TREATMENT OF WASTEWATER FOR RE-USE IN THE DRINKING WATER SYSTEM OF WINDHOEK

J. MENGE

City of Windhoek, PO Box 59, Windhoek, Namibia (jgm@windhoekcc.org.na)

ABSTRACT

Windhoek, situated in the center of Namibia, one of the most arid countries in Africa, with perennial rivers in excess of 500 km to the North or South, mainly depends on water supply from boreholes and three surface dams in ephemeral rivers some 60 to 200 km away. Water shortages from these supplies prompted the city to look for alternatives to augment the water supply. The first reclamation plant started to operate in 1968 with a capacity of 4,800 m3/d. Since then the reclamation process has undergone various changes of improvement. In September 2002 the New Goreangab Reclamation Plant (NGRP) was commissioned having a 21,000 m3/day capacity. The old plant is now treating effluents for irrigation of parks and sports fields.

Design criteria and process selection are a rigorous process and demand a multidisciplinary team approach. Monitoring of the total water cycle for operational control and health requirements are an integral part of the reclamation and reuse scheme.

INTRODUCTION

While certain experts are of the opinion that reclaimed drinking water in many instances is of a better quality than the water that is consumed by many people, this principle is not acceptable for all people. Why is it then that Windhoek is still the only city in the world directly reclaiming treated wastewater effluent for drinking water for the past 35 years?

Windhoek, situated in the center of one of the most arid countries in Africa, with perennial rivers either 500 km to the North or South, mainly depends on water supply from boreholes and three surface dams in ephemeral rivers some 60 to 200 km away. To supply water from further away through the North Eastern Water Carrier is not economically feasible at this stage (Central Areas JV Consultants, 2004).

High population growth rates over the past 100 years continued to increase the water demand. Supply authorities had to develop new resources as existing sources were depleted (du Pisani, 2005). Repeated periods of erratic rainfall ensured that direct reclamation continued to play an important role to augment the Windhoek water supply.

Direct reclamation became a reality in 1968 when severe water shortages were experienced before the extension of the state water supply scheme could be completed. The first reclamation plant started to operate in 1968 with a capacity of 4,800 m^3/d. Since then the reclamation process has undergone various changes of improvement (Haarhoff and van der Merwe, 1995). Investigations conducted during 1991 recommended that with minor changes to the plant, the capacity could be extended and the final water quality improved (Haarhoff, 1991). During a drought in 1992, where state supplies could not deliver the required quantity, the then existing plant was upgraded and extended to an interim capacity of 14,000 m^3/d with the intention of ultimately reclaiming 21,000 m^3/d. During another severe drought in 1997 it was however decided to build a new reclamation plant at an adjacent site to the Old Goreangab Reclamation Plant. During the period 1992 to 1998, all the components of the reclamation system were reviewed and re-analyzed and incorporated into the design of a new reclamation plant. In September 2002 the New Goreangab Reclamation Plant (NGRP) was commissioned. The old plant is now treating effluents for irrigation of parks and sports fields.

The practical experience at Windhoek demonstrates that a direct wastewater reclamation system can be a practical, responsible way of augmenting potable water supplies in arid regions, but it requires comprehensive planning, training and on-going commitment for its continued success. (Haarhoff and van der Merwe, 1995).

POLICIES

(Amy *et al*., 2005) recommend a new perspective in water resources management, where all concerned, the wastewater and water engineer, take the full hydrological water cycle into consideration in order to provide sustainable water supply. Wastewater should be seen as a resource and natural treatment within the water cycle, like an aquifer, a reservoir or a river should be included in the reclamation/reuse approach where possible. The City of Windhoek adopted a similar approach over many years. The water cycle of Windhoek is shown diagrammatically in Figure 1.

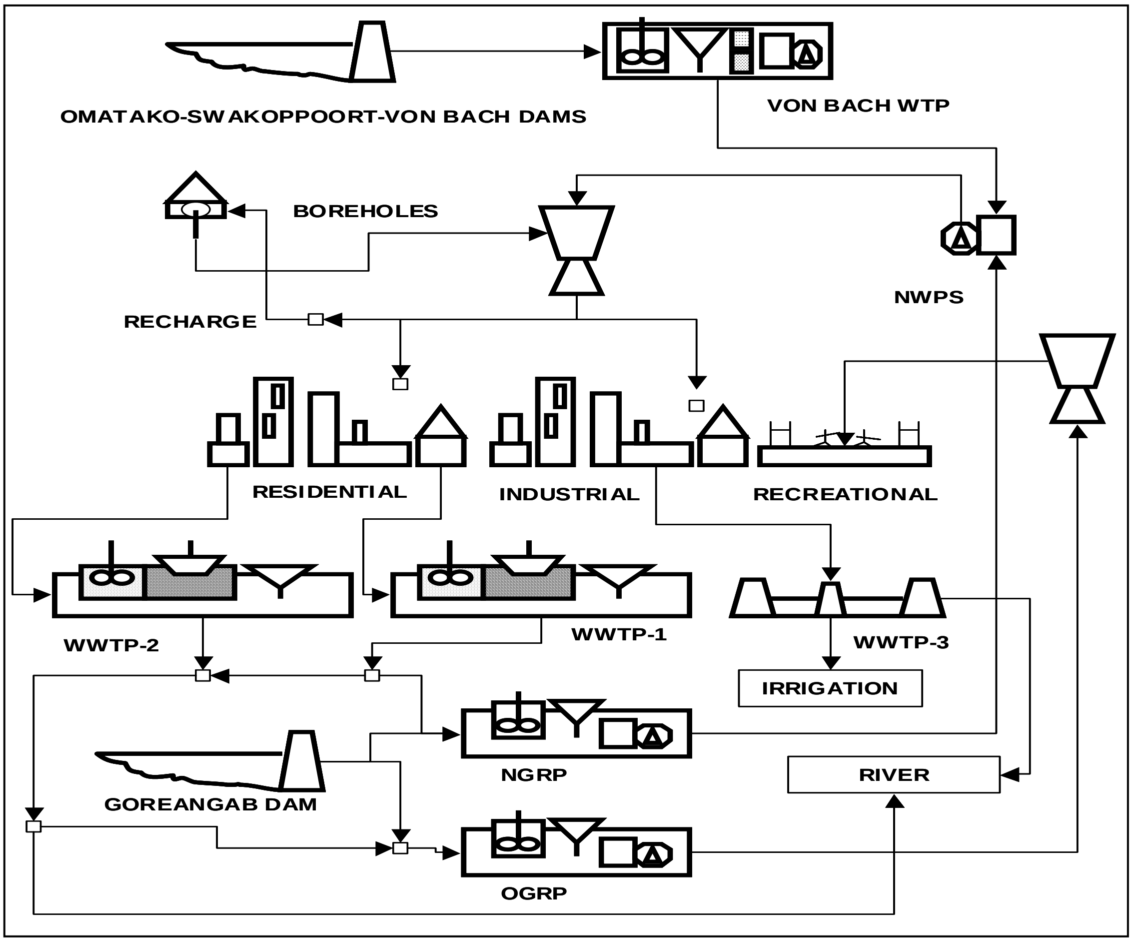

Figure 1 -: The Windhoek Water Cycle – Drinking water supply, reclamation and reuse scheme.

Policies to enhance reuse on national and local authority level

A dry country with low and irregular rainfall, extended periods of drought and mainly dependant on underground resources and surface dams in ephemeral rivers is very vulnerable. When the main perennial rivers are national borders originating in the neighboring countries, long-term supply agreements cannot be 100% guaranteed. Large supply schemes are very costly and in certain regions not economical to implement for various reasons. In such cases well-planned use and reuse of water can play a vital role to sustainability.

National and local policies should support reuse of wastewater, taking the constraints of the region as well as the potential threats of wastewater reuse into consideration. Active participation through educational programs are needed to encourage planners and engineers to design systems that cater for reuse or that can at any time be changed to a reuse scheme. The following principles for reuse and reclamation are proposed in Namibia in the following order of priorities:

1. *Industrial*: cooling water for power plants and oil refineries, process water, boiler feed, construction activities, concrete mixing
2. *Agriculture*: crop and commercial nurseries
3. *Landscape*: public parks, golf course, school yards, cemeteries, greenbelts, residential
4. *Recreation/environment*: lakes, ponds, marsh enhancement, stream flow augmentation, fisheries
5. *On site re-use of Grey water*: lawns, trees, ornamentals and food crops
6. *Non-potable urban*: fire protection, air conditioning, toilet flushing
7. *Groundwater recharge*: groundwater replenish, saltwater intrusion control, subsidence control
8. *Potable reuse*: through advanced water treatment based on multi barrier approach provided that reclaimed water is blended with water from other sources.

WATER REUSE

Historic development of the Windhoek reclamation processes

The treatment of wastewater for direct reuse in a drinking water system, derived from the effluents of a large city poses extraordinary challenges and needs careful consideration on a number of topics. The reason why the City of Windhoek has been directly reclaiming sewage effluent to drinking water for so long are discussed by (Clayton *et al*., 1972; du Pisani, 2005) and others. Early research and successes of the first and subsequent upgrades of the reclamation plant in Windhoek are reported by (Van Vuuren *et al*., 1971; Hausmann, 1983; Haarhoff and van der Merwe, 1995). Quality targets, economic considerations, micro pollutants research, biological and virological testing and recent pilot research work at Windhoek are reported on by (Van Vuuren, 1975; Hattingh and Nupen, 1976; Hattingh, 1977; Van Rensburg, 1981; Grabow *et al*., 1985; Welch *et al*., 1985; Van Steenderen, 1991; Menge *et al*. 1999; Menge *et al*. 2001; König *et al*., 2000) and many others. The experiences in the engineering and scientific findings in water reclamation in Southern Africa are recorded in many manuals and books; (Meiring and Partners, 1982; Isaäcson *et al*., 1987; Grabow, 1990). The amount of man-hours and resources spend on developing the reclamation and reuse technology in Southern Africa and particularly on the Windhoek Goreangab Reclamation Plant are substantial.

Table 1 shows the different process configurations that were implemented over the years at the Old Goreangab Reclamation Plant (OGRP) and finally the process train of the New Goreangab Reclamation Plant (NGRP).

<u>Wastewater treatment for reclamation and reuse in Windhoek</u>

General considerations

Effluents considered for reclamation must be of highest possible quality, particularly as regards toxic, pathogenic, organic and nitrogenous constituents. Most effluents from sewage treatment plants are subject to marked diurnal and seasonal quality variations, especially as regards constituents such as ammonical nitrogen, organic carbon and alkalinity. These constituents add to reclamation costs in terms of chemical dosages for phosphorus removal, chlorine demand for disinfection and activated carbon requirements. The chlorine demand for disinfection of reclaimed water is perhaps the most important element of difference as compared to conventional water treatment, therefore biological nitrification-denitrification processes are extremely important to remove the ammonia. The salinity problem may to some extend be controlled by blending reclaimed water with surface supplies of lower dissolved solids.

Table 1 – Process configurations and modifications since commissioning

C1-1969 – OGRP	C2-1977 – OGRP	C3-1980 – OGRP	C4-1986 – OGRP	C5-1994 – OGRP	C6-1996 – OGRP	C7-2002 – NGRP
Biofilters	Biofilters	Activated sludge-NR	Activated sludge-NR	Activated sludge-NR	Activated sludge-NR	Activated sludge-NR
Maturation ponds: 14d	Maturation ponds: 12d	Maturation ponds: 10d	Maturation ponds: 10d	Maturation ponds: 6d	Maturation ponds: 6d	Maturation ponds: 3d
>Carbon dioxide	*>Lime*	*>Chlorine*	*>Alum + Lime*	*>Ferric*	*>Ferric*	*>PAC*
>Alum	Settling	*>Alum + Lime*	Dissolved air flotation	Dissolved air flotation	Dissolved air flotation	Pre Ozonation
Algae Flotation	Ammonia stripping	Settling	>Chlorine			*>Ferric*
Foam Fractionation	*>Carbon dioxide*	*>Breakpoint chlorination*	*>Alum + Lime*			Dissolved air flotation
>Alum + Lime	*>Chlorine*	Settling	Settling			*>MnO_4 + NaOH*
>Breakpoint chlorination	Settling					
Settling	*>Carbon dioxide*					
Rapid sand filtration	Rapid sand filtration	Rapid sand filtration	Rapid sand filtration	Rapid sand filtration	RSF(ftw) – RSF(ftw)+GAC	Rapid sand filtration (ftw)
	>Breakpoint chlorination	*>Chlorine*	*>Breakpoint chlorination*			*>Ozonation, H_2O_2*
Activated carbon	Activated carbon	Activated carbon	Activated carbon	Activated carbon	Activated carbon	BAC+GAC
>Chlorine	*>Chlorine*	*>Chlorine*	*>Chlorine*	*>Break point chlorination*	*>Break point chlorination*	Ultra filtration
				>Stabilisation: Lime	*>Stabilisation: NaOH*	*>Chlorine*
				>Chlorine	*>Chlorine*	*>Stabilisation: NaOH*
Blending	Blending	Blending	Blending	Blending	Blending	Blending

Domestic waste treatment

Domestic and industrial effluents are treated separately in Windhoek. Two biological nutrient removal plants treat domestic wastes. The Gammams wastewater treatment plant (GWTP) receives the bulk of the domestic effluent. Otjomuize wastewater treatment plant (OWTP) is still far under design capacity. It receives waste effluent from newer developing townships in the Northern area of Windhoek.

The Gammams wastewater treatment plant (GWTP) process consists of: primary settling and anaerobic digestion with drying beds. Stream a: biofilters with secondary settling and 3 maturation ponds. Stream b: biological nutrient removal activated sludge plant (UCT or modified Johannesburg or Ludzack-Ettinger configuration) and 8 maturation ponds. Especially in winter months the nitrification in the biofilter system is low. To produce sufficient effluent of high quality for drinking water reclamation and irrigation, the biofilter system was integrated into the activated sludge system in 2002.

The Otjomuize wastewater treatment plant (OWTP) process consists of: No primary settling, biological nutrient removal activated sludge plant (UCT configuration), no maturation ponds. The waste streams of NGRP are pumped to OWTP, contributing to one-third of its influent. It contains a high concentration of iron from $FeCl_3$ dosing, thus phosphate is removed to below <1.0 mg/l. Nitrification is complete with very good de-nitrification.

<u>Reclamation of treated effluent</u>

Considerations for the design of the New Goreangab Reclamation Plant (NGRP)

Drinking water treatment has three main goals (Bursill, 2001), i.e.

- To provide safe water
- To provide aesthetically pleasing water, and
- To ensure that the technology applied does not create further problems.

(Haarhoff *et al*., 2001) report how this was achieved with the latest upgrade of the New Goreangab Reclamation Plant (NGRP) commissioned in September 2002 by setting up the process selection criteria and applying the multiple barrier principle. The following is a brief summary of this process with an addition:

- Analyzing of the raw water quality data of both the Gammams Wastewater Treatment plant (GWTP) and the Goreangab Dam over a period of three years.
- Defining of the final water criteria by using the data, comparing it with national and international guidelines and standards for drinking water supply, own experience and recent international developments
- Developing the multiple barrier concept into a quantitative tool to evaluate the process options.
- Critically analyzing different process options used successfully in the past.
- Evaluating the pilot and bench scale research work conducted.
- Proposing a new design based on an alteration of the previous process train and adding additional processes.

Multiple barrier principle

Three types of barriers can be distinguished: non-treatment, treatment and operational.

Non-treatment barriers are

- The diversion of industrial effluent to a different drainage area and the policing of industrial discharges.
- Rigorous continuous quality monitoring (on-line and laboratory) of the raw and treated water to allow for corrective action to protect the consumer.
- Blending of reclaimed water to a maximum of 35% with conventional sources.
- Implementing solid catchment management policies.

Treatment barriers are

- Always present against specific contaminants
- NOTE: they are not absolute “dead-stop”!
- They are regarded as either partial or complete
- Different contaminants respond differently to different treatment methods. The consequence of a failure is different for each contaminant.

Operational barriers

- They are not normally in use but provide backup or additional capacity to an existing process, example PAC for GAC.

Table 2 shows how this concept was put into practice to derive at the current NGRP process configuration. Note this table has been adapted and updated since the publication of (Haarhoff *et al*., 2001) to include the biological treatment process.

Table 2 – Process selection for various objectives in drinking water reclamation

Treatment objective	Required barriers		Required/proposed Process steps P = partial, C = complete
	Partial	Complete	
Aesthetic		2	1.C> CD+DAF+SF 2.C>UF 1.P> GAC
Microbiology and Virus	1	3	1.P> ASP-BNR-MP for TC, TN and TP 2.P> CD+DAF+SF 1.C> O_3 2.C>UF 3.C> Breakpoint chlorination
Protozoa: *Giardia + Cryptosporidium*		3	1.P> MP 1.C> CD+DAF+SF 2.C> O_3 3.C> UF
Organics	2		1.P> CD+DAF+SF 2.P> O_3+BAC+GAC 3.P> PAC
DBPs	2		• Enhanced coagulation • Delay chlorination in process train & reduce dosage
Residuals: Fe, Mn	2		1.P> NaOH+MnO_4+SF 2.P> O_3+BAC+GAC
Stability		1	1.C> NaOH
Nitrogenous and organic constituents	1		1.P> ASP-BNR-MP for TC, TN and TP

CD+DAF+SF – Chemical dosing + Dissolved air flotation + Rapid sand filtration (including slow start + filter-to-waste) (removal of suspended solids and partial removal of dissolved solids). **O_3** – ozonation (oxidation/disinfection). **GAC** – Granular activated carbon (adsorption of micro pollutants). **PAC** – Powdered activated carbon (adsorption of micro pollutants). **O_3+BAC+GAC** – Ozonation + Biological activated carbon + Granular activated carbon (oxidation + biological degradation + adsorption of micro pollutants). **UF** – Ultra filtration (removal of particles). **NaOH** – Sodium hydroxide (stabilization of corrosive water). **NaOH+MnO_4+SF** – Sodium hydroxide + Permanganate (oxidation of iron and manganese + subsequent precipitation). **ASP-BNR for TC, TN and TP** (Biological nutrient removal activated sludge process for Total carbon, Total nitrogen and Total phosphorus removal). **MP** – Maturation ponds with > 5 day retention.

The New Goreangab Reclamation Plant (NGRP)

Capacity: 21,000 m^3/day. Complete process diagram in Figure 2.

-*Raw water sources*: Goreangab Dam, Maturation Pond effluent from Gammams Wastewater Treatment Plant (GWTP). Both sources can be mixed at any ratio or only one source used at a time. Mixing is determined by best plant performance.
-*Powdered activated carbon*: can be added as back up capacity for adsorption should the ozone process fail.
-*Pre-ozonation*: The raw water mix is treated with the off gas and access ozone.
-*Chemical dosing and coagulation*: Ferric chloride is added as primary coagulant in dosages to achieve enhanced coagulation for maximum organic removal in the first solids separation step. Hydrochloric acid can be added if required for pH control. If needed, a polymer can also be added.
-*Dissolved air flotation* (DAF): used for solids separation. This process is used since 1984 successfully in Windhoek and is regarded as the “heart” of the reclamation process.
-*Chemical dosing*: Caustic (NaOH) and permanganate (MnO_4) are added to raise the pH and accelerate the oxidation precipitation of iron and manganese on the sand filter.
-*Rapid sand filtration*: Dual media filters with anthracite and graded sand. The filters are equipped with slow start and filter-to-waste facility for maximum cyst/oocyst removal.
-*Ozonation and ozone contact*: Oxygen is produced on-site with a Pressure Swing Adsorption (PSA) plant. Ozone is dosed at three dosage points. Dosage is regulated for maximum Dissolved organic carbon (DOC) removal (1-1.5 mg O_3/1mg DOC). A Ct value of 15 at 20 minutes needs to be maintained.
-*Chemical dosing*: Peroxide (H_2O_2) is dosed to remove any ozone residuals to protect the biological activity in the next step.
-*Bacteriological activated carbon* (BAC) filters: During ozonation organics with high molecular weight and especially the refractory organic matter are oxidized to produce molecules that are readily biodegradable. These are removed by the biological activated carbon.
-*Granular activated carbon filters* (GAC): Consist of primary and secondary filters with a contact time of EBCT = 30 minutes at maximum flow to remove organic molecules from the water.
-*Ultra filtration* (UF): Chlorinated water is filtered through ultra filtration membrane modules to remove bacteria, protozoa and virus. The decision to introduce UF into the process train was based on the fact that protozoa were detected in the final water of the OGRP (Menge *et al*., 2001).
-*Chlorination and chlorine contact*: Breakpoint chlorination, free residual of 1 mg/l and contact time of 1 hour.
-*Stabilisation*: Adding of caustic to raise the pH to ascertain positive precipitation potential of 4 mg/l.
-*High lift pumps*: Pumping the final water to New Western Pump Station.

-*Blending*: New Western Pump Station (NWPS) where the water is blended with surface water from the Von Bach scheme at a ratio 1:3 and introduced into the distribution system.

Old Goreangab Reclamation plant (OGRP)

The old plant is now used to purify effluent for irrigation. The carbon columns were decommissioned, but the rest of the process remains the same. On average some 3,600 m^3/day are currently treated. The demand varies depending whether it is summer or winter or if it rains or not.

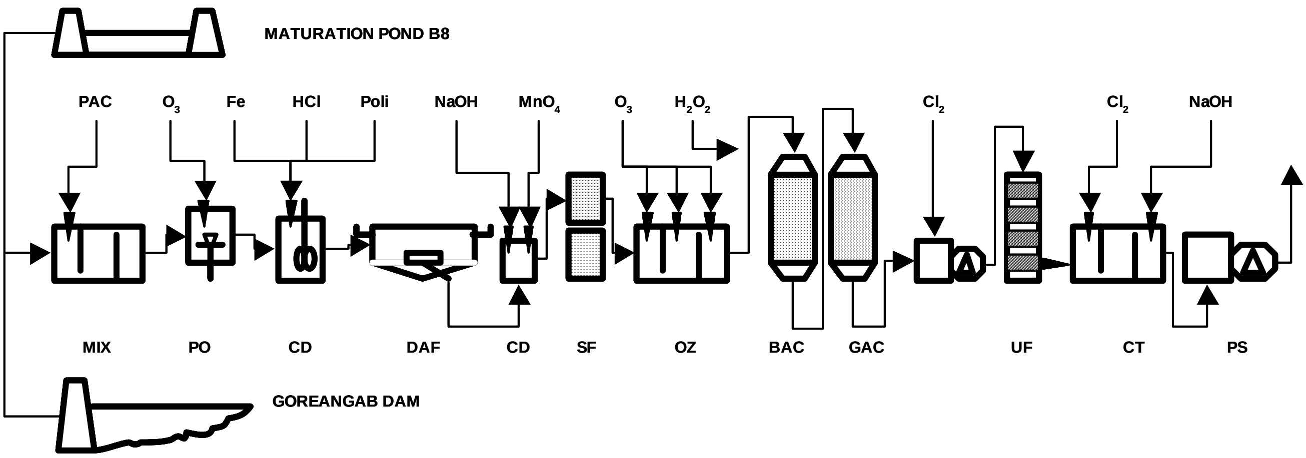

Figure 2 – New Goreangab Reclamation Plant – Process Diagram

WATER QUALITY

<u>Monitoring and quality control</u>

Windhoek's main supply is from the Von Bach-Swakoppoort-Omatoko Dam scheme (59,600 m^3/d) and the New Goreangab Reclamation Plant (14,400 m^3/d). It also receives drinking water form about 60 boreholes, divided into three distinctive groups (3,100 m^3/d). The distribution system is served by 17 Reservoirs in 17 pressure zones. There are three wastewater treatment plants, two for domestic and one for industrial effluents. The final treated effluents from the domestic sources are either reclaimed for drinking water or reused for irrigation.

Monitoring is an integral part of water reclamation to ensure the safety of the drinking water supplies and to maintain public trust. It covers the full water cycle. Test parameters for each sample point are determined for either process functionality and/or health implications. Routine tests include: Physical, inorganic and organic chemistry, microbiology and viral indicators. All these tests are conducted in the City of Windhoek's own laboratory.

A health risk program includes all the advanced tests, which are conducted in external laboratories. The programs are linked to research projects. Test work includes: virology, parasites, toxicity, mutagenicity, NOM, pharmaceutical substances, EDCs, DBPs, pesticides, Algae toxins, taste and odours compounds.

On-line instrumentation and sampling plays an important role in Windhoek. The NGRP plant is fully automated and on-line instruments are placed at all the major process units for continuous control. Likewise are on-line instruments now being installed at the wastewater treatment plants and main reservoirs for better system control. On-line instruments include: Turbidity, pH, Conductivity, Dissolved Oxygen, Chlorine (free residual), UV_{245}, TOC and Particle counting. On-line sampling includes on-line cooled 24 composit samplers and on-line filters for Giardia/Crypto and virus.

Quality of reclaimed water

After a three-month trial period the plant was finally commissioned in September 2002. The water produced is of exceptional high quality measured by national and international water quality criteria. Figure 3 shows the performance of the plant with regard to organics removal (DOC, COD and UV_{254}) and Figure 4 particle (Turbidity) and bacteria (Faecal coliform) removal. Table 3 shows the percentage removal of organic surrogates. All the data used in figures and tables are based on 95% percentile values over a two-year period.

Organic surrogates concentrations in final effluent are: DOC: 2.82 mg/l, COD: 11 mg/l, UV_{254}: 0.027 abs/cm. Turbidity in the final water is 0.09 NTU. Bacteria are removed very efficiently by the chemical coagulation flocculation step and numbers hardly exceed the count of 100. From Table 4 it is evident that TDS, Na, Cl and NO_3 do not comply with the set guidelines.

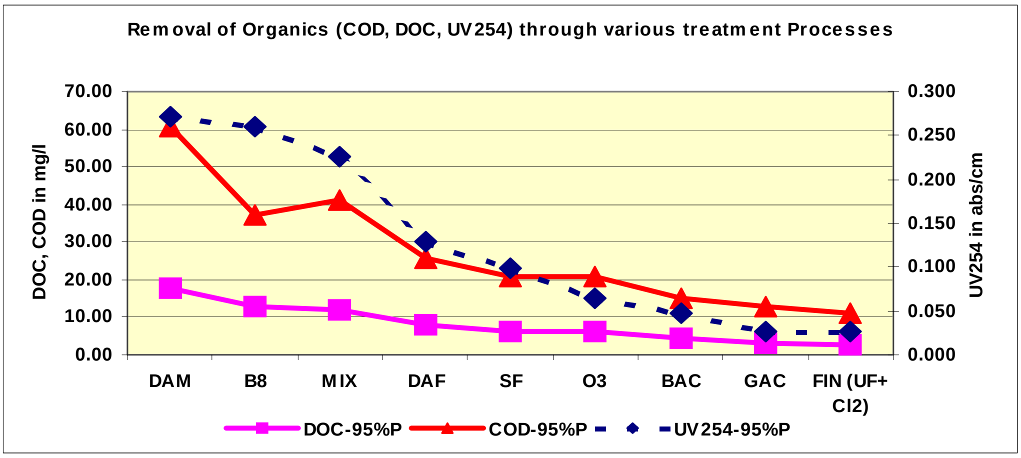

Figure 3 – NGRP: Removal of organics through the treatment train

Table 3 – Removal efficiency of organic surrogates in %			
Process	**DOC**	**COD**	**UV254**
CD-DAF-SF	47	49	56
O_3	0	0	36
BAC	31	29	26
GAC	32	13	43
$UF+Cl_2$	7	15	0

Drinking water quality

The water quality of the distribution system has improved considerably over the past six years using Turbidity, Faecal coliform and Free residual chlorine as indicators. Figure 5 shows the percentage compliance according to the Namibian water quality guideline over a ten-year period. On average about 1500 distribution samples are tested annually. Table 4 shows some parameters that exceed guideline limits.

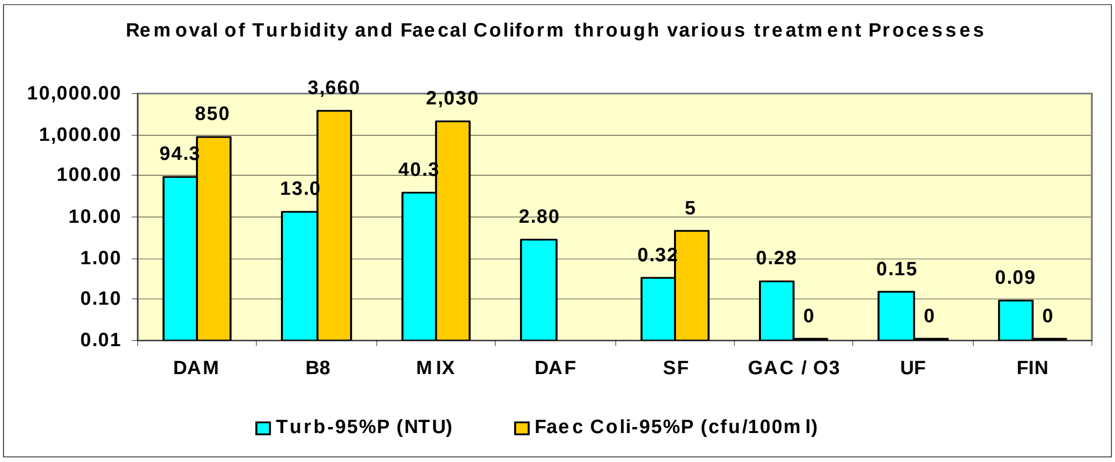

Figure 4 – NGRP: Removal of Turbidity and Faecal coliform through treatment train

Quality problems are still experienced in the distribution system such as high turbidities and color. These emanate from elevated iron and manganese concentrations and corrosiveness in borehole and surface water. Elevated DOC values occasional high chlorine demands from the surface water as well as the high nitrate concentrations from the reclamation plant add to the problem. Seasonal taste and odour problems occur from the surface water supply. The TDS in the network is also slowly rising. The high THM values are also a concern. These problems are being addressed in various programs to eliminate them.

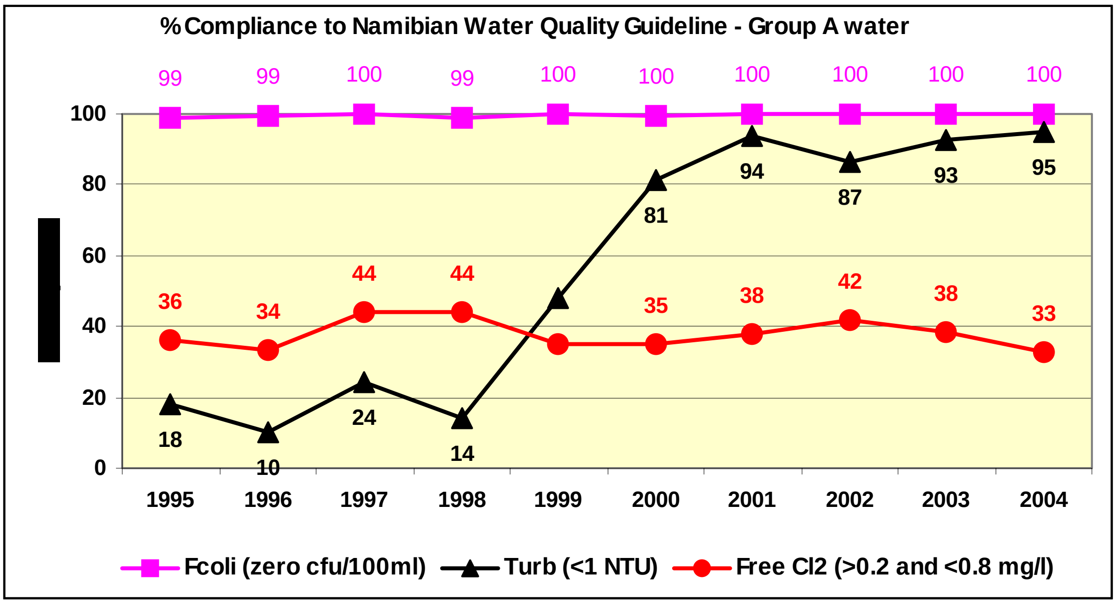

Figure 5 – Water Quality in Windhoek's distribution system

Table 4 - Water Quality (95%tile values)							
	TDS	Na	Cl	NO3	COD	THM	Fe
	mg/l	mg/l Na	mg/l Cl	mg/l N	mg/l	µg/l	mg/l Fe
Namibian Guideline, Group A	1005	100	250	10	-	-	0.1
Reclamation Standard prior to 1990	1000	100	250	10	15	40	0.1
Reclamation Standard 2002	1000	100	250	10	10(15)	20(40)	0.1
Boreholes 1970	498	48	11	-	7	-	
Boreholes 2005	650	**123**	37	0.64	-	**57**	**0.59**
Surface 2005	281	27	31	0.5	-	**85**	**0.17**
Reclamation 1970	600			9	**20.5**	-	
Reclamation 1976	646	**153**	162	9.7	11.6	-	
Reclamation 1996	659		129	8.9	**17**	**82**	**0.43**
Reclamation 2005	**1072**	**285**	**287**	**20**	11	34	0.06
Distribution <1970	375	-	-	0.9	8	-	-
Distribution >1970	475	-	-	3.3	11	-	-
Distribution 2005	543	**126**	136	5.5	-	**110**	**0.19**

CONCLUSION

The Windhoek experience has proven over 35 years that it is possible today to augment drinking water supplies through direct reclaimed water in a safe and responsible way. However it is recommended rather to use an indirect reclamation scheme if it is allowed by geographical circumstances, like storing reclaimed water in an aquifer. A multi disciplinary team approach should be used if a reclamation/reuse scheme is going to be implemented to ensure that the technology employed is operating properly and that the necessary monitoring is conducted to ensure that the product is safe for its intended use. Policies and regulations on a national and local level are needed for proper support to ensure the long-term safety and sustainability of such projects.

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It is herby acknowledged that over more than 35 years many individuals both local and abroad, in government and private sector, academic and technical have contributed tremendously to the continued success of the operation and improvements of the Windhoek water reclamation plant. Their hard work and perseverance has made it possible that reclamation is still a reality in Windhoek. The author whishes to thank the City of Windhoek for permission to present and publish this paper.

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