted that the Beaufort West plant was commissioned in 2011 and secondly that the design capacity of the Beaufort West plant is almost exactly ten times less than that of the NGRP. As a result it can be seen that the Beaufort West plant makes use of and depend on advanced treatment units such as RO and AOP in the form of UV/peroxide.

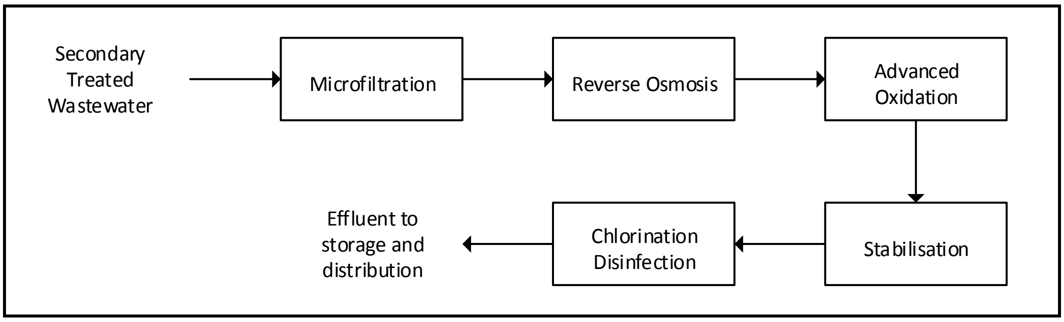

Figure 2.13: Western corridor water reclamation system

Figure 2.13 shows a process layout of two of the three Western Corridor WRPs in Australia. These plants have all been commissioned in 2008 and are similar to the Beaufort West WRP. This trend to reduce the number of treatment barriers by replacing several partial barriers with a single complete barrier, such as the typical double membrane with advanced oxidation configuration, can be seen in most reclamation plants that have been commissioned during the 21st century. This is primarily due to two factors. Firstly, the price of membrane technologies have reduced considerably since the late 1990s; secondly, advances in water analysis methodology have revealed a multitude of water constituents that are primarily unknown and are expected to be removed using RO treatments.

The operational monitoring for the NGWRP and Beaufort West, or Western Corridor WRPs, are not comparable in practice, but the methodology and principles behind the monitoring programme are the same. Each of the treatment units are being sampled in order to ensure that the treatment units are performing within the expected design limits.

2.6.1.3 *Plant performance and operational monitoring*

The log removals for microorganisms achieved at the NGWRP during the period of January 2006 to June 2007 can be seen in Table 2.15.

Table 2.15: Log removal values (LRVs) for microorganisms for the NGWRP

Microorganism	LRVs
HPC	6.02
Total coliforms	5.26
Faecal coliforms	4.32
E. coli Tryptone*	2.01
Faecal streptococci	3.67
Pseudomonas	2.86
Clostridium spores	4.94
Clostridium viable	5.40
Somatic coliphages	4.68

* *E. coli* was measured in the feed water and sand filter effluent
(Adapted from *IB Law, 2013*)

Table 2.16 shows the total LRVs for the plant as a whole as well as the requirements for potable reuse as established by the Australian Guidelines for Water Recycling.

Table 2.16: LRVs for the entire NGWRP for microorganisms

Treatment process	Process Design Parameters	Viruses	Bacteria	Protozoa
Gammams WWTW	BNR (long sludge retention time)	0.5-1.0	1.0	0.5
Pre Ozone and Coagulation/DAF	Contact time: 3 min Coagulant: FeCl3, HCl, polyelectrolyte DAF SLR: 4 $m^3/m^2/hr$	Included in DMF	Included in DMF	Included in DMF
Dual media Filtration (DMF)	Rate: 6 m/hr Anthracite: 0.7 m (ES 1.3) Sand: 0.7 m (ES 0.7)	1.5	1.5	2.0
Ozonation	Dose: 12 mg/L mg O_3/mg DOC: 1.1 Contact time: 24 minutes Contact time: 12 mg/L/min	4.0	4.0	(>0.6) 1.5-2.0
BAC	EBCT: 10 minutes minimum Bed depth: 1.5 m	Included in GAC	Included in GAC	Included in GAC
GAC	EBCT: 20 minutes minimum No of stages: 2 Bed depth: 1.5 m	0.4	1.7	0.9
Ultrafiltration	Flux: 70 $L/m^2/hr$ Recovery: 92%	2.5-3.0	3.0-3.5	3.0-4.0
Chlorination	Contact time: 1 hour Contact time: 27 mg/L/min pH: 7.8-8.2 Temperature: 15-20ºC	4.0	4.0	0.0
Total		**12.4-13.9**	**15.2-15.7**	**7.9-9.4**
Requirements for potable reuse		**9.5**	**8.1**	**8.0**

The log removal values for the Western Corridor system (which has a similar design as the NEWater plants in Singapore) can be seen in Table 2.17 for different microorganisms.

Table 2.17: LRVs for the Western Corridor water reclamation system

Unit treatment process	Viruses*	Protozoa	Bacteria	Helminths
Wastewater treatment (Biological Nutrient Removal)	2	1	2	1
Microfiltration	0	3.5	3.5	3.5
Reverse osmosis	2	2	2	2
AOP (UV disinfection)	4	4	4	2
Chlorination	2	0	2	0
Total	**10**	**10.5**	**13.5**	**8.5**
Requirements for potable reuse	**9.5**	**8**	**8.1**	**8**

* Adenovirus
(Adapted from *IB Law, 2013*)

The critical control points (CCPs) that are monitored as well as the parameters that are monitored at the CCPs throughout the Western Corridor water reuse system can be seen in Table 2.18.

Table 2.18: CCPs and related parameters for the Western Corridor

CCP	Treatment process	Parameter Monitored
CCP 1	WWTP	On-line Ammonia
CCP 2	MF/UF	Pressure decay test
CCP 3	RO	Permeate conductivity Permeate sulphate
CCP 4	AOP/UV	Present power ratio
CCP 5	Chlorination	Contact time

(Adapted from *IB Law, 2013*)

The monitoring of CCPs form a bridge between operational monitoring and compliance monitoring. The ultimate goal of operational monitoring is to ensure that all the CCP levels remain below their respective alarm values. This ensures that the final water produced by the plant complies with the required standards. Operational control monitoring is therefore essential to ensure adequate plant performance as well as a safe final product.

2.7 COMMUNICATION PROGRAMMES AND PROTOCOLS

2.7.1 Incident communication and public relations

Good communication

Water reclamation systems/schemes will always consist of multiple parties (e.g. WWTP, AWTP, final water distributor and all the relevant stakeholders). It is important that the communication between these parties is clear and consistent. There are many reasons why communication between these parties is important, but the following three reasons are especially important when it comes to potable reclamation systems.

Consumer safety

When it comes to potable reuse, there is nothing as important as the health and well-being of the final water consumers. It is for this reason that all the stakeholders must rely on each other and work together to provide a final product that is safe for the consumer. This is easier said than done, especially in the case of treatment failures. Parties should not be afraid to communicate treatment difficulties and especially treatment failures between one another. There must be a safe environment and healthy communication practice available for the different parties to come together and discuss difficulties being experienced. It is important that this communication is not misused for the purpose of allocating blame in cases where losses have occurred. Operational and analytical as well as events recorded should be reported once a year to an expert or steering committee. This will ensure that there is follow up and recommendations for improvement get implemented and monitored.

Fault detection

In the case of errors or treatment failures, it is important that the responsible party communicate clearly when the error or failure occurred, where in the process it occurred, how long it continued, why it occurred and also what actions have been taken to remedy the situation. Incidents need to be properly recorded and reviewed on an annual basis to ensure changes that could constitute an operational or health risk are detected in time. It is important that all the parties share information and knowledge in this regard in order to improve the various processes taking place within the reuse scheme.

Reporting

Water is steadily becoming a financial commodity; it is for this reason that most reuse schemes are being operated like businesses rather than resource fabricants. Management systems are in place within each of the different parties, and they all have the same goals in mind (reducing risk, operating costs, non-compliance, etc.). Good communication between the different parties would benefit all the parties and ensure that the reuse scheme as a whole grows and develops as effectively as possible.

2.7.2 Communication programmes for direct and indirect potable reuse

A well-organised and comprehensive communications programme with stakeholders is essential to all water reuse projects. This has been described in most of the water guideline documents. The US EPA 2012

Guidelines for Water Reuse devotes a section to the importance of communication with the stakeholders. The WHO drinking water quality guidelines has also placed emphasis on the need for communication with the different stakeholders throughout each of the sections of the guideline document (WHO, 2011). The Water Research Commission has a volume in a series of guides intended to provide information to reduce the incidence of water-related diseases, entitled "How great is the problem? Communicating the risks" (WRC, 2008). Australian researchers has recently summarised the major stakeholder communication issues to be addressed and successful means of addressing them. These programmes need to be initiated on different levels, for instance be part of the national or regional education program. Primary, secondary and tertiary education programs need to have an annual project. This will increase awareness and appreciation. Different business and diplomatic corps need to be invited and taken on a familiarisation tour through the reuse plants and all supporting institutions, in order to appreciate the effort that is made to maintain a DPR system. Regular TV, radio and newspaper announcements help to keep consumers informed.

2.7.3 Risk management and risk communication

Risk Management in Diarrhoea incidents

The guidelines on how to deal with diarrhoea incidents when the water quality is suspected to be responsible are given in TT 297/07 emanating from WRC project 1028; what causes the problem? What to do following Diarrhoea Incidents, the general guidelines are briefly discussed here.

Numerous micro-organisms (bacteria, viruses, parasites) that can cause diarrhoea may be found in faecal contaminated water. Many of these water-related pathogens can also be transmitted via food, contaminated utensils and soil, or through person to person contact. This complicates the investigation on whether a specific water source could be responsible for the outbreak. Water suppliers are recommended to monitor water treatment problems and water quality routinely and to conduct epidemiological investigations when a diarrhoea outbreak is blamed on water. When relevant information is obtained, the water supplier can decide whether the water is at fault or not. The investigation consists broadly of the following 5 components:

- *Assess the situation*. Lead by questions such as; has there been an increase in diarrhoea cases?
- *Gather evidence about the water*. Has there been routine monitoring of the water quality and treatment processes?
- *Gather evidence linking cases and water.* Has the pathogen been recognised? Is there any supporting epidemiological studies/results?
- *Draw conclusions*. Once all the evidence has been obtained, the water supplier has to assess the likelihood of water being responsible for the outbreak.
- *Communicate findings.* This is crucial in order to maintain the confidence of the public in water quality.

A comprehensive flowchart with question and action statements has been suggested in TT 297/07 with which to establish whether a diarrhoea incident can be linked to the water quality and what the water supplier reactions should be.

Hazard Assessment and Critical Control Point

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 required are involved in both identifying hazardous scenarios and managing barriers. This complexity necessitates the use of systems to manage risk. 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.

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

1) *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.
2) *Identification of Critical Control Points (CCP).* These are process steps and operational procedures which can be controlled to minimize risk.
3) *Determination of critical limits of every CCP.*
4) *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.
5) *Corrective measures*. Establish corrective actions for CCPs which are not under control.
6) *Verification/validation.*
7) *Registers.* To establish documentation concerning all relevant procedures and records to meet these principles and applications.

A HACCP plan is documentation prepared for concrete risk management based on the HACCP system. The above mentioned principals for a HACCP system are necessary elements for developing a self-control procedure which must be recorded in a HACCP plan in order to ensure the control of risks deemed significant for the safety of water use. A typical HACCP plan as base for risk management was developed in the EU RECLAIM Water project (Contract number 018309, 2008). Herein a HACCP plan was developed as an internal quality management system of parties responsible for groundwater reclaimed or reused from wastewater treatment systems and for artificial groundwater recharge. The derived plan consisted of the following elements:

- Introduction elements
    - Basic information
    - General data
    - HACCP team
    - Domestic wastewater and storm water treatment technology
    - Groundwater recharge system – water supply system.
- Risk management elements
    - Hazard assessment and risk characterization
    - Multiple barrier systems
    - Control and critical control points
    - Operational monitoring

    - Corrective actions.
- Accompanying elements
    - Validation and internal control
    - Documentation and communication procedures.
- Supporting elements
    - Supporting programmes
    - Management procedures.

The primary objective of the RECLAIM Water project was evidence based review on risk assessment, establishment of CCPs and other relevant control points with monitoring, preventative and corrective measures.

2.7.4 Management and communication of water quality data

Effective communications of data or results is all about building trust relationships. Up-down, down-up and sideways. Therefore this process needs to receive necessary attention and diligence. Data without good communication are worthless and will not serve any purpose, should an incident occur where the health of the public is at risk. A relationship needs to be built before the time. You need buy-in and that takes time to establish and is an ongoing process.

2.7.4.1 *Windhoek experience*

Communication happens on different levels. These levels are (other levels are possible)

- Operations level
- Management level
- Corporate level
- Local or national level
- International level.

2.7.4.2 *Operations level*

On this level results are compiled and communicated between the plant operations the plant supervision and the management involved with operations of the plant. It is important that the feedback is in both directions. Involvement of management motivates the operations personnel. Incidents and actions need to be properly recorded and followed up. At strategic meetings, normally twice per year, these incidents need to be discussed to ensure remedial planning and action. Although this is reactive, it acts in a proactive and preventative way.

2.7.4.3 *Management level*

On a management level strategic issues as well as quality and technical issues need to be considered to ensure follow up on incidents happening at the operations level. Thus, all data that are relevant are communicated in a customized form on a regular basis to the responsible managers. Incidents are communicated on a daily basis, otherwise all data are sent through on weekly basis. Monthly, quarterly and annual reports are compiled to see trends and deviations from the norm.

Management needs to follow up and communicate on a regular basis with the operations level in order to direct, support and motivate. Motivation is an extremely important factor, otherwise the operations level will start to hide information due to negative attitude. Such situations can end up in disaster as both parties need each other's support for successful operations. Quality data play an important role as motivator, as they prove that operations have operated the plant well and therefore build trust between management and operations. There need to be training programs and initiatives for management to be informed and be knowledgeable about treatment operations, water quality and risk.

2.7.4.4 *Corporate level*

It is the function of management to inform the senior management of the corporate. An annual plant visit and discussion between top management, management and operations on a more social scale, serve to build relationships and trust as well. Management need to keep senior management informed, especially when incidents happen that have a direct influence on the public. Senior management, especially if they are politicians, do not want to hear it from the newspaper.

2.7.4.5 *Local or national level*

Local communication and national communication can be done in many ways. There is no hard and fast rules. In Windhoek, the politicians are involved in various ways and exposed to the DPR scheme, so that they are aware of it and perhaps can promote it. The newspapers are involved on a regular basis to report on the DPR. It is important to show them the operations and how data are generated, stored and managed, without releasing too much info. They need to be convinced that you operate professionally. The scientific and engineering side should involve the local university in research and student projects. This keeps a part of the public informed, builds trust that you allow others to participate in the project. Public events that should be used to sell the project and release statistical data (performance over past five years). Participation in scientific and community forums should be used. If the project can be incorporated in the national curriculum (water cycle care, reuse, recycling, waste minimisation in connection with environmental issues) it will go a long way to especially get the buy in and trust from households. The data cannot be purely communicated on their own. They need to be brought into relation or be connected with a beneficial aspect of the DPR to the local community. The internet serves a good purpose, but you cannot solely depend on it. You need to connect to decision makers in the community to establish trust. The internet is only a support tool.

2.7.4.6 *International level*

On an international level no one will be aware of your project. So it is important to pursue various avenues to establish contact. International contact is only needed if you need international support, such as financing, international contractors or operators or research support and cooperation. Signing research contracts with international universities is one option. Make it a point to receive international visitors on a regular basis on your plant and let them link with local decision makers. Use your national flight magazine, national and international TV shows to promote your project. Regular attendance and presentations at national and international conferences, workshops and other forums will over time establish cooperation, links and goodwill.

2.7.5 Conclusion

Professionalism and care! If you want to win and convince the public, it is very important that these two aspects feature on an ongoing basis in your community. It will keep the internal communications lines clean, the public happy and the critics (newspapers or specialists) convinced that they can trust your efforts to rectify a situation, should something go wrong.

CHAPTER 3: GUIDELINES FOR DIRECT POTABLE WATER REUSE – WATER QUALITY MONITORING, MANAGEMENT AND COMMUNICATION IN SOUTH AFRICA

3.1 DEVELOPMENT OF WATER QUALITY MONITORING GUIDELINES FOR DPR IN SOUTH AFRICA

3.1.1 Approach

Since the three types of monitoring covered in this report are so much different, the approaches to these monitoring systems are also different and are discussed below.

3.1.1.1 *Catchment and intake water monitoring programmes*

For the monitoring and operation of a WRP a risk based approach is proposed, based on HACCP and internationally incorporated in the WHO-WSP, locally in the SANS and green drop/blue drop guidelines for operation of water and wastewater treatment plants. The raw water treated at a WRP originates as raw sewage from the consumers in the sewer collection network, and is treated by the local WWTP. This source is rated as a hazard. Therefore the treatment approach is different to that of a natural water source which is treated in a conventional WTP. A different set of guidelines for design, operation and water quality monitoring and evaluation will apply. The approach to guarantee a safe potable drinking water supply through a WRP for DPR/IPR is anchored as follows:

- Good catchment management / source protection
- Effective water treatment processes
- Efficient maintenance and operation
- Diligent quality monitoring.

More than one set of water quality guideline and policy will apply for the full water cycle. These include the following:

- International drinking water quality guidelines
- National drinking water quality guidelines
- In-house drinking water quality guidelines
- Industrial effluents standards
- Promulgated Water Act, Environmental Act, Water Demand Management Policy, Bulk Water Master Plan, Sewer Master Plan, Drainage regulation and bylaws, Aquifer rezoning.

As mentioned in 2.3.1 an international approach to reuse monitoring was officially formulated in a publication titled: "Health Effects relating to direct and indirect re-use of wastewater for human consumption." (WHO, 1975). Of the seven considerations, the following principles apply to raw water monitoring:

- An essential pre-condition for any reuse of waste water is the control of industrial waste to the maximum degree, so as to remove at source as many potentially toxic chemicals as possible.
- As rapid changes in water quality can be expected a systematic water quality monitoring is needed for both chemical and microbial parameters.
- Continuous monitoring systems and the development of toxicity monitoring systems using living organisms is recommended.

In most cases, in the Southern African setup, two or even three different organisations will be operating the WTP, WWTP and the AWTP. The WWTP is operated mostly by a municipality or local authority, whereas the WTP is operated by a local water board. Reuse facilities have been contracted out to private operators. According to Figure 2.1 in section 2.4.1.4, the WTP is part of the primary catchment of raw water source, whereas the WWTP and AWTP are part of the secondary catchment or effluent source. The question arises: who is responsible for the control of the full water cycle or who takes ownership for the risks posed in the water cycle? From past experience, there was very little or no communication between WTP operators and WWTP operators.

For the WTP operator, the risk is from the raw water source to the entry into the municipal distribution network. The municipality is responsible for the risk from the receiving reservoir to the consumer, as well as for the effluent from the consumer to the WWTP and back into the environment. The AWTP operator receives the effluent from the WWTP operator or municipality on a contractual basis and delivers drinking water back to the municipal network. The AWTP has no control which pollutants or hazards end up in the sewer collection system, or what quality of water is introduced by the WTP operator into the distribution network, which could end up in the raw water source of the AWTP and effect its operation, cost and final water quality.

3.1.1.2 *Final water compliance monitoring programmes*

A selection of constituents and parameters that will require monitoring (in particular those known to be harmful to humans) was done, which included analytical methods, detection limits, quality assurance/quality control methods, frequency and analytical costs. Comparisons are currently being performed of different testing and analytical techniques available, based on cost, laboratories that can undertake the analysis, and the detection limits. The project team held a workshop in Windhoek to discuss how monitoring systems should be designed in relation to process design for the various unit treatment processes in direct and indirect potable reuse to maintain the treatment barriers, *i.e.* pathogens, organic substances and other micro-pollutants. The development of "minimum" monitoring programmes is also being coordinated within the Blue Drop programmes (for the water reclamation plants), and the Green Drop programmes (for the wastewater treatment plants feeding the water reclamation plants).

A database was compiled of South African laboratories that can perform the various physical, chemical and microbiological analyses required for water reclamation compliance measurements and research purposes (discussed in detail in Section 3.5). This was done in cooperation with DWA's Regulation Branch, who has already developed databases with information on available laboratories and accreditation status thereof.

3.1.1.3 *Operational control monitoring*

Establishing guidelines for operational control monitoring programmes are different from establishing guidelines for final water compliance or similar monitoring programmes. This is mainly because there are much more factors to take into account when it comes to operational control monitoring. Unlike final water quality monitoring which is primarily based on human health concerns, there is no definitive goal or limitation that can be used to determine the most appropriate performance measure for treatment process units. Each unit must be evaluated individually as well as taking the other treatment units and their configuration into account. The operational control monitoring for a given plant can therefore be different to that of another plant, since they have different process configurations, feed waters and possibly final water quality standards.

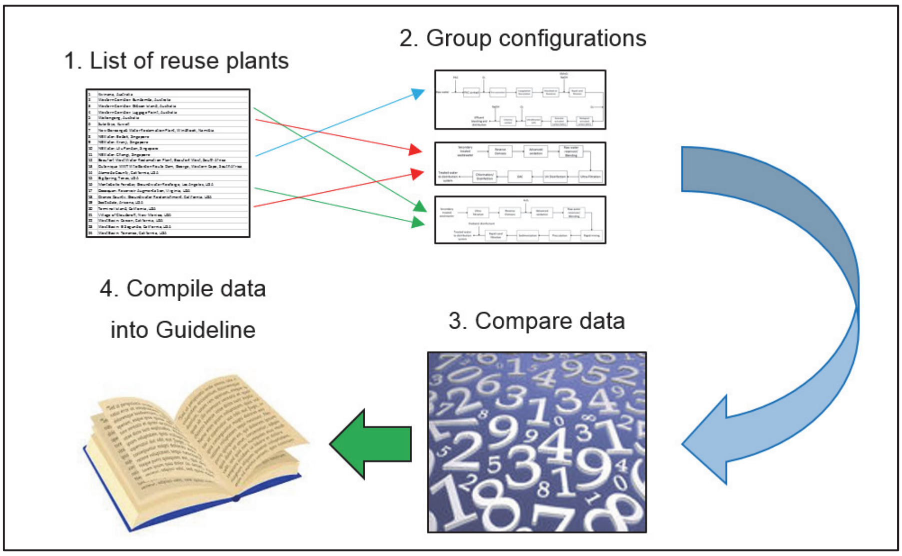

Figure 3.1: Operational control monitoring guideline creation process

Figure 3.1 shows a diagram of the methodology that was used to create the guidelines for operational control monitoring that would be applicable to the largest number of users. This is done by compiling a list of water reuse plants (preferably IPR and DPR) in the world and organising it according to the different configurations of the reuse plants. Once the plants have been sorted according to their configurations, the operational control monitoring programmes and target values used to control the different individual process units can be researched and grouped together. All the available information for a given process unit, with regard to operational control monitoring, can then be compared and combined to create a guideline for each process unit for each of the most common plant configurations.

Table 2.2 and Table 2.3 show a list of reclamation plants that was compiled using published literature. It is assumed that the more recent plants will also consist of the most popular plant configurations since the designers had the most information available for their designs. This list also includes old reuse plants that have recently been renovated since these renovations will affect the operational control monitoring of most of the process units of the plant. Table 2.2 and Table 2.3 also shows the different treatment configurations used at the plants which can be used to make a list of common treatment units used at water reclamation plants. From Table 2.2 and Table 2.3 it can be seen that the majority of reuse plants are located in the USA, Australia and Singapore. The Namibian and South African plants are of great importance since they are two of only a few DPR plants on the list. The guidelines used in these countries can be used as examples for the guidelines that will be produced by this document. Unfortunately only Australia, Namibia and Singapore have defined potable water reclamation water quality guidelines and no operational control guidelines available in the public domain.

Since there are no operational control monitoring guidelines available to specify target parameter levels for the different treatment units of the reclamation plants, an alternative methodology had to be developed. The alternative methodology makes use of some 'reverse engineering' principles. By looking at the feed water quality data, final water quality standards and the process configuration of each of the plants, it is possible to determine the minimum reduction or removal that have to be achieved by each of the treatment units. Operational monitoring can also be based on the history of pollutants detected in the source water, or are possibly expected to arise from the activities in the catchments. This requires thorough monitoring of the catchment areas before commissioning the WRP.

Operational surrogates should be monitored on a continuous basis, by means of regular composite samples for chemical constituents, on-line (real-time) monitoring and on-line concentration techniques for key parameters of each process. Incidents should be recorded by the operational staff and evaluated on a regular basis by management. It is important that the operator understands the operation of the plant under a variety of conditions. Performance needs to be monitored continuously. This will assure greater confidence in water safety at the treatment plant. Regular reviews by top management and steering committees should be held to identify ineffective treatment processes or where processes were operating out of range. Inadequate process control monitoring, not paying attention to changes in the process or not understanding the significance of process monitoring are important risk factors of water borne disease.

The technical staff should also keep incident, performance and maintenance records of individual equipment to identify weaknesses in the technical (mechanical) capability of the treatment plant. Inadequate equipment can lead to higher incidence of process failure and can compromise treatment barriers. Comparison with monitoring data will in most cases verify the failure of equipment. The DPR plant operations should be ISO 9001 certified. A HACCP/WSP program should be introduced. In addition it is recommended to do a quantitative risk assessment and fault tree analysis to evaluate if the extensive treatment barriers are sufficient under extreme conditions. Out of specification water needs to be directed to an alternative location or where allowed, recycled.

Validation monitoring is an intensive activity used to prove that preventive measures are capable of adequately controlling recycled water quality within the bounds required to achieve health and environmental target criteria. As far as practicable, validation monitoring should be completed before recycled water is supplied for use, although it may continue into a pilot-testing period. Once the setup of the whole system has been validated, it is generally sufficient to monitor and audit samples of the system, as part of operational and verification monitoring. However, further validation is needed for variations such as seasonal changes, and all new processes and configurations should be validated to confirm that a modified recycled water system achieves the required results. Online monitoring devices must be reliable; they should also be properly and regularly calibrated, and compared with laboratory determinations of reference meters.

Contamination will only enter occasionally into the water system. It is almost impossible to pick that up in a sampling program, where sampling is done once a week. Continuous on-line or real-time monitoring equipment, using surrogate parameters, allows picking up changes in the raw water composition more easily. The parameters can be rainfall and wind monitoring, turbidity, chlorine residual, total suspended solids, conductivity, DOC, UV_{254}. These parameters are not absolute and it is therefore important to establish relationships between these operational surrogates and specific investigations under a variety of conditions (event monitoring). 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.

3.1.2 Guidance on DPR monitoring for South Africa

3.1.2.1 *Catchment and intake water monitoring*

The basin committee or institution responsible for the raw water supply source need to draw up a risk table of all human and hydrological activity, patterns or events in the catchment. There are different approaches or methods that can be followed. A very basic approach is explained here.

STEP 1: Based on the activities in the catchment, the approach predicts the probability of a risk for each water source. It determines the probability of possible operational or health problems that can be caused, should human activity or a hydrological event take place. It identifies the hazard that could be caused by the incident on the raw water source water quality or during treatment and in the distribution system. See Table 3.1 below. Such a risk activity table is drawn up. The Probability that an incident will occur can be High, Medium or Low. This will determine the frequency of monitoring. From the experience of the committee members, a list of possible expected problems that could arise is presented.

Table 3.1: Catchment Risk: Activities that can cause an incident in the catchment

Activity	Expected problems in water supply	Surface Source	Ground Source	Reclamation
Life stock (overgrazing)	Taste & Odour, Toxins, Filter clogging, Eutrophication, parasites Water difficult to treat, higher treatment cost High chlorine demand, Pathogens, Dissolved Metals Corrosion, DBPPs, Toxicity, Mutagenicity, AOX & other	H	M	
Mining		H		
Settlements (urban & rural)		H	M	H
Boating		H		
Evaporation		H		
Treatment chemicals		H		M
Industrial Pollution			M	H
Probability of occurrence: High (H), Medium (M), Low (L)				

STEP 2: Based on the activities and expected problems that can occur a monitoring program is drawn up. See Table 3.2. Based on the activity in the catchment and the possible water quality problem that could occur, the different chemical, microbiological and biological and toxicological parameters are determined as well as the frequency of sampling. For each parameter the risk and the probability of occurrence is inserted. The probability determines the frequency of monitoring or sampling. If the Probability was high, even on-line measuring and sampling is considered. The risk assessment and adjustment of the monitoring program must be done at least on an annual basis, involving all relevant stakeholders. Should any important interim changes occur which impact on the risks in the catchment, a new risk assessment may have to be done following these changes. New information on activities or natural incidents that happened in the catchment will determine the level of risk and probability and the frequency of monitoring for the next season.

Since there may be up to three different operators involved with a reuse scheme, the following points should be taken into consideration:

- All three operators: WTP, WWTP and AWTP have an effect on the water cycle and the operations of the downstream treatment plant.
- One institution needs to take control of the full water cycle to ensure that maximum control is exercised to minimize pollution and spillage into the water cycle to reduce the risk of potential harmful compounds in the water cycle.
- Even storm water control, which in many municipalities is part of the roads department, needs to become part of the pollution control program and strategy.
- Responsibility to operate an IPR or DPR scheme needs to be seen much wider than just the actual AWTP itself.
- It is the opinion of the authors of the report that DWS should be the custodian, passing legislation for a proper pollution control program that covers the full catchment. This is similar to the Water Basin Management Committee, Namibia, which played a role to bring the different ministries, local authorities, municipalities, industries and treatment plant owners to the table to steer the pollution

control program and exercise proper control over the natural as well as the unconventional water sources.

There are several other responsibilities or tasks that will also have to be assigned and allocated in order to deal with the following issues that may arise from managing a reuse scheme:

1. Who will take responsibility for the pollution monitoring control program in the primary catchment of the natural water sources. This should include all river beds, water courses and storm water systems.
2. Who will take responsibility for the Pollution monitoring control program in the secondary catchment of the domestic and industrial sewer system.
3. For DPR/IPR, the WWTP should be designed and operated to remove maximum COD/DOC, TN and TSS in order to reduce (i) possible operational risks which can lead to health risks and (ii) operating costs at the AWTP.
4. When the WWTP supplying the raw water source to the AWTP reaches 80% of its treatment capacity,
    a. The planning, design and provision of funds for the extension phase needs to be put in motion.
    b. Increased frequency of monitoring of certain critical parameters needs to take place to be able to better control the operation of the WWTP. At many WWTP the diurnal flow has increased and certain operational units are not able to cope with the peak flows and loads, especially aeration can cause problems so that nitrification is inadequate and higher incidences of ammonia spikes can be expected in the effluent.
5. The raw sewerage flow and concentration or load of the WWTP should be monitored and compared against the design values of the plant. This should be compared with the final treated effluent specifications.
6. WWTP operational changes should be communicated with the AWTP operator, so that they can adjust their operations and monitoring frequency accordingly.
7. Data communication: There should be a contract whereby operational data and raw and final water quality data (in the case of a WWTP: sewerage influent and treated effluent) laboratory and on-line monitoring data are exchanged between the parties, so that the operator of the AWTP facility can take the necessary precautionary measures to deal with an event or incident.
8. There should be a contract whereby the WWTP operator is penalised for non-compliance of the effluent when maximum values are exceeded. The AWTP operator should have the option to bypass the raw water or treat at a higher cost and risk and be compensated for it.
9. Events or incidents registers need to be kept. Whatever happens outside the norm needs to be recorded in the full water cycle by the relevant operator and needs to be presented to the steering committee. If these data are evaluated in isolation, the overall risk management and prevention measures cannot be optimised over the full water cycle. On the positive side, it will over time exclude duplication and reduce operational costs.
10. A steering committee should annually review all monitoring and operational data as well as incident/event records, with the specifications which are in the agreements and against recommended water or wastewater guidelines specifications.

11. Data storage: There needs to be an agreement for central data storage of major SCADA and water quality and operational monitoring parameters of the treatment plants and control stations in water cycle, so that meaningful evaluations and conclusions can be drawn with regard to potential hazards entering the cycle and removal thereof by the treatment units.
12. Communication on all levels needs to happen according to a fixed schedule, agreed upon by all relevant stakeholders.

To mitigate the risk in the catchment, the basin committee, local authority or municipality needs to consider the adoption of either or all of the following three approaches: zoning and promulgation, awareness campaigns and inspections. The best way is the preventative way. Authorities should rely on consumer awareness and inspections. Monitoring needs to be done were the risk is high. The polluter pays principle should be adopted. The authority should enforce the installation of proper sampling and monitoring equipment with every industry. The on-line equipment needs to send signals to an operations room. Should an incident or event happen the authority can react immediately with the necessary sampling and corrective action.

Many times it is difficult to manage the approval process of a new industry in the catchment area. Different Ministries are responsible to grant environmental or resource conditions. Often there is no communication and the monitoring and control body is faced with a situation that needs a lot of mitigation to reduce the risk to the minimum with regard to effluent restrictions. Often exemptions are given to such industries that make it extremely difficult to monitor. Therefore flexible legislation, local bylaws and customer awareness strategies need to be in place to be able to mitigate risk.

Tables 3.2 and 3.3 show proposed monitoring programmes for the entire catchment system sourcing the WRP as well as the intake water feeding the WRP, respectively.

Table 3.2: Total catchment system monitoring programme

Main groups of determinants : Water and Wastewater	Surface water		Ground water		Catchment Pollution		Industrial Pollution		Raw Sewerage	
	R & P	Frequency	R & P	Frequency	R & P	Frequency	R & P	Frequency	R & P	Frequency
Physical and organoleptic: Turbidity, pH, Conductivity, Colour, Alkalinity, Hardness	M, H	1pw	M, H	1pw						
Inorganic – anions: Cl, SO4, F, Br, NO3, NO2, PO4,	L, L	1pm	M, H	1pm	L, M	1pm	H, H	1pm	M, M	1pm
Inorganic – cations non-metals: K, Na, Ca, Mg, NH3,	L, L	1pm	M, H	1pm	L, M	1pm	H, H	1pm	M, M	
Inorganic – cations metals: Fe, Mn, Al, Cd, Hg, Pb…	L, L	1pm	L, M	1pm	L, M	1pm	H, H	1pm	M, M	1pm
Organics: DOC, COD, UV254, OA, THM, AOX, Phenol, Formaldehyde	M, H	1pw	L,L	1pm	L, M	1pm	H, H	1pm	M, M	1pm
Nutrients: TKN, PO4, NH3, NO3, NO2	M,M	1pw	L, L	1pm						
Solids: TSS, TS, TFS, TVS, COD, OA	L, L		L, L		L, M	1pm	H, H	1pm	H, H	1pm
Microbiology: HPC, Total coliform, Faecal coliform, Faecal streptococci, Pseudomonas aeroginosa, Clostridium (spores, viable)	M, H	1pw	H, M	1pw						
Virology: CPE+PCR, Somatic Coliphage,	M, M	1pw	M, L	1pm						
Biology: *Giardia*, *Cryptosporidium*, Algae, Toxins, Geosmin, 2MIB	H, M	ONL	L, L	ONL						
Disinfection (residuals): Free + Total CL2, Ozone	M, H	1pd	H, M	1pw						
Disinfection by-products: THM, BrO3,	H, H	1pm	L, L	1pa						
Toxicity (acute): Daphnia, Bacterial growth, Urease enzyme	H, L	1pq	M, L	1pa						
Mutagenicity (chronic): Ames Salmonella (S98+S100)	H, L	1pq	M, L	1pa						
Plant and system performance: Isotherms, Beaker settling tests, Sieve analysis, Lime test, Settling tests, AOC, BDOC, AOX	H, M		H, L							
DEEP					L, M	1pm	H, H	1pm	H, H	
Specialised tests and studies:										
Medical and other substances: Pharmaceuticals, Endocrine	H, L	1pa	H, L	1pa	L, M		H, H		H, H	
Organic Pollution Index (OPI)	NA	1pa	NA	1pa	L, M		H, H		H, H	
On-line fish bio-monitoring	NA		NA							
Epidemiology or fault tree microbial risk assessment	Included		Included		Included		Included		Included	
On-line monitoring:										
Turbidity, TSS, Conductivity	H,H	ONL	M,H	ONL	L, M	ONL	H, H	ONL	H, H	ONL
Free – chlorine residual	M, H		H, M							
pH	M,L	ONL	M, L	ONL	L, M	ONL	H, H	ONL	H, H	ONL
Particle counting	NA		NA		NA		NA		NA	
NH4, NO3, NO2, DO, ORP	M, M		L, L		L, M	ONL	H, H	ONL	H, H	ONL
DOC/TOC/UV254	M, H	ONL	M, L		L, M	ONL	H, H	ONL	H, H	ONL
On-line continuous concentration:										
Giardia, Crypto, Virus (risk management)	M, H	ONL	L, L	ONL	H, H		NA		H,H	
R & P: Risk & Probability: High (H), Medium (M), Low (L);	Frequency of sampling: NA = not applicable; ONL = on-line; per day (pd), per week (pw), per month (pm), per quarter (pq) and per annum (pa).									

Table 3.3: WRP intake water monitoring programme

Parameter group	Frequency	Sample
Physical and organoleptic: Turbidity, pH, Conductivity, Colour, Alkalinity, Hardness	Weekly	Composit
Inorganic – anions: Cl, SO4, F, Br, NO3, NO2, PO4,	Monthly	Composit
Inorganic – cations non-metals: K, Na, Ca, Mg, NH3,	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, UV254, Phenol, Formaldehyde	Weekly	Composite
Organics: THM, THMFP, AOX	Monthly	Composite
Nutrients: TKN, PO4, NH3, NO3, NO2	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
Biology: Algae, [Toxins, Geosmin, 2MIB #1]	Weekly	Grab
Biology: Chlorophyll	Weekly	Grab
Biology: *Giardia, Cryptosporidium*	Weekly	On-Line Concentration
Disinfection (residuals): Free + Total CL2, Ozone	Weekly	Grab
Disinfection by-products: THM, BrO3,	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 Cl2	Daily	On-Line
#1 to be tested only when incident occurs, #2 program determined by specialist team, #3 only done when required		

3.1.2.2 *Operational control monitoring programmes*

With the list of treatment units available, and the configurations to show the intended purpose of each of the units it is possible to link certain water quality parameters to treatment processes performed by the different treatment units, as seen in Table 3.4. The relevant parameter that would be measured in each case is also indicated. As mentioned, the target values as well as the measured parameters may vary depending on the combination of process units used at any given plant. It should, however, be mentioned that in most cases certain process units are always used for certain treatments which makes it possible to identify one or two measured parameters that can be used as performance indicators for treatment units.

Table 3.4: Performance indicators for various treatment units

Treatment unit	Treatment step	Performance indicator	Measured Parameter
Coagulation/Enhanced coagulation/ Flocculation	Floc formation	Visual inspection (Flock size, stability, density, etc.)	Settling test
Clarification (Floc removal)	NOM removal	Concentration of NOM in treated water	mg/L TOC, DOC, etc.
	Pathogen removal	Concentration or count of pathogens in treated water	plaques, count/volume, etc.
	Inorganics removal	Concentration inorganics in treated water	mg/L Fe, F, Mn, etc.
	Phosphate removal	Concentration PO4 in treated water	mg/L PO4
Clarification (Phase separation)	Sludge thickening	Visual inspection (solid carry-over, etc.)	Turbidity (if feasible)
DAF	Aesthetic treatment	Treated water aesthetics/quality (Clarity, taste and odour)	Turbidity, Colour
	Constituent removal	Concentration of constituent in treated water (FOG, algae, colloids, etc.)	mg/L constituent, Turbidity
Filtration (sand or multi-media)	Constituent removal	Concentration of constituent in treated water (flocks, fine materials, etc.)	Turbidity, Colour
BAC (biologically activated carbon)	Constituent removal	Concentration of constituent in treated water (Organics, inorganics, CECs, etc.)	µg/L constituent
	Aesthetic treatment	Treated water aesthetics/quality (Clarity, taste and odour)	Turbidity, Colour
GAC (granular activated carbon)	Constituent removal	Concentration of constituent in treated water (Organics, DBPs, EDCs, etc.)	µg/L constituent
	Aesthetic treatment	Treated water aesthetics/quality (Clarity, taste and odour)	Turbidity, Colour
PAC (powder activated carbon)	Constituent removal	Concentration of constituent in treated water (Organics, DBPs, EDCs, etc.)	µg/L constituent
	Aesthetic treatment	Treated water aesthetics/quality (Clarity, taste and odour)	Turbidity, Colour
Microfiltration	Constituent removal	Concentration of constituent in treated water (1-0.1 µm)	Turbidity, TSS, SDI

Treatment unit	Treatment step	Performance indicator	Measured Parameter
Ultrafiltration	Constituent removal	Concentration of constituent in treated water (0.1-0.01 µm)	Turbidity, HPC, SDI
Nanofiltration	Constituent removal	Concentration of constituent in treated water (0.0 0.001 µm)	Turbidity, UV254, EC
Reverse Osmosis	Constituent removal	Concentration of constituent in treated water (0.001-0.0001 µm)	Turbidity, UV254, EC
Ozonation	Constituent removal	Concentration of constituent in treated water (Organics, CECs, EDCs, etc.)	UV254, TOC/DOC
	Disinfection	Microbial activity in treated water (Parasites, bacteria, viruses)	HPC, total coliforms, etc.
UV/H2O2	Constituent removal	Concentration of constituent in treated water (Organics, CECs, EDCs, etc.)	UV254, TOC/DOC
	Disinfection	Microbial activity in treated water (Parasites, bacteria, viruses)	HPC, total coliforms, etc.
Chlorination	Disinfection	Microbial activity in treated water (Parasites, bacteria, viruses)	HPC, total coliforms, etc.

As mentioned, there are many different parameters that can be used and in many cases more than one parameter can be measured at a treatment unit. Since treatment units are responsible for treating water based on different needs, stands to reason that the performance indicators used for the different treatment units can also be linked to different purposes. The measured parameters in Table 3.4 are grouped according to the treatment process unit where the parameters are measured. The parameters can also be grouped according to the type of parameter, as seen in Table 3.5.

From a process control perspective, it is important to have safe, yet realistic, alarm and target levels for these parameters. From Table 3.4 it is clear that different treatment units may share similar performance indicating parameters. The measured parameters may be applicable to more than one treatment process, but the alarm and target levels of the measured parameters may differ from one treatment process to another. This also depends on the purpose (as seen in Table 3.6) of the treatment unit as well as the configuration of the plant, specifically relating the treatment units that are directly downstream of the given treatment unit.

Tables 3.7 shows the different alarm and target levels for the different measured parameters that may be used as performance indicators in order to aid process control of the different treatment units and their processes.

Table 3.5: Measured parameter groupings based on parameter type

Process Unit	Performance indicators			
	Physical	Chemical	Microbiological	Other
Coagulation/ Flocculation				Contact time, Mixing speed
Clarification	TSS, Colour		Parasites	
DAF	Colour, Turbidity, TSS	Inorganics	Parasites	
Filtration (sand or multi-media)	Colour, Turbidity, TSS	Inorganics	Parasites	
BAC (biologically activated carbon)	Colour, DOC/TOC	Organics, Inorganics	All	UV254
GAC (granular activated carbon)	Colour, DOC/TOC	Organics, Inorganics	All	UV254
PAC (powder activated carbon)	Colour	Organics, Inorganics	All	UV254
Microfiltration	Turbidity, TSS	Inorganics	All	UV254
Ultrafiltration	Turbidity, TSS	Inorganics	All	UV254
Nanofiltration	Turbidity, EC	Inorganics, Organics	All	UV254
Reverse Osmosis	Turbidity, EC	Inorganics, Organics	All	UV254
Ozonation	DOC/TOC	Organics	All	Residual O_3
UV/H_2O_2	DOC/TOC	Organics	All	
Chlorination			All	

Table 3.6: Measured parameter groupings based on purpose

Human and environmental health	Aesthetic	Unit control	Stability
F	Colour	Colour	Turbidity
Fe	TSS	EC	pH
Mn	Turbidity	TSS	
PO4	DOC/TOC	Turbidity	
total coliforms		DOC/TOC	
HPC		UV254	

Table 3.7: Alert levels and maximum allowed values for various measured parameters

Process unit	Measured Parameter	Unit	Alert level	Maximum level
Coagulation/ Flocculation				
DAF	Turbidity	NTU	1.5	5
Sand Filter	Turbidity	NTU	0.2	0.35
	Iron	mg/L	0.05	0.05
	Manganese	mg/L	0.03	0.05
GAC	UV254	-		0.06
	TOC	mg/L	0.05	
	Total Trihalomethanes	µg/L	20	
	DOC	mg/L	3	5
BAC	Iron	mg/L	0.05	0.05
	Manganese	mg/L	0.01	0.025
PAC				
MF				
UF	COD	mg/L	<70% reduction	
	Turbidity	NTU	0.15	
	Suspended solids	mg/L	<98% reduction	
	TOC	mg/L	<50% reduction	
NF (Not used often)				
RO	TOC/DOC	mg/L	Below detection (0.01)	0.05
	Turbidity	NTU	0.10	0.20
	Nitrite	mg/L	0.50	
	Nitrate	mg/L	0.20	

Process unit	Measured Parameter	Unit	Alert level	Maximum level
	Ammonia	mg/L	0.10	
	Electrical conductivity	mS/m	< 90% removal	
	Heterotrophic Plate Count	cfu/mL	100	
	Total Trihalomethanes	µg/L	20	
	Colour	mg/L as Pt	5	
Ozonation	DOC	mg/L	15	15
	COD	mg/L	25	25
	Heterotrophic Plate Count	cfu/mL	80	100
	Total Coliforms	cfu/100 mL		0
UV/H2O2	TOC	mg/L	0.1	
	Total Trihalomethanes	ug/L	20	
	Heterotrophic Plate Count	cfu/mL	5	
Chlorination	Heterotrophic Plate Count	cfu/mL	2	
	Total Coliforms	cfu/100 mL	0	
	E. coli	cfu/100 mL	0	
	Entrerococcus	cfu/100 mL	0	
	Somatic Coliphage	pfu/100 mL	0	
	Cryptosporidium	Oocyst/100 L	0	
	Giardia lamblia	Cysts/100 L	0	
	Total Trihalomethanes	µg/L	20	

The different methods used to measure each of the measured parameters are very important. High measuring frequencies are required for optimal plant control. Final water compliance monitoring is not as dependent on measurement frequencies as operational control monitoring. This is because of the relative time that is available to correct substandard water qualities. In operational control monitoring the time available to determine if it is safe to pass a stream to the next treatment unit, or whether the stream should by-pass a treatment unit or be recycled, is much less than the time that is available to determine whether the final water leaving the plant is safe for human consumption.

The time that is available in any case is determined by the hydraulic retention time of the water in the streams. With final water compliance, the hydraulic retention time from the outlet of the water reclamation plant to the destination of the water is high because of the size of the distribution system. But with operational control monitoring, there is only a small pipe length and sometimes a balancing tank between two treatment units which provides very little hydraulic retention time for determining the suitability of the water for the receiving treatment unit. The different measuring methods used to analyse the different measured parameters used for operational control can be seen in Table 3.8.

Table 3.8: Methods and frequencies for measuring parameters

Parameter	Measurement Method	Minimum Frequency
pH	On-line, portable instrument	Hourly
TSS	Laboratory/On-line (inferred)	Four times per day
EC	On-line, portable instrument	Hourly
Colour	Laboratory/On-line (inferred)	Hourly
Turbidity	On-line, portable instrument	Hourly
DOC	Laboratory/On-line (inferred)	Hourly
Inorganics	Laboratory	Daily
Organics	Laboratory/On-line (inferred)	Four times per day
Microbiological	Laboratory	Daily
UV254	On-line	Hourly

In principle, operational control monitoring dictates that the measured parameters, which are used as performance indicators for the different treatment processes, should always be indicative of the performance of the treatment unit. It is for this reason that the measured parameters which are used as performance indicators will rarely report a zero level, or 100% removal. This is an important feature of measured parameters since it would be impossible to determine the performance of a treatment process if the measured parameter that indicates the performance of the treatment process is zero at the inlet of the treatment unit. When the operational control of a water reclamation plant is performed correctly, each of the treatment units of the plant will operate at its optimal conditions. This will result in each of the treatment units achieving the performance capacity for which it was designed. The expected treatment efficiency for various treatment processes, treating contaminants of emerging concern, can be seen in Table 3.9.

Table 3.9: Treatment efficiencies of different treatment processes (Metcalf & Eddy, 2006)

Group	Classification	Reverse Osmosis	BAC	Activated Carbon	Nano-filtration	Bio-degradation	Advanced Oxidation	Photo-degradation	Activated Sludge	UV	Cl_2/CLO_2	Softening	Coag/Floc
EDCs	Pesticides	E	E	E	G	v	L-E	E	v	E	v	G	P
	Industrial Chemicals	E	E	E	E	G-E	G-G	v	v	E	P	P-L	P-L
	Steroids	E	E	E	G	L-E	E	v	v	E	E	P-L	P
	Metal	E	G	G	G	P	P	v	E	P	P	F-G	F-G
	Inorganics	E	F	P-L	G	P-L	P	P-L	P-L	P	P	G	P
	Organometallics	E	G-E	G-E	G-E	L-E	L-E	L-E	L-E	F-G	P-F	P-L	P-L
PHACs	Antibiotics	E	E	F-G	E	E	L-E	G-E	v	F-G	P-G	P-L	P-L
	Anti-depressants	E	G-E	G-E	G-E	G-E	L-E	G-E	G-E	F-G	P-F	P-L	P-L
	Anti-inflammatory	E	G-E	E	G-E	E	E	v	v	E	P-F	P-L	P
	Lipid regulators	E	E	E	G-E	P	E	v	v	F-G	P-F	P-L	P
	X-ray contrast media	E	G-E	G-E	G-E	E	L-E	E	v	F-G	P-F	P-L	P-L
	Phsychiatric control	E	G-E	G-E	G-E	G-E	L-E	G-E	G-E	F-G	P-F	P-L	P-L
PCPs	Synthetic musks	E	G-E	G-E	G-E	E	L-E	v	v	E	P-F	P-L	P-L
	Sunscreens	E	G-E	G-E	G-E	G-E	L-E	G-E	G-E	F-G	P-F	P-L	P-L
	Antimicrobials	E	G-E	G-E	G-E	v	L-E	F	v	F-G	P-F	P-L	P-L
	Detergents	E	E	E	E	L-E	F-G	v	v	F-G	P	P-L	P-L

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

3.1.2.3 *Final water compliance monitoring*

The proposed water quality targets for potable water reclamation in Southern Africa can be seen in section 3.2 of this report. This chapter, however, is dedicated to the monitoring protocols of the final water, rather than the target levels for the parameters. Distribution systems play a major role in final water quality and therefore the monitoring protocols for distribution systems will be the focus of this section.

When it comes to the water quality monitoring of distribution systems, the main parameter of concern is the human health implications of the water being distributed. The water quality parameters that impact on human health (primarily pathogens) are typically monitored using a risk-based monitoring program. These risk based monitoring programs will typically determine an acceptable amount of end user health implications over a given period of time. The amount of health implications will typically also be weighed against the severity of the implication. One example of this is the DALY (disability adjusted life year) system that determines the average amount of time (typically in years) that an end user would lose due to disability (unable to perform his normal daily activities), illness or premature death. The different illnesses will then be rated according to their severity which will then also determine the severity of the water constituent responsible for the given illness. With the acceptable amount of end user health implications in a given period of time fixed, the levels of various health impacting water constituents can be calculated based on the daily production capacity of the plant.

The goal of a distribution system quality monitoring programme is therefore to ensure that the health impacting water constituents remain below the target levels for that specific plant (or distribution area). Most plants will use a disinfectant with some residual disinfection properties to reduce the regrowth of pathogens. In cases where a residual disinfectant are not used, several disinfection stations will be required through the distribution network to ensure that all pathogen levels remain below the target levels until the water reaches the end user. Irrespective of the disinfection methods used by a plant, the monitoring of the distribution system is crucial since it is impossible to guarantee that there will not be anything affecting the quality of the water after it left the plant. Storm water intrusion, leaking pipes, aging pipes and vandalism are but a few factors that affect the quality of water in distribution systems irrespective of the disinfection method used by the water producing plant.

Monitoring a water distribution system requires advanced and expensive monitoring systems if it is to be done automatically, and even then, at some point manual samples will have to be taken by hand to check on the monitoring system and calibrate sensors that are used. Alternatively, a utility or plant can only make use of manual samples. This may require more human resources and will lead to a reduction in the amount of data collected. In any instance, the personnel collecting the samples (by hand or with kits/hand held devices) must be well trained and capable of ensuring that the samples are taken correctly, without any cross-contamination taking place.

Many pathogens can be detected in water, although the methods of detection and quantification are expensive and takes a lot of time to produce a result. This is unacceptable when it comes to ensuring the health of end users. Indicator organisms are therefore used in order to simplify and reduce the turnaround time for resulting on microbiological water monitoring. The location of sampling points in the distribution network is of critical importance. The following criteria should be used to ensure that the entire distribution network is taken into account and that all the potentially different water quality zones in the network are sampled and analysed for:

- All low flow regions in the distribution network
- The different pressure zones in the network.
- Different residential areas.
- Population densities in the different supply areas.
- Water supply and mixing zones
- Water sources and major supply pipelines supplying the network
- All reservoirs in use in the distribution network
- All current distribution sampling points
- Sensitive locations: Hospitals, schools, old age homes, clinics, etc.

The different sampling points can be grouped into five categories. The respective sampling frequencies for these categories can be seen in Table 3.10.

Table 3.10: Distribution network sampling frequency

Category	Description	Sampling frequency
A	All supply sources, including Von Bach Terminal reservoir and NGRP Final (OGRP Final = WG7), including New Western Pump Station, (previously Midway pump station)	Twice a week or daily
B	All reservoirs supplying the distribution network, not included in A	Once a week
C	Critical sample points representing the criteria	Once per week at least
D	Important but not critical sample points, representing the criteria	Once per month at least
E	Points of public interest or hotspots: hospitals, clinics, crèches, schools, colleges, universities, old age homes, etc.	Twice per annum at least

According to the SABS (WRC, 1995), whenever a sample is analysed that exceeds the allowed microbial level the authorities must be informed and resampling must be done immediately. No coliforms should be detected during the analyses of the repeated samples. If it is found that repeated samples indicate unacceptable microbial levels there are several actions that can and should be taken:

- A sanitary survey should be initiated in order to determine the source of the contamination.
- Changes should be made to alleviate the problem; this can be done by increasing disinfection dosages, flushing the supply pipelines, supplying water from an alternative water source.

- The responsible authority must post public notices informing the end users to take precautions, i.e. to boil the water before using it.

The sanitary survey should be conducted by a professional person or body that is knowledgeable about the workings of the water treatment and supply process and has experience with these systems. The sanitary survey typically consists of a thorough inspection (looking at all the conditions, devices and practices) of all the treatment processes and the distribution system.

3.1.3 Summary

Community size should be taken into account when it comes to monitoring. Currently the tendency is to have a more extensive monitoring system with larger communities since the risk is higher. However, monitoring should be extensive, irrespective of the number of users. *Giardia, Cryptosporidium*, viruses and other like pathogens, should never exceed limits. Some chemical constituents may on occasion spike, but should not remain at elevated concentrations.

Develop baseline sources and concentrations of selected critical constituents

- For each of the selected critical constituents, provide baseline sources (origin), typical concentration ranges, and target levels (maximum allowable concentrations) of each of the main regions/regulators globally, i.e.
  - EPA
  - WHO
  - California WateReuse
  - Singapore
  - European Commission
  - Australia
  - City of Windhoek
  - SANS 241
  - etc.

3.2 PROPOSED WATER QUALITY TARGETS FOR DPR IN SOUTHERN AFRICA

3.2.1 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.

Ideally drinking water should not contain any known pathogenic microorganisms and it should be free from bacteria indicative of pollution with excreta. To ensure that a supply of drinking water satisfies these guidelines of bacterial quality, it is important that water be examined regularly for indicators of pollution (WHO, 2004). 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:

- 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.

<u>Exceptions where pathogen presence is set in water quality guidelines</u>

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.

Some chemical constituents, which do not constitute a direct or acute health risk, may on occasion spike, but should not remain at elevated concentrations. Plants making use of RO treatment processes should, however, never allow any spikes in chemical constituent levels in the final treated water.

<u>International Guidelines to Assess the Safety of Water</u>

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 taking into account 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, 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 ideally 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 quality guidelines are currently not legally enforceable. The WRC has started the process (2014) of updating the South African water quality guidelines to include updated guideline levels and chemicals of emerging concern for which quantitative and qualitative data is available. Updated on-line South African water quality guidelines should be available by 2018.

3.2.2 Proposed water quality targets

Tables 3.11-3.16 show the proposed water quality targets for direct potable reuse in Southern Africa.

Table 3.11: Proposed water quality targets for physical parameters

Parameter	Unit	Proposed Guidelines (adapted from CoW guidelines)		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

Table 3.12: Proposed water quality targets for chemical parameters (macro determinants)

Parameter	Unit	Proposed Guidelines (adapted from CoW guidelines)		Existing Guidelines ranges			
				International		Southern Africa	
		Target value	Maximum allowed	Target value range	Maximum allowed range	Target value range	Maximum allowed range
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

Table 3.13: Proposed water quality targets for chemical parameters (micro determinants)

Parameter	Unit	Proposed Guidelines (adapted from CoW guidelines)		Existing Guidelines ranges			
				International		Southern Africa	
		Target value	Maximum allowed	Target value range	Maximum allowed range	Target value range	Maximum allowed range
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
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

Table 3.14: Proposed water quality targets for microbiological parameters (algae, bacteria, viruses and parasites)

Parameter	Unit	Proposed Guidelines (adapted from CoW guidelines)		Existing Guidelines ranges			
				International		Southern Africa	
		Target value	Maximum allowed	Target value range	Maximum allowed range	Target value range	Maximum allowed range
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

Table 3.15: Proposed water quality targets for disinfection by-products

Parameter	Unit	Proposed Guidelines (adapted from CoW guidelines)		Existing Guidelines ranges			
				International		Southern Africa	
		Target value	Maximum allowed	Target value range	Maximum allowed range	Target value range	Maximum allowed range
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
Dibromochlorom-ethane	µg/L	20	40		60 - 100		50-100
Total THMs	µg/L	20	40	0	80	20	40-100

Table 3.16: Proposed water quality targets for priority pollutants (chemicals of emerging concern)

Parameter	Unit	Proposed Guidelines (adapted from CoW guidelines)		Existing Guidelines ranges			
				International		Southern Africa	
		Target value	Maximum allowed	Target value range	Maximum allowed range	Target value range	Maximum allowed range
Priority Pollutants (Chemicals of Emerging Concern)(EDCs)							
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	

EXISTING GUIDELINES SOURCES:

International

1. United States Environmental Protection Agency (US EPA), Guidelines for Water Reuse, 1st edition, 2012
2. World Health Organization (WHO), Guidelines for Drinking-water Quality, 4th edition, 2011
3. Australia, Australian Guidelines for Water Recycling, 2008
4. Singapore, Environmental Public Health Regulations, 2008

Southern African

1. City of Windhoek (CoW)
2. South Africa, SANS 241:2011
3. South Africa, Rand Water, Potable water Quality Criteria, 1994
4. WINGOC operational and compliance monitoring protocols

3.3 WATER QUALITY TESTING LABORATORIES IN SOUTH AFRICA

3.3.1 Accredited Laboratories

Table 3.17 shows accredited water laboratories in South Africa (SANAS website, February 2014). A list will also be compiled of research laboratories and university laboratories that perform specialised analyses such as the hormones, pharmaceuticals and other CECs.

Table 3.17: Accredited water laboratories in South Africa

Name	Location (City)	Province	Status	Disciplines
AL Abbott and Associates (Pty) Ltd	Cape Town	The Western Cape	Accredited	Chemical and Microbiological Analysis
Amatola Water	East London	The Eastern Cape	Withdrawn	Chemical and Microbiological Analysis
Buckman Laboratories (PTY) Ltd	New Castle	Kwazulu-Natal	Accredited	Chemical Analysis
City of Cape Town, Water and Sanitation, Scientific Services Department	Cape Town	The Western Cape	Accredited	Chemical and Hydrobiology Analysis
CSIR Water Laboratories: Stellenbosch	Stellenbosch	The Western Cape	Accredited	Chemical Analysis & Microbiological Testing: Water
eThekwini Water & Sanitation – Scientific Services	Durban	Kwazulu-Natal	Accredited	Chemical & Microbiology Analysis
Integral laboratories (Pty) Ltd	Empangeni	Kwazulu-Natal	Accredited	Chemical and Microbiological Analysis
Johannesburg Water (Pty) Ltd	Houghton	Gauteng	Accredited	Chemical Analysis
Mhlathuze Water	Richards Bay	Kwazulu-Natal	Accredited	Chemical & Microbiological Analysis
Midvaal Water Company Laboratory	Klerksdorp	North West	Accredited	Chemical and Microbiological Analysis
National Health Laboratory Service (NHLS)	Parktown	Gauteng	Suspended	Testing Laboratory: Microbiology
SABS Commercial (Pty) Ltd	Secunda	Mpumalanga	Withdrawn	Chemical & physical analysis
Sedibeng Water-Quality Control Laboratory	Bothaville	The Free State	Accredited	Chemical & Biological Analysis
Talbot Laboratories (Pty) Ltd	Pietermaritzburg	Kwazulu-Natal	Accredited	Chemical and Microbiological Analysis
Umgeni Water – Amanzi	Pietermaritzburg	Kwazulu-Natal	Accredited	Chemical, Hydrobiology & Microbiological Analysis
Water Analytical Laboratory cc	Stellenbosch	The Western Cape	Accredited	Microbiological Analysis

3.3.2 Accreditation and quality control

Drinking-water supply agencies are responsible for quality assurance and quality control. The International Standards Organisation (ISO) provides documentation on the quality control process for "Guidance on analytical quality control for chemical and physicochemical water analysis" (ISO 13530:2009). ISO has also established quality management standards relating to drinking-water supply, including ISO 24510:2007, Activities relating to drinking water and wastewater services—Guidelines for the assessment and for the improvement of the service to users; and ISO 24512:2007, Activities relating to drinking water and wastewater services – Guidelines for the management of drinking water utilities and for the assessment of drinking water services. On a municipal level there are no financial penalties to motivate quality assurance. Also, many monitoring tests and equipment are only financially viable when the consequence of financial penalties is taken into account.

3.3.3 Cost of analyses

The cost of analysing samples for the parameters proposed in Tables 3.18-3.20 can be seen in the following tables. These costs include VAT and are applicable to the year 2015. It should be noted that costs vary depending on laboratories and that the costs shown in these tables are generalised to provide an approximate cost.

Table 3.18: Typical costs for analyses (2015)

Parameter	Price
pH	R 40.00
Colour	R 100.00
Electrical Conductivity (EC)	R 40.00
Turbidity	R 40.00
Dissolved Organic Carbon (DOC)	R 180.00
Total Organic Carbon (TOC)	R 180.00
Chemical Oxygen Demand (COD)	R 190.00
Soluble Phosphate	R 100.00
Total Phosphate (TP)	R 190.00
Alkalinity	R 100.00
Ammonia	R 100.00
Iron	R 90.00
Magnesium	R 90.00
Cadmium	R 100.00
Chromium	R 100.00
Hexavalent Chromium (Cr^{6+})	R 100.00
Phenols	R 320.00
Chlorophyll a	R 190.00
Bromide	R 150.00
Polycyclic Aromatic Hydrocarbons (PAHs)	R 1,380.00

Table 3.19: Typical costs for analyses (2015)

Parameters	Price
Viruses	R 2,000.00 Each
Parasites	
Estrogenic activity	
Pesticides	
Pharmaceutical screening	

Table 3.20: Microbiological analysis prices (2015)

Parameter	Price
E. coli	R 200.00
Faecal Coliform	R 150.00
Total Coliform	R 150.00
Heterotrophic Plate Count (HPC)	R 150.00
Clostridium	R 190.00
Enteric viruses	R 2,400.00
Cholera	R 430.00
Legionella Q	R 670.00
Legionella PA	R 470.00
Protozoan Parasites	R 2,160.00
Pseudomonas aer	R 200.00
Pseudomonas spp	R 200.00
Salmonella	R 330.00
Somatic coliphages	R 200.00
Streptococci	R 150.00
Yeast & Moulds	R 230.00

Screening (presence/absence) tests are also available. Laboratories can screen samples at a fixed cost and then do further quantitative analyses for compounds found in the samples at an additional cost. Table 3.21 shows a list of parameters that are included in the WHO's guidelines for drinking water that can be screened for at a cost of R 5 130 for all the parameters, or R 4 000, if inorganics are excluded (2015 costs). The laboratory is located in Bloemfontein and courier cost should also be taken into consideration.

Test kits are also available for plants to purchase and use in their own laboratories. Table 3.22 shows the prices and testing procedure for three tests kits that are typically used to perform advanced water quality tests with.

Table 3.21: WHO parameter list for screening

Parameters		
Antimony	Bromodichloromethane	Hexachlorobutadiene
Arsenic	Bromoform	Isoproturon
Barium	Carbofuran	MCPA
Boron	Carbon tetrachloride	Mecoprop
Bromate	Chlordane	Mercury
Cadmium	Chloroform	Methoxychlor
Chlorate	Chlorotoluron	Metolachlor
Chlorine	Chlorpyrifos	Microcystin-LR
Chlorite	Cyanazine	Molinate
Chromium	2,4D	Monochloroacetate
Copper	2,4DB	Nitrilotriacetic acid (NTA)
Cyanide	DDT and metabolites	N-Nitrosodimethylamine (NDMA)
Fluoride	Di(2-ethylhexyl)phthalate	Pendimethalin
Lead	Dibromochloromethane	Pentachlorophenol
Manganese	1,2-Dibromo-3-chloropropane	Permethrin
Molybdenum	1,2-Dibromoethane	Pyriproxyfen
Nickel	1,2-Dichlorobenzene	Simazine
Nitrate (as NO_3^-)	1,4-Dichlorobenzene	Sodium dichloroisocyanurate
Nitrite (as NO_2^-)	Dichloroethane	Sodium dichloroisocyanurate (as Cyanuric acid)
Selenium	Dichloroethene	Styrene
Uranium	Dichloromethane	2,4,5-T
Acrylamide	1,2-Dichloropropane	Terbuthylazine
Alachlor	1,3-Dichloropropene	Tetrachloroethene
Aldicarb	Dichlorprop	Toluene
Aldrin and Dieldrin	Dimethoate	Trifluralin
Atrazine	Endrin	Trihalomethanes (Total THMs)
Benzene	Ethylbenzene	Xylenes
Benzo[a]pyrene	Fenoprop	

Table 3.22: Tests kits for advanced analyses

Kit	Sampling	Price (2015)
Microcystin	5 Individual tests	R 2,500.00
Elisa for Estradiol	Approximately 80 samples/tests. Must be performed at the same time.	R 8,000.00
Ames test for Mutagenicity	16 tests to be performed at the same time	R 8,000.00

3.4 COMMUNICATION PROGRAMMES AND INCIDENT MANAGEMENT PROTOCOLS

3.4.1 Communication programmes

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 needs 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.

3.4.2 Incident management protocols

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.

CHAPTER 4: SUMMARY OF GUIDELINES AND GOOD PRACTICES IN DIRECT POTABLE REUSE

4.1 GUIDELINES FOR WATER QUALITY MONITORING AND MANAGEMENT

Water sustains life and it is in public interest that the water supplied by the public utility conforms to required water quality guidelines. These are determined by specialist team and according to the raw water supply the treatment process is designed. Regular monitoring of the raw water source, the treatment process steps themselves and the final water produced, is the only evidence that the utility can produce to ensure to the consumers that the water treatment process indeed met all the required targets that have been set.

When dealing with DPR there is an all-important risk that the utility should keep in mind: One incident, which can be proven to stem from the DPR, where people in the community have been severely compromised (death or serious suffering, mostly caused by acute infection) will lead to a high probability that the treatment unit may be closed in the extreme or that financial losses will occur due to law suits. During periods of investigations the treatment unit will most probably not be allowed to operate. With all this said, it is in the interest of the owner and operator of the DPR to ensure that at all times good data are produced from a robust monitoring program. The higher cost of monitoring is like an insurance policy, one any doubt occurs, it will prove its value to ensure to the public as well as any panel of judges (either in court or the media) that the treatment unit complied with all set guidelines and regulations.

This policy is a proven one practiced in Windhoek since the first DPR came into operation in 1968. With the upgrades and extension of capacity of the DPR scheme in Windhoek, monitoring was intensified. With numerous water quality issues mainly caused because the natural sources did not comply, the public could be convinced that DPR technology (monitoring is an integral part of it) is functioning well and is not causing any threat. Like an insurance policy, it also gives peace of mind to the operational staff component, because it proves their commitment. This is one of the reasons ensuring that both the citizens of Windhoek, as well as the owner and operator of the DPR are proud about their reclamation scheme.

Conclusion: Rather more tests than less should be performed. For that reason, profit margin should never drive decisions around a monitoring scheme.

4.2 GUIDELINES FOR EFFECTIVE MANAGEMENT

The following guidelines are applicable to the water quality management of direct and indirect potable reuse schemes in Southern Africa:

Scheme feasibility:

- Political will is an important factor in determining whether the reclamation plant project will be a success

- A steering committee should be established before a Water Reclamation Plant (WRP) is constructed. It should review the different catchments and sources to the plant and establish proper monitoring protocols
- Thorough Environmental Impact Assessment (EIA) studies should be completed and the reduced return flow factored into the feasibility of the WRP. A minimum return flow to the environment can compete against upgrading the WRP in the future
- Financial feasibility must be established. It is also important to take into consideration that many WRP's are built during extreme droughts and that the production capacity of the plant may reduce significantly once conventional water sources are no longer depleted

Raw water:

- A steering committee should be established to review water quality results on an annual basis
- Catchments should be reviewed and verified annually to see if the monitoring programme addresses all water quality aspects
- A catchment (including all the sources to the Waste Water Treatment Works (WWTW) and WRP) status should be completed once a year to identify parameters of concern and ensure that the plants are prepared to treat the influent they receive to the required standard
- Ammonia is not effectively removed by reverse osmosis (RO); this should be kept in mind. Ammonia should preferably be removed at the source or by the wastewater treatment processes.
- The design of maturation ponds is critical; if the pond is too shallow (or has large open surface areas), the wind will stir the water and rise the sediments at the bottom of the pond, increasing the turbidity.

Water reuse plant:

- Proper operation and maintenance is very important to ensure the required water quality over time.
- Treatment process units must be thoroughly monitored. The monitoring data should be stored and reviewed in order to ensure that each of the treatment units performs as intended. Impromptu maintenance should also be carried out based on the monitoring results. (However, risk-based maintenance is still the most important too to properly maintain the plant).
- Filters should have a filter-to-waste option to ensure low turbidity (i.e. it should prevent particle breakthrough) after backwashing to ensure proper removal of *Giardia* and *Cryptosporidium.*
- If a unit process is out of a target specification it should automatically go into bypass or recycle mode, providing that the final water quality can still be attained. (If not, the plant should be shut down and the problems fixed).

Monitoring instruments:

- On-line monitoring, using high quality instrumentation, is not optional for direct and indirect potable reuse plants, because of the high demands placed on treatment efficiency and water qualities.
- The feed and final water of each of the treatment units should further be measured at a high frequency in order to detect treatment failures.

Plant operators/process controllers:

- The process controllers of WRPs should have a sufficient skills level to understand each of the treatment processes on the plant.

- Sufficient guidelines or operational manuals should be available on-site at each of the applicable treatment process units that can guide a process controller, especially during emergencies.
- All process controllers must be able to use and calibrate hand held sampling and measuring devices.

Public participation:

- Good analytical results and data management (archiving) is a very important aspect for public participation and motivating the use of certain technologies. The laboratory should also set high standards and be promoted to set the minds of the public at ease. Open communication channels with the public, will further enhance public participation in, and acceptance of, water reuse schemes.

CHAPTER 5: OUTCOMES AND FINDINGS

5.1 SUMMARY OF FINDINGS

It was emphasised in the report that the success of a DPR scheme depends on five important elements, namely:

- A reputable specialist team to accompany the project from design to implementation
- A robust treatment train
- A proven treatment technology with a good track record elsewhere
- Water quality monitoring
- Good communication.

The guidelines provided here are focused on water quality monitoring as an important link in the various potable reuse chain. Important conclusions drawn from the development and presentation of guidelines are summarised below.

With good technologies, personnel and communication protocols, and barriers and monitoring systems in place, direct and indirect potable reuse is becoming increasingly attractive as a water source.

Although the technological development and analytical and engineering procedures for monitoring are well advanced, and potable water quality can be ensured, there are still a number of challenges and issues that are receiving attention and which are currently studied further at research centres across the world.

The successful implementation of IPR and DPR schemes depends strongly on the expertise of design and monitoring teams and the availability thereof in the particular region. A good example is the management of brine streams, and addressing the technological and economic challenges that are evident in this regard.

In the design of DPR monitoring programs, information about the water quality should be clearly communicated to the consumer as well as within the water service provider. Negative communication should be avoided at all cost (without distorting facts), because any negative information and publicity about a water quality event at the consumer point will be blamed on DPR. A good monitoring program will allow the water quality manager to convince all stakeholders about the true reflection of water quality in the system.

The most common and widespread health risk associated with drinking water is microbial contamination and therefore the control of microbial contamination must always be of primary importance. Ensuring the chemical safety of water requires a different approach as not all the chemicals specified in most guidelines and standards for drinking water will occur in all locations, and if they do exist, they may be present below levels of concern. However, the importance of chemicals in drinking water should not be underestimated, and it is therefore imperative that chemical contaminants be prioritised so that the most important ones are included in monitoring programmes.

For the optimisation of the performance of unit treatment processes, it is important to note that the measurement of control parameters should not aim at concentrations of zero, but rather an indication of the removal percentage or log removal. This is an important feature of measured parameters since it would be impossible to determine the performance of a treatment process of the measured parameter that indicates the performance of the treatment process is zero at the inlet of the treatment unit. When the operational control of a water reclamation plant is performed correctly, each of the treatment units of the plant will operate at its optimal conditions.

Monitoring a water distribution system requires advanced and expensive monitoring systems if it is to be done automatically, which is the situation that is strived towards. Even then, at some point manual samples will have to be taken by hand to check on the monitoring system and to calibrate the sensors that are used. Good protocols will ensure that this can be achieved in an efficient manner.

Community size should be taken into account when it comes to monitoring. Currently the tendency is to have a more extensive monitoring system with larger communities since the risk is higher. However, monitoring should be extensive, irrespective of the number of users. This is a very important point, as it is often considered that smaller communities using IPR or DPR may have a scaled-down version of a monitoring program. <u>For obvious reasons, this should never be allowed.</u>

Effective communications of data or results is all about building trust relationships. Data without good communication are worthless and will not serve any purpose, should an incident occur where the health of the public is at risk.

Professionalism and care! Trust from the public in drinking water provision is paramount. Internal lines should be open, the public happy and the critics (newspapers or specialists) convinced that they can trust the water service provider to rectify a situation, should something go wrong.

5.2 RECOMMENDATIONS

1. Standards for drinking water quality from IPR and DPR plants should be included in the SANS 241 guidelines as a separate section for water reclamation plants for producing drinking water.
2. DWS should help water service providers (municipalities and water boards) to have access to proficient scheme and plant managers, and skilled process controllers, by funding training programmes for scare skills (such as membrane treatment plant operation). Although DWS could take the lead in this regard, they should be closely assisted by other departments and institutions, such as CoGTA, SALGA, Department of Health, etc. in the implementation thereof.
3. DWS should use the information provided in this report to adopt and implement standards for direct and indirect potable reuse in South Africa as a high priority.

4. Regulation of IPR and DPR plants should be included in, and given specific attention to, in both the Blue Drop program, as well as the Green Drop program (for wastewater treatment plants supplying reuse plants with secondary or tertiary treated wastewater).

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APPENDICES

Appendix A:

Direct and indirect potable reuse potential in South Africa

Information sources

The source of information on the water supply status of towns in the country was the water reconciliation reports that were compiled by the Department of Water Affairs (DWA) (now DWS). DWS had embarked on a nationwide programme to develop water-reconciliation strategies for all towns across the country. Reconciliation strategies for the major metropolitan areas and systems (i.e. Johannesburg/Pretoria, East London, Bloemfontein, Kimberley, Cape Town and Durban) were developed in a follow-up phase. The studies required thorough research, analysis and documentation of the available information to estimate growth scenarios for water needs over the next 25 years, followed by an identification of potential additional sources to meet this growing requirement. These additional water supply measures not only include supplemental or new, alternative, water sources such as groundwater abstraction, new dams or increasing the capacity of existing dams and rainwater harvesting, but are also embarking on water savings programs to reduce the often significant water losses in municipal water supply systems. Unconventional sources of supply to meet the increasing water demands, that were also considered in the water- reconciliation strategies, are desalination of seawater or brackish groundwater, and reuse of secondary treated wastewater.

Reuse of wastewater for potable use, either directly or indirectly, constitutes an attractive option since the generally poor management of discharge of treated wastewater forms a threat to downstream surface water and groundwater quality. It may further be less costly than desalination options, where, of necessity, the management of brine has to be included.

The development of surface water and groundwater sources are the most feasible options to meet any current or projected future water-supply shortfalls. However, these options are becoming increasingly limited, resulting in a current focus on desalination and water reuse as supplemental water supply options. An example of this is the desalination and reuse plants that were constructed in the Southern Coastal areas of the country during the past five or so years.
This Southern Coastal zone was subsequently used as example to evaluate water requirements of towns in a certain geographical region, with the reuse potential database used as the basis for the example.

Criteria

As mentioned above, a number of supplemental water supply options were considered in die water reconciliation studies. These include the following:

- Implementation of water conservation and water demand management measures to reduce losses and wastage
- Upgrading of existing infrastructure to increase yield or assurance of supply
- Groundwater development
- Small-scale surface water development
- Water trading
- Water re-use
- Desalination of seawater (for coastal towns) or brackish water
- Rainwater harvesting.

Database structure

The Reuse Potential Database compiled for this project was done in Excel, and includes fields for the details of each town, population, water demand, water available, shortfall, current water sources available and new water sources that could potentially be utilized. From these data, which were all obtained from the DWA reconciliation studies, the towns with shortfalls can then be identified and prioritised, and the potential supplemental sources further evaluated (see Example in Section 5). For this project, the focus was then in particular on those towns with water reuse as a high ranking water supply option. Unfortunately not all the reports from the All-Town-Study have the same format; therefore, the database is not as user friendly with all the different report types with regard to finding the required information from the report. The current database, therefore, primarily consists of data from the Western Cape, Limpopo and the Eastern Cape.

The database is available to the user. Different search and filter functionalities can be used to make the database more versatile and convenient

Database fields

The different database fields can be seen in the table that follows (Table A1).

Search and filtering functionality

The database can be used to identify towns according to the following search functionalities:

- Towns in a district municipality
- Towns per province
- Towns with current water deficit
- Listing of towns according to magnitude of water surplus (+) or water deficit (-)

- Listing of towns with specific type of current water source
    - Surface water
    - Groundwater
    - Desalination
    - Water reuse

- Listing of towns with specific type of potential new water source
    - Surface water
    - Groundwater
    - Desalination
    - Water reuse

- Listing of towns with specific types of wastewater treatment plants
    - Activated sludge
    - Biofilters
    - Oxidation ponds
    - Package plants

- Listing of towns per main industry type(s) discharging to the WWTPs
- Listing of towns according to the technical capacity
- Listing of towns according to the financial capacity.

Conclusions on the potable reuse potential of cities and towns in South Africa

Within the development of the analysis it was realised that the analysis can be utilized as an optimisation tool to determine the optimum combination of alternative options for a specific region. This can be achieved owing to the predicted shortfall being taken into account for each town. The main procedure can therefore be used as both a ranking system as well as to optimise the most efficient combination of alternatives to augment the water supply.

The study of available water reuse potential can be extended to also provide a summary of the recommended actions for each Local Municipality that was ranked in the top ten. This information is available in the water-reconciliation reports (All Towns Strategy), as captured in the Water Reuse Potential database.

Table A1: Reuse Potential Database

Details of			
Name of Town	Local Municipality	District Municipality	Province
A	A	A3	A4

Water			
Population	Water Demand (2011)	Water Availability (2011)	Water Surplus/Deficit
B	B2	B3	B

Water Sources (Existing)					
Existing Water Source 1 Type	Existing Water Source 1 Max. Yield	Existing Water Source 2 Type	Existing Water Source 2 Max. Yield	Existing Water Source 3 Type	Existing Water Source 3 Max. Yield
C1	C2	C3	C4	C5	C6

Water Sources (Potential)					
Potential Water Source 1 Type	Potential Water Source 1 Max. Yield	Potential Water Source 2 Type	Potential Water Source 2 Max. Yield	Potential Water Source 3 Type	Potential Water Source 3 Max. Yield
D1	D2	D3	D4	D5	D6

Wastewater Treatment Works (WWTW)						
WWTW 1 Design Capacity	WWTW 1 Type	WWTW 2 Design Capacity	WWTW 2 Type	WWTW 3 Design Capacity	WWTW 3 Type	Total Availability of treated wastewater
E1	E2	E3	E4	E5	E6	E7

Other					
Technical Capacity of Local Municipality	Financial Capacity of Local Municipality	Industries percentage contribution	Industries Type 1	Industries Type 2	Industries Type 3
F1	F2	F3	F4	F5	F6

APPENDIX B:

DATABASE OF TOWNS WITH POTENTIAL POTABLE REUSE

The Database can be found in the attached CD as an Excel File

APPENDIX C:

SUMMARY TABLE OF WATER QUALITY GUIDELINES FOR POTABLE REUSE

The Table can be found in the attached CD as an Excel File