

Based on Table 7 the wastewater treatment works is expected to exceed its design capacity of 40 000 m³/day by 2005 and as a result is currently being expanded. The expansion to the plant has also included various modifications allowing for not only an increase in capacity but also an improvement in effluent quality. The Bergstan and Rites 2004³² design report details the upgrade and expansion that is currently being undertaken at the plant. The plant is being upgraded in two phases with each phase increasing the capacity by 25 000 m³/day. The current expansion will increase capacity to 65 000 m³/day which is predicted to be reached by 2012. The main upgrades currently being undertaken at present include:

1. Expansion of the existing PST capacity by including one additional 32m diameter tank with an ADWF of 25 000 m³/day, similar to the existing PSTs.
2. The upgrading and expansion of the biological reactors from a Modified Ludzack-Ettinger (MLE) configuration to a Modified University of Cape Town (MUCT) configuration. This upgrade has been designed such that the configuration may be changed at a later stage from a MUCT configuration to either a MLE or a University of Cape Town (UCT) system Bergstan and Rites 2004³². An additional two reactors of similar layout to the existing reactors will be constructed along with penstocks enabling the recycling of mixed liquor to the different zones (anoxic, anaerobic, or aerobic) in the reactors.
3. Two more SST's will be included based on a similar design to the existing SST's with a 37m diameter enabling detention time to be between approximately 3 – 4 hours based on flows.
4. Expansion of the sludge handling capacity by separating the secondary sludge from the primary sludge, with the secondary sludge being treated using aerobic digesters whilst the primary sludge will be treated using anaerobic digesters. Three new

anaerobic digesters of the same size as the existing digesters will be constructed enabling at least 20 days of sludge retention time. Biogas generated from these digesters will be used to power both the heat exchangers and an on site incinerator. A boiler, heat exchanger and mixing system will be included in the new primary digesters, to ensure efficient digestion maintaining a temperature of 35°C. One new secondary anaerobic digester similar to the existing digester will be provided enabling between 10 and 15 days of retention time.

5. Construction of a secondary sludge thickener for the thickening of sludge prior to aerobic digestion, which will take approximately 10 days. Aerobic digestion will require the two new tanks with each tank having an aeration system capable of providing 162 kgO₂/h. Once digested sludge will be pumped to the digested sludge pump station.
6. Changing of the dewatering system from drying beds to a belt filter press system. The two different sludge's (primary and secondary) will remain separated until the belt filter presses have dewatered them. Once dewatered the sludge's will be conveyed to storage hoppers capable of storing three days worth of sludge, which will be loaded into trucks and sent to landfill sites.

These are the main areas of expansion, although some of the details regarding pipe expansions and such have not been detailed. Figure 11 shows the details of how the final process will be configured.

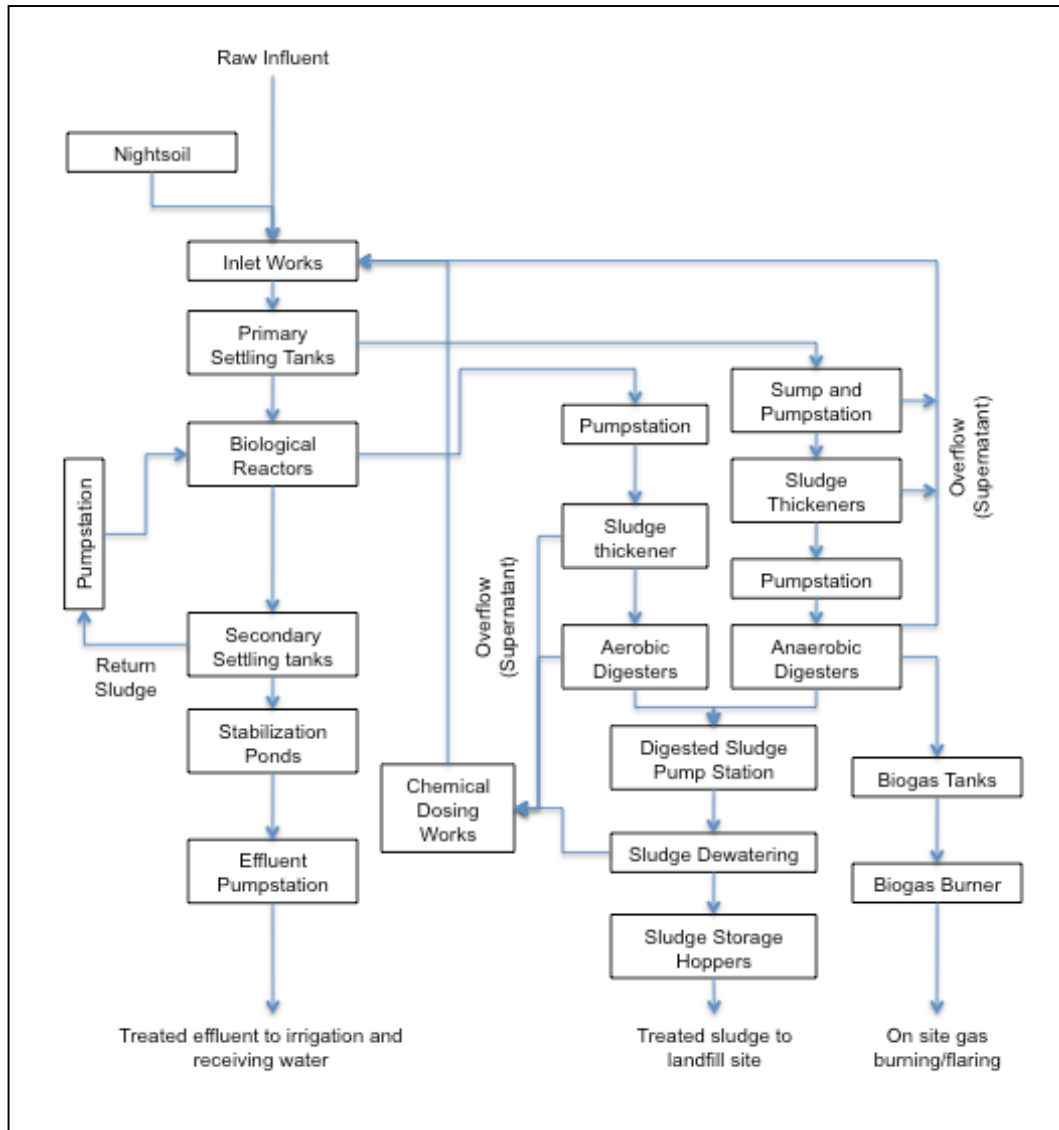


Figure 11. Current upgrading of the Gaborone wastewater treatment works (Based on information from Bergstan and Rites 2004³²).

WASTEWATER CHARACTERISATION

The characterisation of the influent and effluent quality and quantity is vital for planning of any upgrades to works. Not only will this give an indication of factors such as changes in flow rates over time but it will also provide information regarding the level of contamination of the wastewater influent and effluent.

The sources of wastewater found at the Glen Valley treatment works are derived from domestic, commercial and industrial activities and can be classified as “sanitary wastewater” (Spellman⁶).

Wastewater can be characterised by various different parameters although some of the more common parameters are detailed below.

Parameter	Description of Measurement
Suspended solids	Various filter types are used to measure the amount of suspended solids captured by the filter.
Settleable solids	Measurement of solids settled over a 2 hour period.
Organic matter	Typically measured through the amount of O ₂ produced or CO ₂ consumed, measured by either COD, BOD ₅ , BOD ₇ , or TOC.
Nitrogen	Measured as total nitrogen (TN)
Phosphorus	Measured as total phosphorus (TP)
Alkalinity	Measured as total alkalinity (TA)
Sludge volume index	Based on the settling characteristics of the activated sludge.

Table 6. Common parameters for the characterisation of wastewater (modified from Henze, *et al*³⁴).

Two reports have recently characterised the wastewaters from the Glen Valley wastewater treatment plant, these being the:

1. “Evaluation of the Existing WWTW and Remedial Works, Discussion Report” produced by Liebenberg and Stander in joint venture with Rites Afrika (Pty) Ltd. 2003.
2. “Engineering Consultancy on the Proposed Reclamation and Treatment of the Gaborone Wastewater for Potable Use, Preliminary Feasibility Report” produced by GIBB and PULA joint venture. 2007.

Each of the two reports has a different objective and as such has focus on different constituents. The Liebenberg & Stander and Rites 2003³³ report focuses primarily on chemical oxygen demand (COD), Total Kjeldahl Nitrogen (TKN), Total Phosphate (TP) and influent flows. The Gibb and Pula 2007³¹ report details more diversity of constituents but focuses on the effluent from the wastewater treatment works.

The Gaborone City Council has onsite laboratories undertaking and analysing samples continuously from different points in the treatment works although this has been highlighted as being not very reliable and as such both reports made use of independent sampling undertaken by private companies.

This report has made use of both studies to characterise the wastewaters both influent and effluent.

Influent flows

The Liebenberg & Stander and Rites 2003³³ evaluation report gives the average flow to the plant as being between 30 000 and 35 000 m³/day. Data from the Gaborone City Council for the month of September 2007 shows the average inflows for the month as being 25 349 m³/day (Gaborone City Council¹⁶). Inflow data from Gibb and Pula³¹ in 2005 and 2006 over a 11 month period shows the average monthly inflow to the plant as being 32 762 m³/day. A detailed table based on a predicted average inflow increase at a rate of approximately 3000 m³/day per year has been developed by Liebenberg & Stander and Rites 2003³³ as detailed below, Table 7.

Year	ADWF (m³/day)	PDWF (m³/day) 1.4 x ADWF	PWWF (m³/day) 1.75 x ADWF	Comment
2003	35 000	49 000	61 000	Assessed flow at 2003
2004	38 000	54 000	67 000	
2005	42 000	58 000	73 000	
2006	45 000	63 000	79 000	

2007	48 000	68 000	85 000	
2008	52 000	72 000	90 000	
2009	55 000	77 000	96 000	
2010	58 000	82 000	102 000	
2011	62 000	86 000	108 000	
2012	65 000	91 000	114 000	Expansion phase 1 to cater for this flow
2013	68 000	96 000	120 000	
2014	72 000	100 000	125 000	
2015	75 000	105 000	131 000	
2016	78 000	109 000	136 000	
2017	80 000	112 000	141 000	
2018	83 000	116 000	145 000	
2019	86 000	120 000	150 000	
2020	88 000	124 000	155 000	
2021	91 000	127 000	159 000	Expansion Phase 2

Table 7 Design flows for next planning periods (Modified from Liebenberg & Stander and Rites 2003³³)

The current expansion to the treatment plant will increase the capacity of the plant by 25 000 m³/day to a total capacity of 65 000 m³/day, which based on the above table should be exceeded by 2012.

Effluent flow

In terms of secondary effluent production, data for these volumes is rather erratic although over a 7-month period an average outflow of 25 821 m³/day of was recorded Gibb and Pula 2007³¹. This report assumes for design purposes that the effluent flow is 26 000 m³/day from the treatment works (Gibb and Pula 2007³¹).

Wastewater Constituents

The wastewater influent received by the treatment works is comprised on commercial, industrial and domestic wastewaters and as such does have a higher diversity of constituents compared to treatment plants with separate waste streams. Although sampling is undertaken regularly onsite this is focussed primarily on the core processes of the plant, which for the

most part is biological nutrient removal and as such sampling, is limited to monitoring these components. A clear example of this is illustrated in the “Upgrading of the Gaborone Wastewater Treatment Works – Evaluation Report”, Liebenberg & Stander and Rites 2003³³ which focuses on the treatment objectives in light of the water quality objectives.

The Liebenberg & Stander and Rites³³ report highlights issues with the treatment plant and the resulting fluctuations in Chemical Oxygen Demand (COD) although the final agreed influent characteristics are as follows:

- Average settled influent COD - 550 mg/l
- Average settled influent TKN – 33.0 mg/l
- Average settled influent Total Phosphates – 16.5 mg/l

This report focuses on the biological nutrient removal as the key objective of the treatment plant and as such limits sampling to these constituents.

The Gibb and Pula 2007³¹ report looks into the reuse of wastewater but focuses on the final quality produced by the treatment works. The sampling of this was limited to three samples, which have been averaged and provided below. Although the sampling was conducted at a point after secondary settling had occurred this information does provide some insight to some of the constituents likely to be found in the wastewater influent. As the existing plant does not provide any complete barrier for any of these constituents it is likely to assume that these occur in a marginally high concentration that provided here, with the exception of some of the parameters related to biological nutrients such as those highlighted.

Parameter	Units	Average Effluent Quality Before Maturation Ponds	Average Effluent Quality After Maturation Ponds
pH	-	7.6	8.3
Conductivity at 25 ⁰ C	mS/m	62.2	57.3
Colour	mg/l as Pt-Co	71	63.67
Alkalinity	mg/l as CaCO ₃	182.7	164
Carbonate alkalinity	mg/l as CaCO ₃	<5	22
Bicarbonate alkalinity	mg/l as CaCO ₃	182.7	145.3
Chloride	mg/l as Cl	57.3	56.3
Sulphate	mg/l as SO ₄	32	28
Silica	mg/l as Si	5.4	4.5
Fluoride	mg/l as F	0.6	0.5
Sodium	mg/l as Na	75	77.67
Potassium	mg/l as K	19.3	20.4
Calcium	mg/l as Ca	26.7	19.67
Magnesium	mg/l as Mg	12	11.67
Aluminium	mg/l as Al	0.211	0.12
Barium	mg/l as Ba	0.036	0.031
Boron	mg/l as B	0.187	0.26
Cadmium	mg/l as Cd	<0.01	<0.01
Chromium	mg/l as Cr	<0.026	<0.025
Iron	mg/l as Fe	0.216	0.16
Lead	mg/l as Pb	<0.05	<0.05
Manganese	mg/l as Mn	0.067	0.045
Mercury	mg/l as Hg	<0.002	<0.002
Nickel	mg/l as Ni	0.052	0.056
Strontium	mg/l as Sr	0.05	0.053
Suspended Solids at 150 ⁰ C	mg/l	28.7	34.7
Turbidity	NTU	10.2	40.1
Ammonia	mg/l as N	5	1.47
Nitrate	mg/l as N	3.6	2.3
Nitrite	mg/l as N	0.1	0.17

Ortho-phosphate	mg/l as P	2.2	3.6
Total Organic Carbon	mg/l as C	14	16.3
Dissolved Organic Carbon	mg/l as C	11.9	14.3
Biochemical Oxygen Demand	mg/l as O ₂	14.67	10.3
Chemical Oxygen Demand	mg/l as O ₂	80.67	65
Oil and grease	mg/l	7.57	5.9
Total Coli form Bacteria	No./100ml	33037	1043
Faecal Coli form Bacteria	No./100ml	25 248	167

Table 8 Averaged water quality results – Averaged from Gibb and Pula 2007³¹

The parameters highlighted in the above table are those, which will have significant reductions as a result of the various unit processes of the treatment plant.

In terms of controlling influent quality the Gaborone City Council has put in place “agreements” with certain companies in order to control discharge qualities. These agreements are however not well policed and often not adhered to, with many of the newer manufacturing companies not having agreements (Gibb and Pula 2007³¹).

The Gibb/Pula report identifies 45 different companies, which are of concern regarding their discharge to the sewage system. Amongst other these include, paint industries, oil depots, soap industries, battery manufacturing, chemical industries, vaccine industry, and cement manufacturers.

Point source control of discharges to the sewage system should be more effectively controlled and monitored in order to prevent a lowering of the influent quality at the treatment plant.

TREATMENT STANDARDS

In Botswana the Botswana Bureau of Standards is responsible for the setting of water quality standards. To this effect various different standards exist for both water and wastewater dealing with sampling, preservation of samples, techniques for determining different constituents, and actual

quality. Currently Botswana has standards for both wastewater quality, and drinking water quality although these standards are comprehensive they are not designed for potable reuse scenarios.

Overview of Botswana Drinking Water Standards

The Botswana Water Quality – Drinking Water – Specifications, (BOS32:2000)¹⁷ have been divided into four categories,

1. Physical and organoleptic requirements,
2. Inorganic requirements.
3. Organic requirements.
4. Microbiological requirements.

Within each of these four categories three different classes have been allocated based on the different types of consumption. Class I being an ideal standard (comparable to current international standards), Class II being maximum allowable for “whole lifetime consumption”, and Class III specifying the maximum requirements for “short term consumption”. Class III is supposed to be used as an interim measure.

Microbiological requirements are not divided into different classes with all types of water having to comply with the given requirements.

These standards simply detail the limits or requirements as well as the sampling frequency. Details on sampling have been compiled in other standards.

Physical and organoleptic requirements include seven factors, namely: colour, conductivity, dissolved solids, odour, pH, taste, and turbidity.

Although these are for the most part quantified Odour and Taste are not quantified with values being “not objectionable”.

Chemical requirements are comprised of two types inorganic determinants (Macro and Micro) and organic determinants.

Inorganic chemicals have been divided into 2 types macro and micro chemicals, with macro determinants (13) being measured in mg/l whilst micro (15) determinants being in µg/l.

Within the Macro determinants 13 different determinants have been regulated with only two being the same as international standards (i.e. Class I and Class II have the same maximum levels) for Nitrate and Nitrite. Included in these macro chemical limits is hardness, which has been measured by CaCO₃.

The micro inorganic chemical determinants include 15 determinants the majority of which (11) are the same as the international standards and do not vary between the different classes of water.

Organic Determinants consist of eleven determinants that have been regulated for with all no variation existing between the different classes (all classes complying with international standards).

Included in this category is “Total Pesticides” which is a combination of different pesticide groups including carbamate, chlorinated, organo phosphate, pyrethroid and atriazine pesticides as well as any specific pesticide such as DDT and methoxychlor.

Microbiological requirements are not divided into different classes as all classes have to comply with these requirements.

These requirements focus predominantly on coliforms, including total coliforms, faecal coliforms and faecal streptococci.

Sampling frequency is determined by the population served and has been detailed in the following table.

Population Size	Frequency of Sampling per Month
> 100 000	10 samples per month per 100 000
25 000 – 100 000	10
10 000 – 25 000	3
2500 – 10 000	2
< 2500	1

These standards are sufficient for the treatment of water from conventional sources but for potable reuse these standards are insufficient.

By comparison to the United States Environmental Protection Agency (US EPA) standards the Botswana standards are limited. This is especially obvious in the category of organic chemical requirements.

Namibia has adopted a set of standards based on the Namibian Guideline, US EPA, European Union (EU), World Health Organisation (WHO) and Rand Water (South Africa) when standards were required for the New Goreangab Water Reclamation Plant, including intermediate standards to ensure optimal performance of the plant (Du Pisani⁵⁴). Botswana should adopt a similar approach rather than attempt to formulate standards from scratch.

Wastewater Quality Standards

Botswana wastewater quality standards are designed to guide the discharge of wastewater into the environment (Botswana Bureau of Standards³⁵). Due to this they are rather limited with respect to reuse applications. The standards have been divided into two categories, physical and microbiological requirements and chemical requirements. Currently these standards focus purely on the discharge of treated wastewater without referring to reuse applications.

Based on the findings of the water sampling and analysis by Gibb and Pula³¹ these standards are currently not being met with various contaminant levels being exceeded. These have been highlighted in the table below.

In addition to these standards, standards also exist detailing the sampling procedures for wastewater sampling. These standards are documented in a separate standard.

Category	Parameter	Upper limit or range
Physical and Microbiological	Temperature	35 ^o C
	pH	6 – 9
	Dissolved Oxygen	60 % sat.
	BOD ₅ (max)	30 mg/l
	COD (max)	75 mg/l (filtered)
	COD (max)	150 mg/l (unfiltered)
	Colour	50 TCU
	Turbidity	30 NTU *
	Total Dissolved Solids	2000 mg/l
	Total Suspended Solids	25 mg/l *
	Faecal Coli form	1000 counts/100ml
Chemical	Ammonia (as N)	10 mg/l
	Ortho phosphate (as P)	1.5 mg/l
	Calcium	500 mg/l
	Chloride	600 mg/l
	Chlorine residual	1 mg/l
	Fluoride	1.5 mg/l
	Nitrate	22 mg/l
	Potassium	100 mg/l
	Sodium	400 mg/l
	Sulphate	400 mg/l
	Zinc	5 mg/l
	Arsenic	0.1 mg/l
	Boron	0.5 mg/l
	Cadmium	0.02 mg/l
	Chromium VI	0.25 mg/l
	Chromium total	0.5 mg/l
	Cobalt	1 mg/l
	Copper	1 mg/l
	Cyanide	0.1 mg/l
	Iron	2 mg/l
Lead	0.05 mg/l	
Manganese	0.1 mg/l	
Mercury	0.01 mg/l	

	Nickel	0.3 mg/l
	Selenium	0.02 mg/l

Table 9 Botswana of Bureau of Standards for the discharge of wastewaters.

* - Contaminant levels, which have not been met, based on the Gibb and Pula sampling results.

EXISTING REUSE

Water reuse is currently occurring from the maturation ponds with the majority of this being for some form of irrigation, whether it be landscaping, commercial farming, golf course irrigation, or private residential gardens. Some of the other uses of this water are dust control, and construction activities. In order to ensure that there is enough water available for reuse the Gibb and Pula 2007³¹ report analyses the availability of water for reclamation.

The report assumes that there is 26 000 m³/day based on the average outflow volumes recorded over a six month period (Gibb and Pula 2007³¹). Findings show that there two sources of reuse of treated effluent. The first is direct abstraction from the ponds and the second is abstraction from the Notwane River downstream of the treatment plant. All users of wastewater directly from the ponds have an agreement with the Gaborone City Council and the total allocation of these agreements is 37 000 m³/day although this could be reduced to 27 000 m³/day as some of the agreements are annually based Gibb and Pula 2007³¹. In addition to this the downstream users abstracting waters from the Notwane River whom have agreements with the Water Apportionment Board total 11 419 m³/day Gibb and Pula 2007³¹.

It was however revealed that the many of these agreements are not being utilised and that based on the reclamation works having a capacity of 20% of Gaborone demand, there is enough water available for the project to begin and by 2015 there should be an even greater percentage available for reclamation Gibb and Pula 2007³¹.

FUTURE PLANNING AND DEVELOPMENT

The Water Utilities Corporation has recognised that there is a need to develop new sources of water as demand is expected to exceed supply in approximately twenty years. In order to alleviate this problem two projects have been proposed the construction of a dam in the north Dikgathlong Dam and a pipeline connecting this to Gaborone, and the possible reuse of Gaborone wastewater.

The water reuse project was awarded to a partnership of two companies, Gibb Botswana and Pula Consultants and is currently at a preliminary feasibility report stage. The report has covered issues regarding the reuse of wastewaters, factors affecting process selection, existing infrastructure, demand and supply issues, environmental issues, institutional arrangements, a preliminary design and financial evaluation. The report has concluded that 'it is both technically and economically viable to treat effluent from the Glen Valley works for potable use at a volume of approximately 20% of the demand on the Gaborone Water Treatment Works' (Gibb and Pula 2007³¹).

This design has been reviewed in detail as a potential option in chapter 4.

CHAPTER 3: EXISTING SITUATION IN THE WORLD - LITERATURE REVIEW

This chapter is comprised of a literature review including case studies of three different countries reusing wastewater to augment water supply. The aim being to establish what processes are being used in the world and how they could be applied in Botswana. The main areas of focus include:

- Case studies of different facilities reusing wastewater focussing on how the wastewater is treated (secondary treatment), and what treatment processes are being used for final treatment.
- An overview of some of the different treatment processes available and which ones would be most suitable for the various environmental conditions.

This review has focussed primarily on potable water reuse systems with one case study (Singapore) showing the benefits of augmenting the non-potable supply.

CASE STUDIES

An assessment of different countries treatment processes was undertaken to gain an understanding of what is being implemented in the industry and the benefits of these. These assessments are based on literature reviews, observations and consultations.

As water reuse is becoming more and more common in the world three different reuse processes were selected based on their similarities to Botswana regarding environmental conditions (California and Namibia) and similarities in infrastructure capacity regarding water storage (Singapore), and similarities in the influent characteristics (California and Singapore).

- *California, Orange County.* Orange County is currently importing a large percentage of its water from the Northern part of the state much like Botswana does with the North South carrier pipeline. This supply is both costly and is being constantly being reduced

(Markus³⁶). As a result of these issues IPR has been implemented with sub surface storage making use of a large deep aquifer as an 'environmental barrier'.

- Singapore. Singapore is not similar environmentally to Botswana but does have similar issues regarding the storage of water, and supply issues.
- Namibia, Windhoek. This country is the most similar to Botswana in its environmental factors being a direct neighbour. Namibia makes use of a direct reuse system, providing water for drinking that is what is currently being planned for in Botswana. This system also provides a clear example of the multiple barrier approach including aspects such as public health as well as odour, and taste.

The question regarding **indirect** versus **direct** reuse is the largest differentiating factor between the different studies, thus these have been reviewed similarly.

Indirect Potable Reuse – California (United States of America), Orange County

The USA has many different states reusing wastewater to varying degrees. Many of these facilities only treat wastewater to the secondary treatment level with disinfection, as the final reuse is simply for agriculture, landscaping or industrial processes.

California has had many issues regarding water supply and as such as developed considerable technologies, standards, policies and management systems for reclaiming water. This has led California to have the "the most stringent in the US and are often the precursor of other states' regulations" (Jansen, Stenstrom and de Koning¹).

A large portion of southern California imports water from Northern California (San Francisco Delta) from the Colorado River (Markus³⁶). The importing of this water is expensive and the pressure on these sources is continuously increasing. In an attempt to augment this supply Orange County has been implementing IPR since the late 1970's.

The Orange County Water District (OCWD) is the agency responsible for managing the groundwater basin situated under Orange County. The OCWD obtains effluent water from the adjacent wastewater treatment plant, which is managed by the Orange County Sanitation Department (OCSD). The treated secondary effluent from the OCSD passes through to the OCWD for treatment at the Groundwater Replenishment System (GWR System). Once treated the water is either pumped into an underground aquifer or is used to maintain a barrier preventing seawater from contaminating the aquifer.

In order to gain a full understanding of the specific 'water cycle' for the Orange County a flow diagram has been compiled to detail how the water is recycled, highlighting some of the key issues such as waste streams, storage, and source waters, see Figure 12. This flow diagram provides an overview into the cycle, a more detailed explanation of the treatment processes has been provided below.

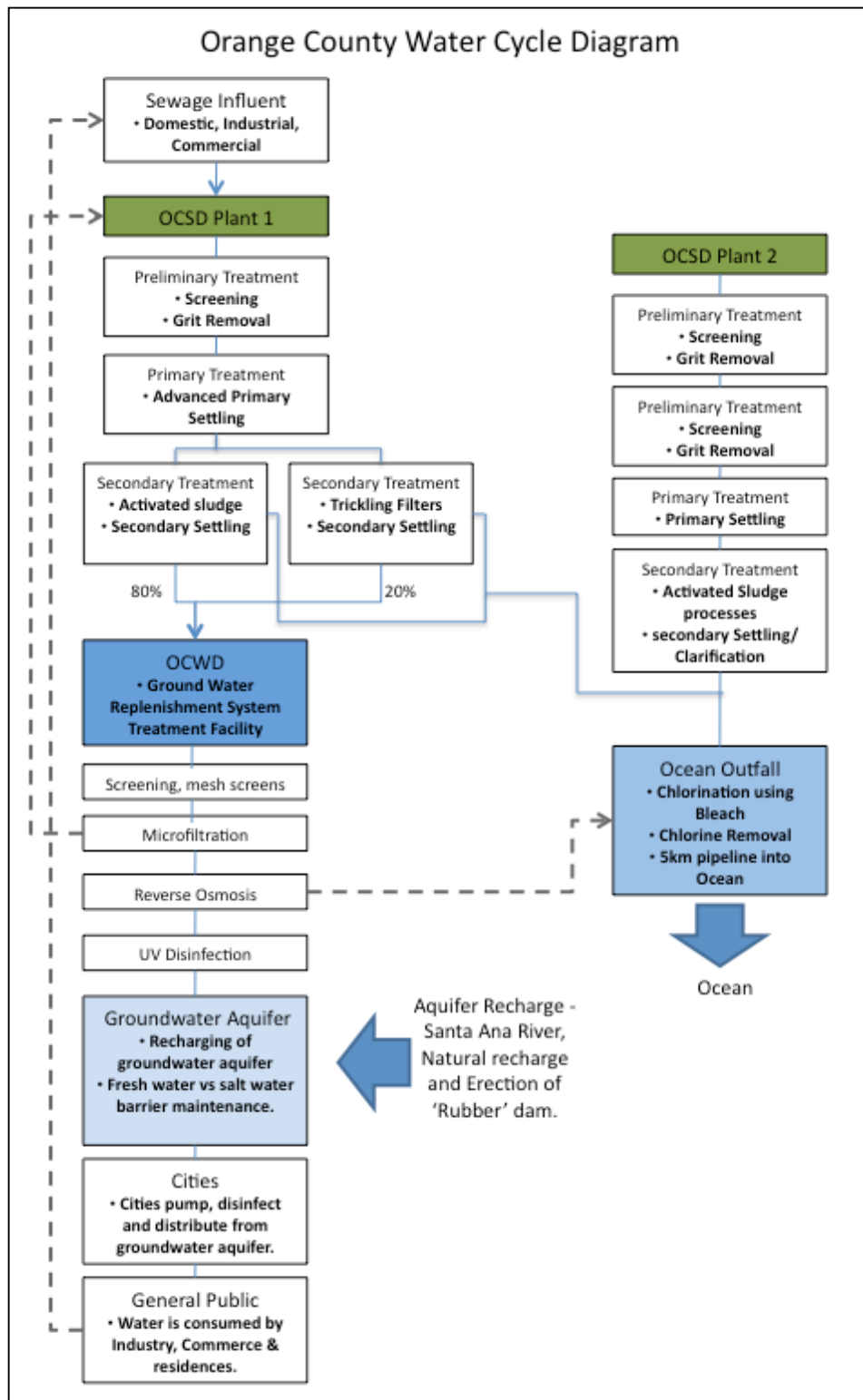


Figure 12. Process flow diagram of the Orange county indirect potable reuse system (Markus 2008³⁶).

Wastewater Treatment - Orange County Sanitation District (OCSD)

The Orange County Sanitation District (OCSD) is the agency responsible for the treatment of wastewater generated from residential, commercial and industrial sources in the Orange County. Two separate treatment plants (Plant 1 and 2), collectively serve a population of 2.5 million people handling 866765m³/day of sewage (Orange County Sanitation District³⁷).

Although these two plants are not vastly different from each other some differences occur such as;

- Influent is not evenly split between the two plants with Plant 2 treating more (60%) than Plant 1 (40%) due to its size (Orange County Sanitation District³⁷).
- Plant 1 makes use of both 'Activated Sludge' and 'Trickling filters' (in parallel) in the secondary treatment level whilst Plant 2 only makes use of 'Activated Sludge' as a secondary treatment process.
- Effluent from Plant 1 is split with some going to the OCWD for reuse and the rest being sent to the ocean outfall whilst Plant 2 discharges mainly to the ocean outfall although some reuse of wastewater is also made for landscaping purposes.
- The OCSD manages the quality of wastewater by, directing where possible, lower quality wastewater to Plant 2 and higher quality wastewater to Plant 1 (OCSD and OCWD³⁸).

As Plant 1 is the only supplier of effluent to the OCWD with treatment comprising four stages, preliminary and advanced primary treatment, secondary treatment, disinfection and sludge treatment.

- Preliminary treatment involved fairly standard unit operations whilst the primary treatment includes the use of coagulants to increase settling of suspended solids. Previously this enabled some of the effluent from the primary treatment to be discharged directly to the

ocean outfall, skipping the secondary treatment stage. This has been changed due to public pressure, with all influent now being required to undergo both primary and secondary treatment levels.

- The secondary treatment involves activated sludge processes and trickling filters in parallel. The effluent from the secondary treatment processes is passed to the OCWD in a blend of 80% from the activated sludge processes and 20% from the trickling filters (Orange County Sanitation District³⁷).
- The disinfection of the effluent only occurs at the ocean outfall with Sodium hypochlorite (bleach) being added to disinfect effluent of any potentially harmful pathogens or bacteria. As the disinfectant is chlorine based this can be toxic to aquatic species unless removed. A further de-chlorination step is then undertaken using sodium bisulfite to remove the chlorine prior to final disposal (OCSD³⁹). Once the disinfection process has taken place the final effluent is then released through a five-kilometre pipeline into the ocean.
- The treatment of sludge generated from the different processes is undertaken using anaerobic digesters. After digestion sludge is dewatered using belt filter presses. Biosolids management and reuse is a key activity being implemented by the OCSD with a large proportion of this being sold to farmers for agricultural uses.

The actual process involved in the treatment of the wastewater at Plant 1 has been outlined in the process diagram below Figure 13.

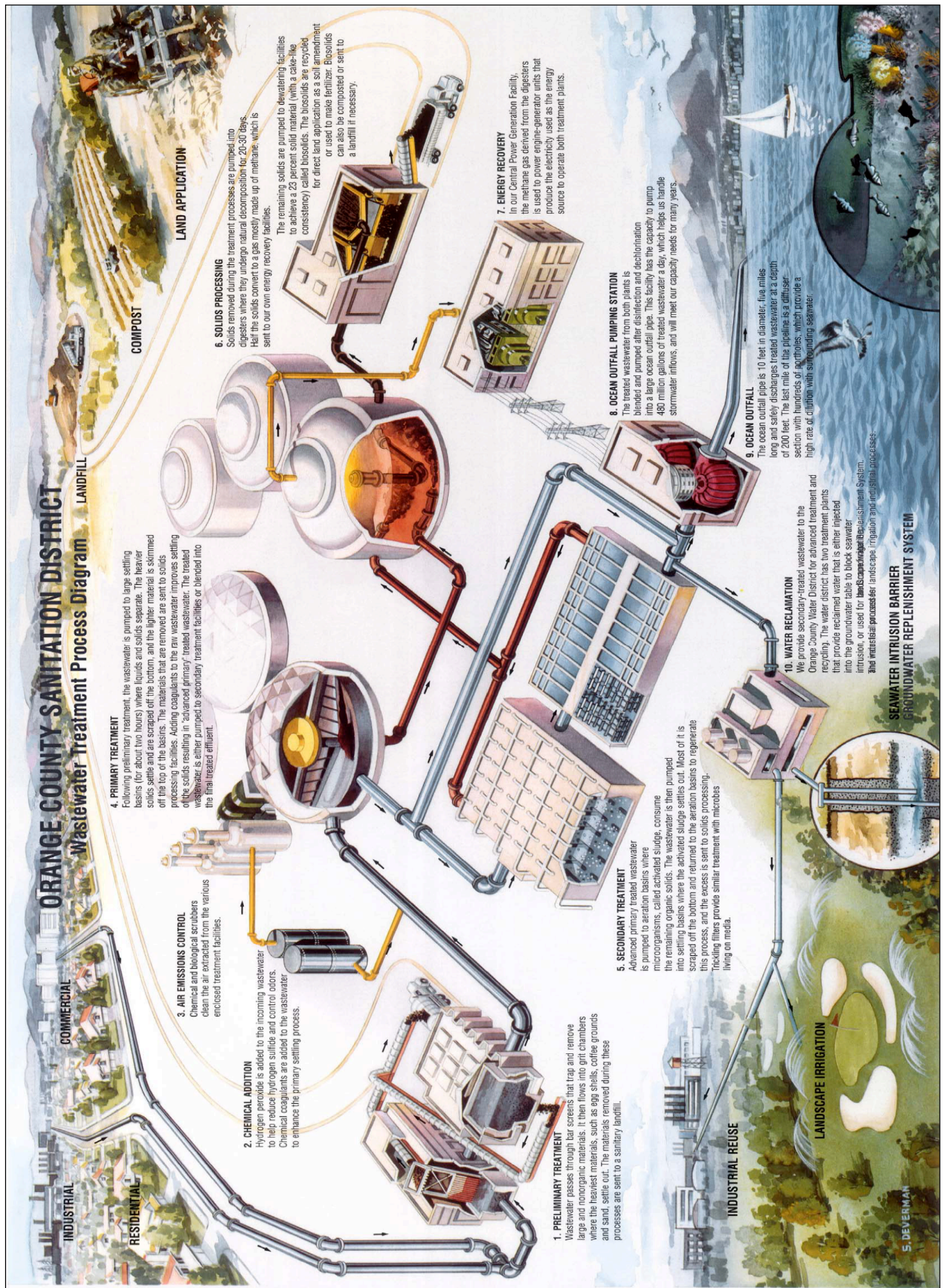


Figure 13. OCSD wastewater treatment process (OCSD³⁸).

In addition to the processes taking place at the different plants there are various other systems in place assisting in the overall treatment of wastewater, these include:

1. The plant is able to treat industrial, commercial and domestic wastewater effectively, due to not only the effectiveness of the processes on site but to a large extent to the continuous monitoring and control of point source polluters. By monitoring and controlling what is discharged into the sewer systems the influent wastewater quality is both consistent and does not require specialised treatment processes to remove constituents such as heavy metals and synthetic organics.
2. The final discharge is made into the ocean 5km offshore and as such there are few downstream users of the final effluent other than the OCWD.

Reclamation plant - Orange County Water District (OCWD)

The OCWD's primary objective is to manage the groundwater basin lying under the county of Orange. The management of this basin involves numerous activities some of the key activities include:

1. Direct recharge through the use of recharge basins.
2. De-silting the Santa Ana River to assist in the recharge of this aquifer.
3. Monitoring of water quality and clean up of man made and natural contamination.
4. Continuous pumping of water into the 'Seawater Intrusion Barrier' designed to keep seawater from mixing with the fresh groundwater.
5. Continuous operation of the Ground Water Replenishment System, purifying effluent from the OCSD, to provide water for the maintenance of the groundwater basin.

Each one of these different activities is vital for the management of the groundwater resource, with each component being managed and operated as a specific division of the OCWD. This report focuses primarily

on the treatment of the wastewater for reuse (Groundwater Replenishment System) whilst only highlighting some of the other activities relevant to the reuse of wastewater.

Overview of the Groundwater Replenishment System (GWR System)

The GWR System receives approximately 30% (264 950m³/day or 70 million gallons per day) of the total effluent of the OCSD (Orange County Sanitation District³⁷).

The influent from the OCSD comes exclusively from Plant 1 with a blend of 80% from the activated sludge processes and 20% from the trickling filter processes. This influent has undergone all stages of the treatment process (preliminary, primary, and secondary), except for disinfection. Once the influent has undergone secondary settling at Plant 1 approximately 77% is diverted to the GWR System before disinfection whilst the remainder is sent to Plant 2 for disinfection.

The treatment process comprises three main stages; Microfiltration, Reverse Osmosis, and UV Disinfection. In order to ensure no larger particles pass to the microfiltration modules the influent undergoes screening prior to these units.

Microfiltration

Microfiltration is essentially a pre-treatment process ahead of the reverse osmosis process. Microfiltration operates at approximately 90% recovery rate with capacity at normal flow rate of 325 510 m³/day and peak flow of 423 920 m³/day peak flow (OCWD and OCSD³⁸).

Microfiltration is a “submersible vacuum pressure driven system” (OCWD and OCSD³⁸) consisting of 26 basins each with 19 filtration units, each being operated at a relatively low vacuum pressure of between 0.138 – 0.827 Bars.

Backwashing typically occurs every twenty minutes for approximately two minutes, producing a backwash waste effluent, which accounts for approximately 10% of the total volume of the water influent.

The membranes in the microfiltration units are all under staggered warranties from the manufacturers with a complete warranty for 5 years and then a partial warranty for 7 years. This warranty is based on specified operation and maintenance standards detailing among other things the influent quality, backwashing and cleaning and pressure standards.

From the microfiltration two outputs result one is permeate (water effluent) and the other retentate (waste or reject effluent). The waste effluent is returned to the head of the OCSD Plant 1 (OCWD and OCSD³⁸) whilst the filtered water then passes through the racks and is directed to the Reverse Osmosis (RO) plant.

Reverse Osmosis

The Reverse Osmosis Plant is designed to produce 264 950 m³/day of treated water, peak flows above this capacity being redirected to the Santa Ana River (OCWD and OCSD³⁸).

This is the most energy intensive process involving the increasing of the pressure of the influent water, to between 10 and 14 Bars and forcing it through RO membranes.

Reverse Osmosis has been employed by the OCWD since 1977 resulting in a large amount of experience being gained from this operation. Currently 16-inch pressure vessels are being used opposed to the older 8-inch vessels previously used for reverse osmosis.

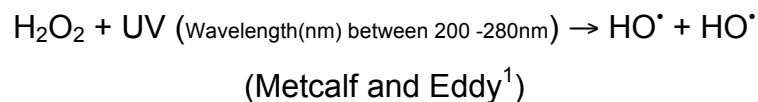
The RO facility is able to treat approximately 85% of the microfiltration filtrate with the remaining 15% being discharged to the OCSD ocean outfall (OCWD and OCSD³⁸).

Ultraviolet Disinfection

Ultraviolet (UV) disinfection will disinfect at a normal flow rate of 264 950 m³/day and a peak flow of 378 500 m³/day. UV was selected as the

disinfection process in order to destroy and disinfect nitro-sodimethylamine (NDMA) (OCWD and OCSD³⁸).

The disinfection process is two fold making use of a combination of UV radiation and hydrogen peroxide. The exposure of the hydrogen peroxide (H₂O₂) to the UV results in the photolysis of the H₂O₂ and the formation of hydroxyl radicals as described in the reaction below (Metcalf and Eddy⁴)



This combination enables thorough disinfection of any trace compounds, which may have passed through the RO process, without the risk of disinfection by-product formation.

Post-treatment

In order to prevent corrosion of the distribution and pumping system some of the RO permeate will pass through de-carbonator towers to remove excess carbon dioxide, thereafter being treated with lime to stabilise the final product water.

Storage and Supply

Product water is either used for pumping in the seawater intrusion barrier protecting the groundwater basin from seawater, or is stored in the groundwater basin. This aquifer is large with a capacity of approximately 500 000 acre-feet or 600 trillion cubic metres and is over 1000m deep (Orange County Water District⁴⁰). The use of this aquifer for storage essentially means there is little evaporative loss (possibly some loss in recharge basins), and as due to it being so deep there would be less risk of contamination.

Supply of this groundwater to consumers is undertaken by approximately 29 retailers in the Orange County area, responsible for the pumping from the aquifer and chlorination before distribution.

The “why not” option

The “Why not” option in this case focuses primarily on the use of indirect potable reuse rather than direct potable reuse? Essentially by treating the water through the GWRS system and then pumping this water underground there is a risk of groundwater contamination.





Two major reasons exist as to why this system is an indirect reuse system. The first is a legal motivation as legislation prevents the direct reuse of water. In 1998 the National Research Council declared that the direct reuse of reclaimed water is not a viable option for public water supplies (Metcalf and Eddy & AECOM²⁴).

The second is that due to the aquifer being both large and deep the risk of groundwater contamination is minimal and therefore there is no further major treatment of the groundwater once extracted before being distributed to the public. The only treatment step is that of disinfection prior to being distributed.

Due to this lack of treatment prior to distribution this ensures the costs involved are kept to a minimum.

Direct reuse non-potable – Singapore, NEWater

Singapore has a highly complex system of water resource management with the four main sources (known as the four “national taps”) being that of:

-  Local catchments,
-  Imported water from Malaysia,
-  Desalination plant,
-  Water reuse from the NEWater facilities.

Although Singapore experiences a large rainfall 2400mm per annum there is little room available on the island for both catchment or storage of the this resource (Tortajada⁴¹). Singapore also has two agreements with

Malaysia for the supply of water the first being due to end in 2011 and the other in 2061 (Tortajada⁴¹). Negotiations have been made for extensions to these agreements in order to provide Singapore with water security past 2061 but with little agreement being made. Due to this lack of water security Singapore has taken to exploring new avenues for ensuring water security. As a result direct water reuse plants called NEWater plants have been developed as one of the solutions to this problem.

Currently Singapore has four NEWater plants (Bedok, Kranji, Ulu Pandan and Seletar) collectively supplying 15% of Singapore's water requirements with the aim of providing 30% of the requirements by 2012 (PUB Singapore⁴²). Although each of the four plants are similar in the overall treatment processes, this study has looked primarily at the Bedok NEWater facility and its treatment processes.

The management the entire water cycle is undertaken by the Public Utilities Board (PUB) enabling them to undertake a holistic approach to water management including both the protection and expansion of water resources (Tortajada⁴¹).

The overall management of the Singapore water resources by the PUB has been rated as one of the top five water utilities in the world with some of the key indicators including (Tortajada⁴¹):

1. 100% of the population has access to both drinking water and sanitation.
2. 100% of water from water works to consumer is metered.
3. Unaccounted for water was 5.18% in 2004, as a percentage of total production.
4. Billing and monthly collection was 99% efficient in 2004.
5. All wastewater is collected and treated, as there is a 100% sewer connection.

Overview

The treatment of Singapore wastewater is undertaken in two stages; firstly wastewater is treated by one of the Water Reclamation Plants (WRP)

using conventional biological nutrient removal processes (Wastewater treatment plants have been renamed as Water Reclamation Plants (WRP), whilst the advanced treatment plants have been named NEWater factories). From the WRP a percentage of the final secondary effluent is transferred to the NEWater plant where the second stage of treatment is undertaken using advanced treatment processes, typically dual membrane technology (MF and RO) and UV disinfection.

Wastewater from the city is collected from domestic, commercial and industrial sources and directed to one of the four Water Reclamation Plants. This is likely to change in the future, as a massive “deep tunnel” sewage system is to be installed which will essentially collect the majority of the sewage from the island and gravity feed this to two large treatment facilities. Wastewater will be treated and then be made available for both potable and non-potable reclamation with all excess treated effluent will be discharged to the ocean.

Singapore currently has three distinct types of reuse:

1. Low quality, non-potable, industrial reuse stream that has been treated to a tertiary level using sand filtration and chlorination.
2. High quality, indirect potable reuse – this water has been treated in the NEWater treatment plant and is of drinking water quality. This is released into reservoirs and dams.
3. High quality, direct non-potable reuse – this water has been treated in the NEWater treatment plant and is of drinking water quality although it is used directly by different industries.

Based on the efficiency of the system and its management discharge to the ocean will not be increasing and could possibly be reduced with the new developments coming into operation.

This report has focussed on the Bedok water cycle including the sources of influent, the Bedok water reclamation plant, Bedok NEWater factory and the final consumers of the final product water.

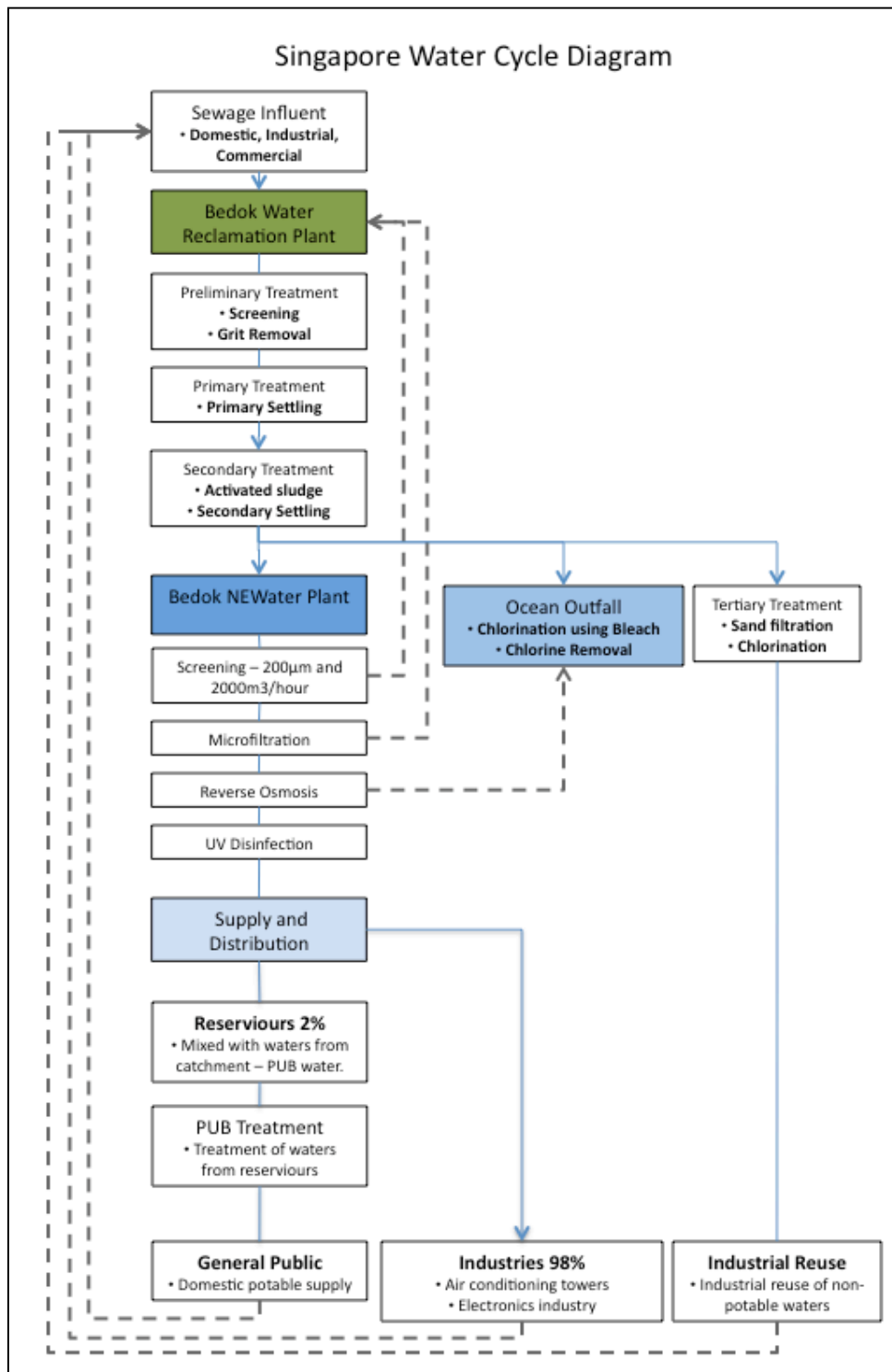


Figure 14. Overview of the water cycle of Bedok, Singapore.

Wastewater Treatment – Bedok Water Reclamation Plant

The Bedok water reclamation plant is a conventional biological nutrient removal treatment processes, using activated sludge. The plant has a capacity of 232 000 m³/day with the main processes being:

- Preliminary Treatment. Mechanical screening is the first process removing the larger debris and floating objects. This is then followed by grit removal tanks, which allow the heavier grit and sands to settle out.
- Primary Treatment. This treatment level simply involves primary settling of influent wastewater allowing the settling of the more solid particles. The water effluent then undergoes secondary treatment, whilst the sludge component is sent to cylindrical digesters for anaerobic treatment, and methane harvesting. This primary settling stage also sees the removal of the floatable materials, which collect on the surface of the settling tanks.
- Secondary Treatment. Return activated sludge making use of aeration basins and surface aerators are used for the secondary treatment process. The secondary treatment process has anoxic zone designed for the removal of nitrogen but has no provision for the removal of phosphates. This is then followed by a secondary settling stage, which allows the sludge to be collected and recycled as activated sludge, with excess sludge being disposed of.
- Sludge Treatment. The sludge is initially thickened using centrifugal or dissolved air flotation. Once thickened cylindrical digesters use anaerobic processes to treat sludge. Sludge retention time in the digesters is between 20 to 30 days generating biogas, which is subsequently used for powering the plant. Treated sludge is finally dewatered using centrifuges and then finally disposed of at land reclamation sites.

This a simple breakdown of the treatment processes employed at the wastewater “reclamation” plant, but is likely to change in the future due to

the recent success of the pilot projects making use of membrane bioreactors (MBR).

Water Treatment for Reuse - Bedok NEWater Factory

The Bedok NEWater plant has been recently expanded from having a capacity of 42 775 m³/day to 117 350 m³/day (GE Water & Process Technologies⁴⁵). No major change has been made to the overall treatment processes although the expansion has made use of new technologies and improvements of the different unit processes.

The Bedok NEWater treatment plant combines four major treatment processes, screening, micro/ultra filtration, Reverse Osmosis (RO), and Ultraviolet (UV) treatment. Based on the different recovery rates from the different unit processes the overall NEWater facility has a recovery rate of approximately 66%.

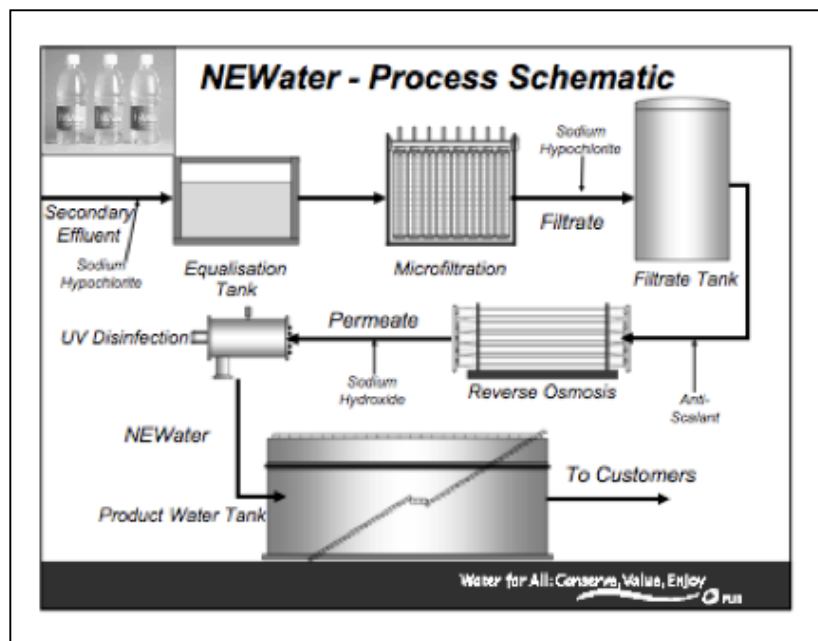


Figure 15 Schematic diagram of NEWater process – Lee Mun Fung 2008⁴⁶.

Screening

Screening is done using automated self-cleaning steel mesh brush filtration units, with between 0.3mm (Metcalf and Eddy & AECOM²⁴) and

0.5mm (500um) staining capacity (Coffey⁴⁷). This process is designed to ensure no larger particles from the reclamation plant are passed onto the membrane processes. On average this process has a recovery rate of approximately 98%.

All back washing waste is returned to the head of the reclamation plant for retreatment. Screened effluent is then chlorinated using sodium hypochlorite to prevent biological fouling on the ultra-/microfiltration membranes.

Microfiltration / Ultrafiltration

The plant was initially designed with ultrafiltration processes with secondary effluent once screened being gravity fed to five membrane tanks. In order to reduce the risk of biological activity in these tanks chlorine is added prior to ultrafiltration (GE Water & Process Technologies⁴⁵).

The more recent expansion of the plant uses microfiltration rather than ultrafiltration. Microfiltration is a more efficient filtration process requiring less energy input and increased flux although permeate quality is not of as high quality as ultrafiltration. The microfiltration runs in parallel to the ultrafiltration. Microfiltration operates on a single pass process with approximately a 90% recovery rate (Metcalf and Eddy & AECOM²⁴), with all retentate being recycled to the water reclamation plant.

MF effluent is then dosed with both sulphuric acid and scale inhibitor in order to reduce fouling due to the formation of scale on the reverse osmosis membranes.

Reverse Osmosis (RO)

Like the filtration process the RO also has some variations in that part of the plant uses 8-inch diameter RO pressure vessels, the new expansion has made use of 16-inch diameter RO vessels. Both of these size vessels are configured for a single pass with a recovery rate of approximately

75%. The waste stream generated from this unit process is diverted and discharged into the ocean.

Ultraviolet (UV)

UV is used as a final disinfecting process making use of two duty and one stand by UV unit. This unit process involves no chemical additions and has no loss of influent water. The system comprises a 254nm wavelength ultraviolet light being emitted, with the influent water being exposed to this light for less than 3 seconds under a low (<3 bar) operating pressure.

Post treatment

Unlike the Orange County there is no final treatment of the product water as this water is of a suitably high quality with low total dissolved solids, thus beneficial to industries sensitive to scaling.

The “why not” option

The “Why not” option in this case focuses primarily on the use of indirect potable reuse rather than direct potable reuse? Essentially all water for potable use will have been treated twice with the second treatment process not being as effective as the NEWater system. As the system only utilises 2% for potable reuse this is not a huge problem.

Singapore also has a large demand for high quality waters with low TDS concentrations (to prevent scaling) such as electronic manufacturing and air conditioning towers. By supplying these industries directly with NEWater this has reduced the overall demand for water.

The waste stream generated by the NEWater plant is comprised of two components, one being the waste from micro-/ultrafiltration and screening whilst the other is from RO plant. These are separated with the first being recycled to the head of the water reclamation plant whilst the RO retentate is discharged to the ocean. This eliminates issues with increasing total dissolved solids in the water cycle.

Direct Potable Reuse - Namibia, Windhoek

The environmental and demographic factors of Windhoek, Namibia are possibly the most similar of all the case studies to that of Gaborone Botswana. Some of the key environmental and demographic factors that are similar to Botswana have been tabled below.

Influencing Factors	Windhoek, Namibia	Gaborone, Botswana
Rainfall	370 mm/annum*	537 mm/annum**
Evaporation	3200-3400 mm/annum*	2000 mm/annum**
Population	240 000*	191 269 (in 2006)**
Proximity to permanent water source	750 km – Kunene and Kavango rivers	>700 km – Chobe River
Total Daily Demand	57 500m ³ /day*	69 336 m ³ /day (2006)**

Table 10. Similarities in environmental and demographic issues between Gaborone and Windhoek.

Sources: * - Lahnsteiner and Lempert⁴⁸; ** - Gibb and Pula³¹

Due to these factors Windhoek began reusing wastewater almost 40 years ago, in 1969, with the original Goreangab Water Reclamation Plant being used for the treatment of municipal wastewater for potable use (Du Pisani²⁵). One of the key factors ensuring the success of this plant was the separation of industrial and domestic wastewater, with these being treated in separate treatment works. This separation is viewed as a barrier in itself (Du Pisani²⁵). The Goreangab plant has been expanded upon over the years even as recently as 1997, although in 2002 the New Goreangab water reclamation plant began operation, using new technologies and increasing capacity (Lahnsteiner and Lempert⁴⁸). Today Namibia is still one of the only countries in the world making use of a direct potable reuse system (Metcalf & Eddy and AECOM²⁴ and Asano⁶³).

Along with the development of the reclamation infrastructure Windhoek has also put in place policy changes and regulations to increase the efficiency of water usage, particularly during drought conditions (Lahnsteiner and Lempert⁴⁸). Some of these methods of implementation include, equipment installations (low flow showers, dual flush toilets etc), controlled groundwater abstraction, and controlled water usage (irrigating times for gardens, swimming pool covers).

Overview

Wastewater treatment in Windhoek has two components, industrial (7% or 1.5 million m³/annum) and domestic (45% or 9.6 million m³/annum) wastewater treatment facilities (Lahnsteiner and Lempert⁴⁸). Industrial wastewater treatment is done using anaerobic followed by aerobic ponds with the final effluent being reused to irrigate pastures whilst domestic wastewater is treated at the Gammans Water Care Works (Lahnsteiner and Lempert⁴⁸). This report will look primarily on the domestic wastewater, as this is the component, which would be treated for potable reuse.

The water for potable reuse is derived from two sources; the domestic wastewater stream treated by the Gammans Water Care Works (90%) and the Goreangab Dam (10%) with advanced treatment taking place at the New Goreangab Water Reclamation Plant (Lahnsteiner and Lempert⁴⁸).

One of the key strategies implemented in Windhoek is the separation of industrial and domestic wastewater. By continuously maintaining this separation this minimises the diversity of contaminants that are found in different industries.

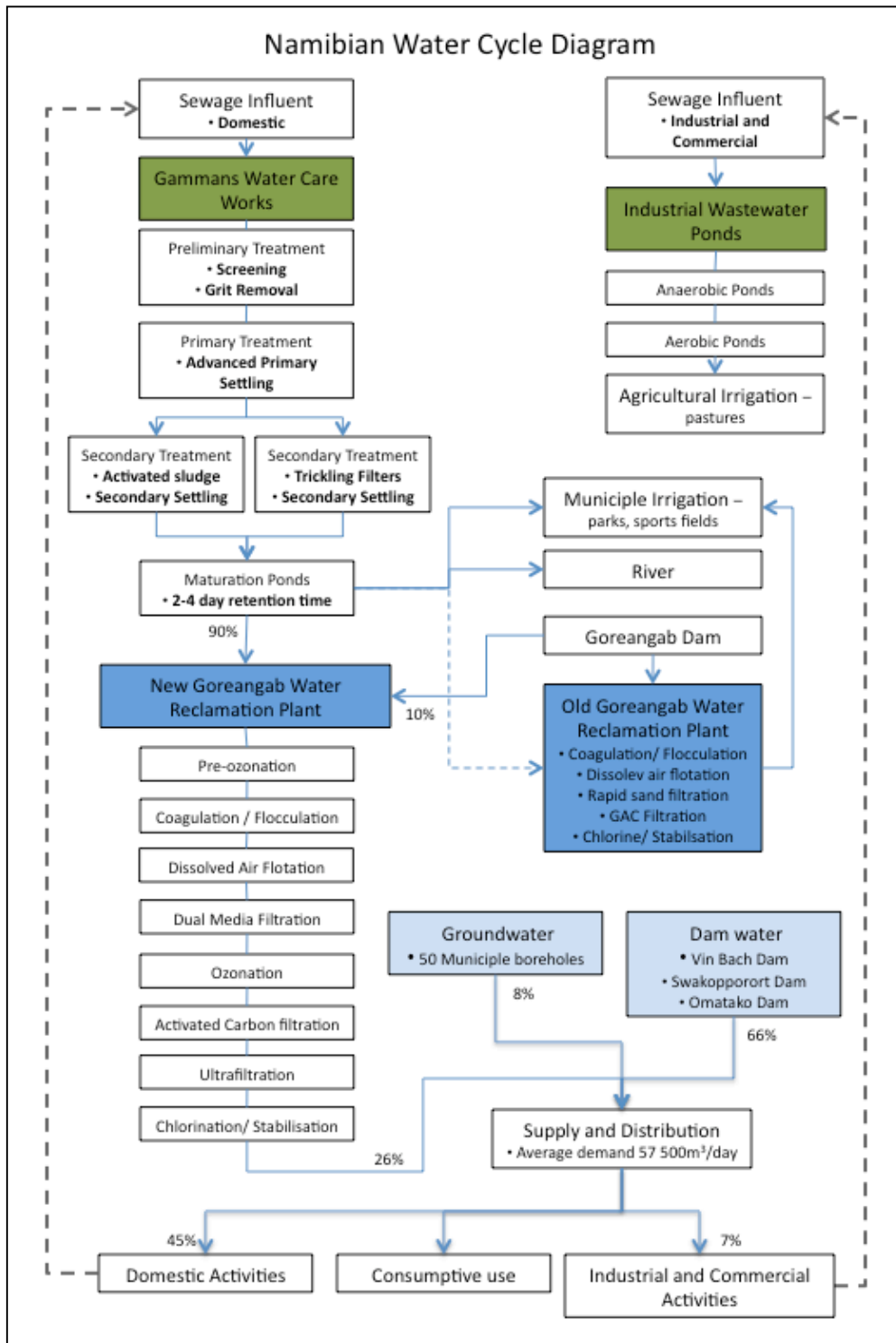


Figure 16. Water cycle of Windhoek, Namibia

Wastewater Treatment

The Gammans Water Care Works is responsible for the treatment of approximately 9.6 million m³/annum of domestic wastewater or 45% of the total wastewater of Windhoek city (Lahnsteiner and Lempert⁴⁸). The majority of the treated effluent being made available to the New Goreangab Water Reclamation Plant whilst the remainder is discharged into the river system, or used for irrigation by the municipality.

The Gammans Water Care Works is a nutrient removal plant comprised of three main components;

1. Primary treatment involving screening, grit removal and primary settling.
2. Secondary treatment making use of both activated sludge and trickling filters in parallel biologically removing nitrogen and phosphorus providing an effluent with a Chemical Oxygen Demand (COD) of approximately 60mg/l (Lahnsteiner and Lempert⁴⁸).
3. Maturation ponds form the final treatment stage with a retention time of 2-4 days. This reduces COD levels by between 33-50% from 60 mg/l to approximately 30 – 40 mg/ (Lahnsteiner and Lempert⁴⁸). This final effluent is used as raw water for the New Goreangab Reclamation Plant.

Water Treatment for Potable Reuse – New Goreangab Water Reclamation Plant

The New Goreangab Water Reclamation Plant has a capacity of 21 000m³/day (Du Pisani 2005⁵⁴). The initial design limited the maximum percentage of reclaimed water in the distribution network to 35% but this has been increased to 50% due to lower dissolved organic carbon (DOC) concentrations being produced (≤ 2.6 mg/l) (Lahnsteiner and Lempert⁴⁸). On average the plant produces approximately 25% of Windhoek's potable supply (Lahnsteiner and Lempert⁴⁸).

Raw water comes from a blend of the Gammans Water Care Works and the Goreangab Dam, 90% and 10% respectively. Reused water accounts for approximately 26% of the total water supply to Windhoek (Lahnsteiner and Lempert⁴⁸).

The New Goreangab Water Reclamation Plant (NGWRP) was completed in 2002 with the capacity to produce 21 Ml/day of high quality water (Windhoek city council⁴⁹).

The Old Goreangab Water Reclamation Plant (OGWRP) was not expanded upon but rather left in place to treat water from the Goreangab Dam. This dam is extremely polluted to the extent that it is now only partially used for drinking purposes (10% is used by the New Goreangab Water Reclamation Plant) with the majority of the water 90% being treated at the Old Goreangab Water Reclamation Plant for irrigation purposes (Lahnsteiner and Lempert⁴⁸).

By comparison to the Orange County and Singapore treatment processes the New Goreangab process seems more complicated, employing more unit processes. This is due to the adoption of a multiple barrier treatment process whereby there is a minimum of “two (in many cases three or more) unit processes are provided for removing each crucial contaminant that could be harmful to the human body or aesthetically objectionable” (Lahnsteiner and Lempert⁴⁸). Whilst the Singapore and Orange County processes have 3 main unit processes the New Goreangab Water Reclamation Plant involves at least 8 unit processes, see

Figure 17.

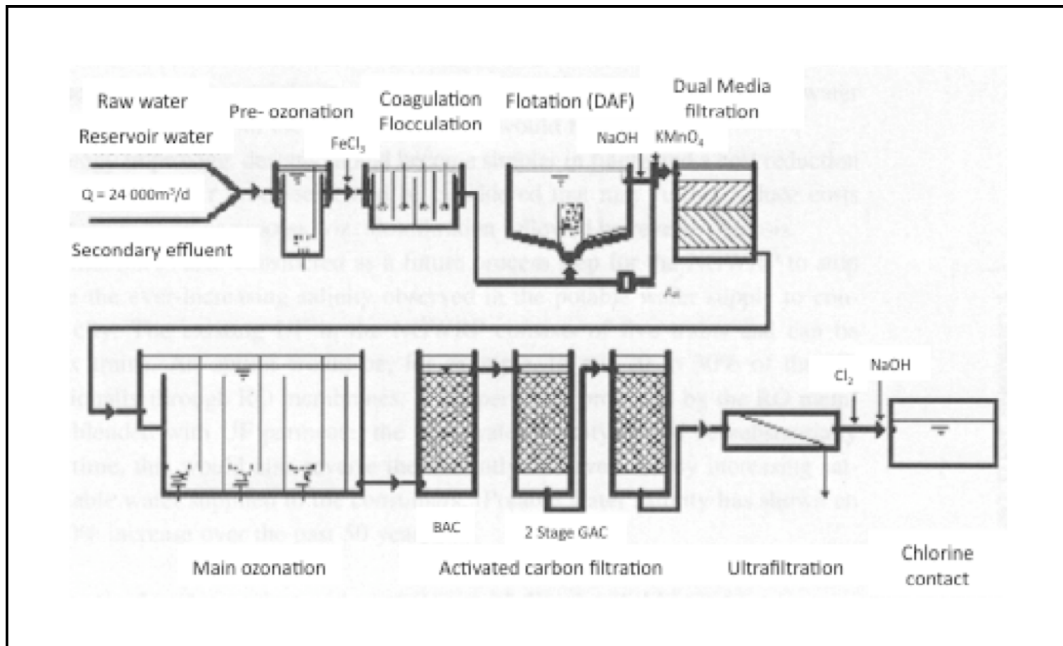


Figure 17 New Goreangab process flow diagram (Lahnsteiner and Lempert⁴⁸).

The New Goreangab Water Reclamation Plant multiple barrier approach involves the following unit processes:

1. Powder activated carbon (PAC), acid, polymers: These are operational barriers, which can be used when required based on operating conditions. PAC is used mainly for adsorbing organic matter often responsible for bad taste and odour (Du Pisani⁵⁰)
2. Pre-ozonation: this step makes use of “off-gas” from the main ozone process, which is collected and used to increase the efficiency of the dissolved air flotation process in removing dissolved organic carbon (Du Pisani⁵⁰).
3. Coagulation and flocculation: enhanced coagulation and flocculation for one of the five barriers against organic substances and partial barrier against *Cryptosporidium* (Lahnsteiner and Lempert⁴⁸).
4. Dissolved air flotation (DAF): combined with coagulation, flocculation and dual media filtration this is considered to be a

complete barrier for turbidity, and a partial step for the removal of both COD and DOC (Du Pisani⁵⁰).

5. Dual media rapid gravity sand filtration: designed as a partial barrier for resistant pathogens (*Cryptosporidium*) and part of complete barrier for turbidity even though the turbidity may not be reduced by 100% (Du Pisani⁵⁰).
6. Ozonation: used to both destroy resistant pathogens such as *Giardia* and *Cryptosporidium*, as well as breaking down long chained organic compounds so that they can be more efficiently removed using biological activated carbon in the next stage (Du Pisani⁵⁰).
7. Activated carbon filtration: has two forms, the first being biological activated carbon (BAC) containing organisms responsible for the physical removal of organic materials made possible by the ozonation step (Du Pisani⁵⁰). Granular activated carbon (GAC) is used for the filtering of bacteria that may pass through the BAC step.
8. Ultrafiltration: consists of 5 membrane racks with each rack holds 14 membrane vessels with a 100µm screen on the feed side to remove large particles. Each vessel houses four 200cm (8 inch) modules each with a membrane area of 35m² providing a total membrane surface of 9800m². Overall the pressure on the membranes is typically between 0.4 – 0.7 bar, with a gross flux of 107L/m²/hour and a recovery rate greater than 91% (NORIT and WINGOC⁵¹).
9. Disinfection and stabilisation: Chlorine is used as the final disinfection as well as providing residual disinfection for the distribution system, secondary chlorination (Menge⁵²).

The “why not” option

The ‘why not’ question in this case refers to indirect versus direct reuse, and why does Windhoek make use of a direct reuse rather than indirect? This is largely related to evaporation losses in surface storage facilities, although contamination of surface waters has also been raised as an issue in Windhoek.

Currently Namibia is undertaking a certain amount of ground water recharge pumping reclaimed water into existing aquifers as supply during drought conditions.

As Namibia has managed to separate its industrial and domestic wastewaters this has enabled the plant to directly reuse water for potable supply without having the risks involved with the reuse of industrial wastewaters.

No reverse osmosis process is currently being employed which eliminates the issue of this waste stream. This process is likely to be installed as it has been reported that the potable water supply has an increasing amount of salinity (Du Pisani⁵⁴).

COMPARISON OF WASTEWATER EFFLUENT AGREEMENTS

There are many different wastewater quality standards throughout the world with each country having a set of standards for wastewater discharge. In order for wastewater to be allocated for potable reuse not only are the standards usually extremely stringent but also there is often an additional agreement between the wastewater treatment plant management and the advanced water treatment plant management. This agreement is designed to set specific parameters regarding wastewater effluent so as to protect final water quality but also to protect the advanced water treatment system.

Often these agreements have built into them limitations covering the guarantee from the supplier of the advanced water treatment process units. This is common where membrane filtration is used and different limitations must be set in order to reduce fouling. These limitations are

often not formalised in an agreement directly but rather will be listed in an operations manual, which the guarantee will be based on.

California

In California the Orange County Water District and the Sanitation District have an agreement known as the “Groundwater Replenishment System, Development, Operation and Maintenance Agreement” signed in 2002 by both parties. Although this agreement makes reference to the Californian Code of Regulations – Water Recycling Criteria it also outlines various details the quantities and quality of effluent from the wastewater treatment works. Aside from the Californian regulations turbidity is the only parameter, which has been clearly specified in the agreement over and above the state regulations. These specifications are 5 NTU on average measured over 30 days and 10 NTU on an instantaneous basis (OCWD and OCSD 2002³⁸). The California Code of Regulations is currently in draft form and covers a vast array of aspects from monitoring, reporting, maximum contaminant limits and procedural obligations to be adhered to for the groundwater recharging.

Singapore

Singapore differs from most countries in that the PUB manages the entire water cycle. Correspondence with the PUB engineers indicated that although some variation does occur between the different NEWater factories the key parameters monitored and adhered to regarding secondary effluent quality for the production of NEWater, are:

Parameter	Unit	Level
Turbidity	NTU	<10
Ammonia	ppm	<5
pH		6 – 6.5
Conductivity	MicroS/cm	<1000

Table 11 Specific parameters required to be met for NEWater production.

Over and above this Singapore also has standards regarding the discharge of wastewaters and the reclamation plants have to adhere to these.

Namibia

Overall the water cycle in Windhoek is managed by the city council but various agreements are in place with the private sector responsible for the management of the plant. This agreement is known as the Private Management Agreement and sets out the conditions for operations, maintenance, hand back requirements, water quality targets and limits, and water volumes (Du Pisani⁵⁴). The agreement sets standards for both final treated water and for “intermediate treated water”, with intermediate treated water standards being set to protect subsequent processes in the plant, mainly membrane filtration (Du Pisani⁵⁴). Overall the agreement is designed to provide incentive to reduce waste and maximize recovery, whilst ensuring that the influent water is of suitable quality for reclamation and that the final quality is safe for reuse. The agreement outlines both target values and absolute maximum values with incentives attached to target values, through the use of penalties. However failure to meet the final absolute maximum values results in the plant being placed in recycle mode until these are met. Payment made to the management of the plant is based on this agreement with the computation being:

$$\begin{aligned} \text{Treated water toll for the day} &= (\text{availability toll for the day}) + \\ &(\text{volumetric toll for the day}) + (\text{raw water surcharge}) - (\text{raw water} \\ &\text{consumption}) - (\text{wastewater treatment}) - (\text{Du Pisani}^{54}). \end{aligned}$$

CHAPTER 4: OPTIONS SELECTION

Before any design can be produced all the various options for reuse must be assessed. Metcalf and Eddy⁴ suggest that the “optimum water reclamation and reuse project is best achieved by integrating both wastewater treatment and water supply needs into one plan”. This report has attempted to implement this approach.

SELECTION PROCESS FOR THE DEVELOPMENT OF OPTIONS

Identification of the available reuse options has been achieved using a key to ensure all aspects are taken into account for the selection of a suitable option.

This key does include some questions, which have been answered outside of the scope of this project and have been taken for granted i.e. “Does Gaborone need to augment its water supply through potable water reuse?” This is taken as a given and regarded as a – “yes”, even though this option has not been explored in the scope of this project.

Only those options on the bottom section of the key,

Figure 18, have been considered as possible options for the reuse of water in Gaborone. This key addresses options for reuse at a ‘macro’ level without looking at the different treatment process options. The ‘micro’ level options dealing with the treatment unit processes have been addressed in the design of the different options.

This study does not attempt to look at the non-potable reuse options (above the dotted line) but must make mention that these options should be considered in the future as they are more easily achievable and can effectively augment supply.

The existing planned option proposed by the Water Utilities Corporation (study undertaken by Gibb and Pula³¹) has been used as the design for Option 3.

Once the different options have been identified and outlined a single option will be selected and a conceptual design undertaken for this. This will be compared to the WUC design, option 3, in terms of being a viable option.

By using the selection key four different options have been identified for potable reuse. These options can be separated into two distinct categories, direct reuse and indirect reuse options. These options are:

1. Option 1 – Indirect potable reuse using surface storage for blending
2. Option 2 – Indirect potable reuse using sub-surface storage in the form of a suitable aquifer for blending.
3. Option 3 – Direct potable reuse using secondary treated wastewater from the Glen Valley treatment works maturation ponds. This is the existing Water Utilities Corporation design.
4. Option 4 – Direct potable reuse involving the treatment of wastewater from raw sewage through to potable quality.

These options have all been discussed below and a single option has been selected for comparison to the existing WUC design (option 3), in chapter 5.