ELSEVIER

Desalination 188 (2006) 79–88

DESALINATION

www.elsevier.com/locate/desal

Direct reclamation of potable water at Windhoek's Goreangab reclamation plant

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Received 14 December 2004; accepted 29 April 2005

Abstract

The Windhoek Goreangab reclamation plant has been a pioneer in direct potable reclamation and is still today, as far as known to the author, the only commercial-scale operation in existence. From a humble beginning in 1969 until the commissioning of a new high technology plant in 2002, Windhoek has managed to do applied research and the original plant had been upgraded on a number of occasions. In any discussion on water reclamation from wastewater, the name Windhoek and its Goreangab reclamation plant enjoy a fair amount of recognition. An article by I.B. Law, published in May 2003 in the publication *Water* of the Australian Water Association was titled, Advanced Re-use — from Windhoek to Singapore and Beyond. Windhoek in Namibia, was indeed the pioneer in direct potable reuse.

Keywords: Arid climate; Direct potable reclamation

1. Introduction

The City of Windhoek is the capital of Namibia, which is located in southwest Africa. Namibia has a number of distinguishing features such as natural beauty and wildlife. One other feature is that it is the most arid country in sub-Saharan Africa. The country has a surface area of 825,000 km^2 and has a total population of 1.8 million, making it one of the most sparsely populated countries in Africa. There are only ephemeral rivers in the interior of the country. The only perennial rivers are on the northern and southern borders of the country, respectively, 750 and 900 km from Windhoek (see Fig. 1). The total length of the western coastline on the Atlantic Ocean is covered by the Namib Desert, one of the oldest deserts on earth. In the southeast, Namibia shares the Kalahari Desert with South Africa and Botswana. Although the desert has major advantages in terms of tourism, because of

Presented at the International Conference on Integrated Concepts on Water Recycling, Wollongong, NSW, Australia, 14–17 February 2005.

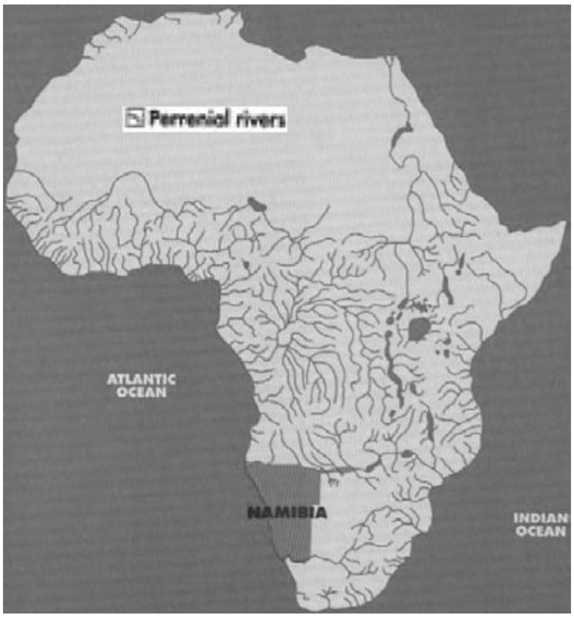

Fig. 1. Location of Namibia and perennial rivers in Africa.

its rare beauty, it is also indicative of the prevailing climatic conditions.

2. City of Windhoek

Windhoek is also the seat of government. The population of Windhoek is approximately 250,000, which in the context of the country, makes it a city. It is situated almost in the centre of the country.

The average annual rainfall is 360 mm or 14.4". The annual evaporation amounts to 3400 mm or 136". The city relies for 70% of its water on three surface reservoirs. These reservoirs are built on ephemeral rivers, these being the rivers that run only for a few days after heavy rainfall events. The three dams range from between 70 and 160 km from the city and are operated by a parastatal water utility called NamWater. These dams were built during the period from 1978 to 1993 to supply water to the central areas of Namibia. Windhoek utilizes approximately 90% of the water consumed in the central areas.

During the last 10 rainy seasons, only on average three out of ten seasons yielded above average inflow into these dams. The efficiency of these reservoirs is also such that the main “consumer” of water is evaporation, which accounts at times for a volume double that of the water utilized by consumers. Security of the water supply to the central areas of Namibia and the City of Windhoek is therefore a major challenge, both for the bulk water supplier, NamWater and the City of Windhoek.

3. Innovations in an arid land

The reason why a settlement originated at Windhoek was the presence of both hot and cold water springs. As the settlement grew, so did exploitation of these sources with the added digging of wells in the area. The water table subsided as a result, and the first municipal borehole was acquired around 1912. Over the period from 1912 to today, some 60 municipal boreholes have been developed in an aquifer with a safe assured yield of 1.73 Mm^3/y.

Groundwater remained to be the sole source of water for Windhoek until 1933 when the Avis Dam with a capacity of 2.4 Mm^3 was constructed. This dam has a small catchment area and therefore a very small assured yield; it often could not supply any water at all. This dam is currently used exclusively for recreational purposes.

During 1958, a second small surface reservoir, the Goreangab Dam, with a capacity of 3.6 Mm^3, was built and a conventional treatment plant was constructed to treat the water from this reservoir to potable standards.

4. Goreangab reclamation plant

In 1969, this plant was converted to treat not only the water from the Goreangab Dam, but also

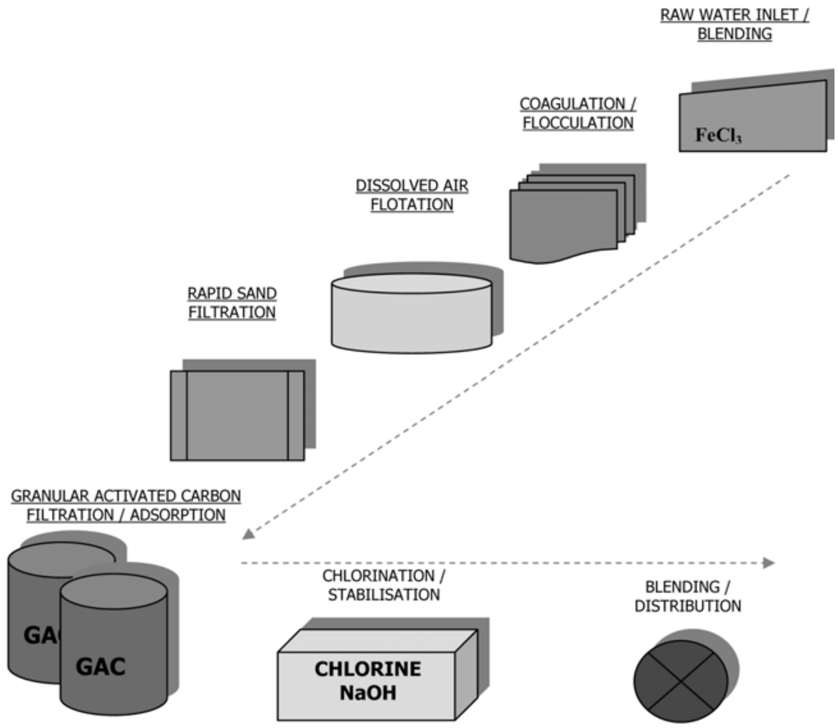

Fig. 2. Old Goreangab process train.

the final effluent from the City's Gammams wastewater treatment plant. The Goreangab reclamation plant was born. It had an initial capacity of 4,300 m³/d. This reclaimed water was blended with water from the well field.

Due to the fact that the whole city as well as its informal settlements lie within the catchment of the Goreangab Dam, the quality of the water from this reservoir is often of a worse quality than the treated sewage and therefore unfit for reclamation.

From its inception, one of the cornerstones of reclamation was that the city separated industrial effluent from domestic effluent and diverted industrial effluents to a separate treatment plant. This is regarded as a first barrier. The effluent used for reclamation, therefore, originates mostly from domestic and business wastewater.

The Goreangab plant went through a series of upgrades, the latest being completed during 1997. The ultimate capacity of the "old" Goreangab plant was 7 500 m³/d of potable water. The process train in its ultimate configuration is depicted in Fig. 2.

5. New Goreangab water reclamation plant

After independence in 1990, the population of Windhoek started growing at a more rapid rate, currently accepted as 5% per annum. This, together with increased investment and development in the city, placed ever-increasing pressure on the supply of water. As the easily accessible natural resources had to a large extent been fully exploited and demand management measures successfully implemented, extended reclamation proved to be the logical choice to augment supply. For this purpose, the City of Windhoek obtained a loan from European financial institutions to construct a new 21,000 m³/d reclamation plant on a site adjacent to the old plant. This plant can now provide 35% of the daily potable requirements of the city.

5.1. Multiple barrier system

The design philosophy for the new plant is based on a multiple barrier system. In this system a certain number of safety barriers are set up, depending on the risk associated with a particular substance or contaminant in the water to the user. These barriers can be one of three types: treatment, non-treatment or operational. The non-treatment barriers in the Goreangab reclamation plant include:

- thorough policing and diversion of industrial effluents to a separate treatment plant;
- complete monitoring at the inlet and outlet of the sewerage treatment plant, allowing action to be taken before the water reaches the reclamation plant;
- extensive monitoring of drinking water quality;
- blending the water derived from reclamation with water of different origins so that at most 35% of the drinking water is reclaimed water.

Apart from these barriers, operational systems are in use that take on the role of a further barrier. One example of an operational barrier is the possibility of dosing powdered activated carbon in case the adsorption capacity of the granular activated carbon (GAC) in the process train drops too low or the organic loading to the plant is too high. Treatment barriers are defined as "continually present systems that reduce the undesired substances in the water to an acceptable level". It is clear that a complete removal of impurities is practically impossible without reverse osmosis, so the barriers are designed to reduce concentrations of substances to fall within drinking water guidelines.

A single complete barrier for turbidity is considered to be a combination such as flocculation, dissolved air flotation and dual-media filtration, even if turbidity is not reduced by 100%. On the other hand, these three steps are not considered to be a barrier for chemical oxygen demand and dissolved organic carbon, but rather only as a step in their partial removal.

As the danger associated with specific impurities varies significantly, different numbers of barriers have been defined:

- For aesthetic parameters, such as turbidity and colour, for which there is no direct correlation between them, and detrimental effects on health, two complete barriers;
- For microbiological pollutants, three barriers;
- For parameters without health risk, such as calcium carbonate, only one barrier was implemented.

The design of the plant is based on the experience gained over 30 years of reclamation, but also includes new processes such as ozone and membrane ultrafiltration. The latter two processes were pilot tested on site over a period of 30 months, whereby the performance with this specific raw water was thoroughly tested and design decisions could be based on actual recorded results.

During these trials and the design process, the City of Windhoek sought the advice of recognized experts in the fields of ozone, membranes and GAC/BAC, as used in the process. The operational protocol of the plant makes provision for the multiple barrier system to be operational at all times.

5.2. Selection of the processes

The new Goreangab reclamation plant is made up of a series of processes, as represented in Fig. 3. Perhaps the most important cornerstone of potable reclamation is public acceptance and trust of consumers in the quality of this water. The most difficult thing for anyone wanting to

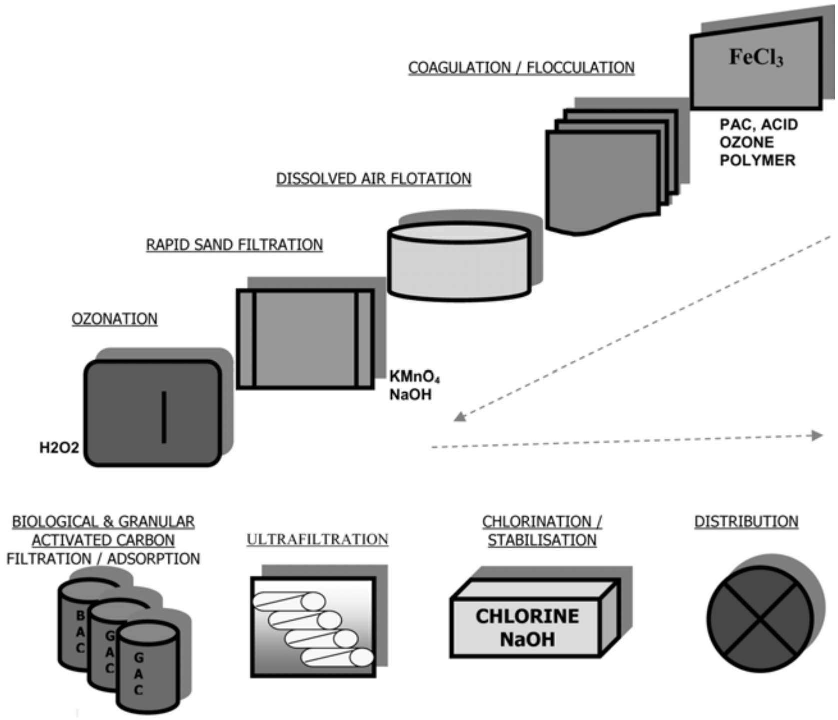

Fig. 3. New Goreangab process train.

emulate what is done at Goreangab in Windhoek, would be to break down the psychological barrier to the principle of direct re-use for potable purposes.

Van Vuuren, a pioneer of water reclamation in South Africa during the 1970s, coined a phrase: "Water should be judged not by its history, but by its quality." To get public acceptance of this viewpoint is, however, not easy and it places a severe responsibility on the city to exercise the required level of control over quality. For this purpose, the city has over the years invested substantially in laboratory facilities and manpower. The Gammams Laboratory of the city's Scientific Services Division therefore boasts state-of-the-art facilities and analytical equipment to provide customers with a level of comfort that they are prepared to accept.

Reclaimed water is widely used for aquifer recharge, during which time it loses its identity as sewage water. Water Factory 21 in Orange County, California, is a prime example, where reclaimed water is injected into the aquifer to prevent saline intrusion into the fresh water aquifer. This water ultimately re-enters the drinking water stream in an indirect manner. Often treated sewage is discharged to water bodies such as rivers and lakes. It is not uncommon that downstream users re-use such releases which are then treated as natural water through conventional methods. Although it has lost its sewage identity, this could be termed indirect reclamation or re-use. At Goreangab, the history of the feed water is recognized as treated sewage and treatment is designed to cope with just that.

To retain public confidence, quality monitoring and control are of utmost importance. Water quality is monitored on an on-going basis through on-line instrumentation as well as composite samplers after every process step. In the event of any quality parameter exceeding an absolute value, the plant goes into recycle mode and water is not delivered. The final product water is also continuously sampled by way of online instrumentation and composite sampling and analyzed for the full range of parameters, inclusive of the pathogens *Giardia* and *Cryptosporidium*. Whereas viruses constitute a real threat in recycled wastewater, these are equally monitored and studied as an on-going research project. Virus studies worldwide are not plentiful or are in the research phase, and much work needs to be devoted to this subject.

The public of Windhoek is furthermore well informed through the media and a municipal newsletter of the importance of wise water use. An on-going water demand management campaign is aimed at and has been successful in reducing water consumption to the extent that it is currently estimated that a further reduction in demand of 13% would lead to an adverse effect on the economy of the city. Reclamation is well publicized and the new plant was launched by the President of the Republic of Namibia, with full TV and media coverage. The plant is often visited by schools and the scientific community, local as well as international. No consumer surveys have been conducted, but over the last 6 years, no consumer complaints have been lodged about the use of or quality of reclaimed water in Windhoek. The citizens of Windhoek have over time become used to the idea that potable re-use is included in the water provision process and they harbour a fair amount of pride in the fact that their city in many respects leads the world in direct reclamation.

7. Water quality guidelines

Due to the fact that direct potable reclamation is not widely practiced, specific water quality guidelines for reclaimed potable water were not readily available. The city therefore selected from relevant drinking water standards such as the Namibian Guideline, USEPA, EU, WHO and Rand Water (South Africa), and compiled a specification for treated water.

In order to ensure optimal performance of the process steps, intermediate treated water criteria were stipulated. These are aimed, for instance, at maximum organic removal through enhanced coagulation to extend carbon life and the effective removal of iron and manganese to protect the membranes. These criteria consist of target values and absolute values that have to be maintained. Failure to meet target values attracts performance failure penalties as described hereunder. Failure to meet absolute values precludes the delivery of water and causes the plant to go into recycle mode, until such target values are reached. The treated water specifications and the intermediate treated water criteria are given in Tables 1 and 2.

8. Operation and maintenance

From the inception of the project, it had been envisaged that the city itself would operate the new plant in the way it had operated the reclamation plant from 1969. The loan conditions of the European Investment Bank, however, dictated that the operation and maintenance of the plant would include the involvement of internationally recognized water sector players. This involvement would be for the term of the loan, which was 20 years.

As construction was already in progress, the options of BOO, BOT or BOOT were not available and the City of Windhoek decided on an operation and maintenance model. The city obtained the services of Stallard Burnsbridge, later Katalyst Solutions, to manage the international procurement process for an operator that would satisfy the criteria of the loan agreement.

The ultimate winner of this bidding process was a consortium of Vivendi Water (now Veolia),

Table 1
Treated water specifications

	Units	Target values (maximum UNO)	Absolute values (maximum UNO)
Physical and organoleptic constituents:			
Calcium carbonate precipitation potential	$CaCO_3$ mg/l	N/A	Must lie in range 0 to 8
Chemical oxygen demand	mg/l	10	15
Colour	mg/l Pt	8	10
Dissolved organic carbon	mg/l	3	5
Total dissolved solids	mg/l	Greater of 1000 or 200 above raw water	Greater of 1200 or 250 above raw water
Turbidity	NTU	0.1	0.2
UV_{254}	Abs/cm	N/A	0.06
Macro elements:			
Aluminium	Al mg/l	N/A	0.15
Ammonia	N mg/l	N/A	0.10
Chloride	Cl mg/l	Not removed by process	
Iron	Fe mg/l	0.05	0.1
Manganese	Mn mg/l	0.01	0.025
Nitrate and nitrite	N mg/l	Not removed by process	
Nitrite	N mg/l	Not removed by process	
Sulfate	SO_4 mg/l	Not removed by process	
Microbiological indicators:	Units		
Heterotrophic plate count	Per 1 ml	80	100
Total toliforms	Per 100 ml	N/A	0
Faecal coliforms	Per 100 ml	N/A	0
E. Coli	Per 100 ml	N/A	0
Coliphage	Per 100 ml	N/A	0
Enteric viruses	Per 10 l	N/A	Greater of 0 per 10 l or a 4 log removal
Faecal streptococci	Per 100 ml	N/A	0
Clostridium spores	Per 100 ml	N/A	0
Clostridium viable cells	Per 100 ml	N/A	0
Disinfection by-products:			
Total trihalomethanes	μg/l	20	40
Biological indicators:			
Chlorophyll *a*	μg/l	N/A	1
Giardia	Per 100 l	Greater of 0 per 100 l or a 6 log removal	Greater of 0 per 100 l or a 5 log removal
Cryptosporidium	Per 100 l	Greater of 0 per 100 l or a 6 log removal	Greater of 0 per 100 l or a 5 log removal

Note: Other parameters that are not included in Table 2 will be required to comply with the Rand Water Standards (RSA) for potable water as valid at the effective date. The treated water will not exceed the lower of the RSA limits or the background concentration for those parameters as found in the raw water.

Table 2
Intermediate treated water criteria

Treatment process/ parameters	Units	Target values	Target values (maximum UNO)[a]	Absolute values (maximum UNO)
After DAF:				
Turbidity	NTU	1.5 (exceeded by no more than eight readings in one day; readings are taken at 15-min intervals) 5.0 (exceeded by no more than four readings in one day; readings are taken at 15-min intervals)	5.0 (exceeded by no more than four readings in one day; readings are taken at 15-min intervals)	8.0 (absolute maximum peak reading; readings are taken by on-line measuring equipment at preset intervals and computed for 15-min intervals as per Section 2.21 of Annexure 9 Part 1)
After rapid sand filters:				
Turbidity	NTU	0.2 (exceeded by no more than four readings in one day; readings are taken at 15-min intervals)	0.35 (exceeded by no more than four readings in one day; readings are taken at 15-min intervals)	0.5 (absolute maximum peak reading; readings are taken by on-line measuring equipment at preset intervals and computed for 15-min intervals as per Section 2.21 of Annexure 9 Part 1)
Manganese	mg/l	0.03	0.05	N/A
Iron	mg/l	0.05	0.05	N/A
After ozonation:				
Ozone concentration	mg/l			Minimum (absolute minimum trough as registered by on-line measuring equipment)
COD	mg/l	25	25	N/A
DOC	mg/l	15	15	N/A
Microbiological, disinfection by-products and		According to Treated Water Specification (Table 2)		
After GAC filters:				
DOC	mg/l	5 (exceeded by no more than four readings; readings are taken at 15-min intervals)	5 (exceeded by no more than four readings in one day; readings are taken at 15-min intervals)	8 (absolute maximum peak reading; readings are taken by on-line measuring equipment at preset intervals and computed for 15-min te intervals as per Section 2.21 of Annexure 9 Part 1)

[a]Refer clause 5.5.5 of Part 1 of Annexure 11.

Berlinwasser International and VA Tech Wabag. A contract, the Private Management Agreement (PMA) was concluded, with work starting in September 2002, for a period of 20 years. During this period, the manager is responsible for the total maintenance of the plant, all scheduled replacements and specific hand back conditions, which are stipulated.

The PMA was crafted in a way that would provide maximum incentive to the manager to reach quality guidelines and to produce according to the requirements of the City. Payment to the manager consists of two parts or tolls, being the aggregate of the availability toll and the volumetric toll. Both these tolls are subject to performance failure factors and availability factors.

Failure to meet the daily treated water requirement would attract an availability factor (AF) of less than one, which would mean a percentage reduction in the availability rate. This rate could be further reduced through the application of performance failure factors (PFF), which could vary from 0.96 to 0.98 for every quality parameter breached. These PFFs are applicable to breaches of both intermediate and final water quality specifications.

In the event that the raw water does not meet specifications, the manager can opt to treat such water, but all quality guidelines/specifications remain in force. The manager would, however, be paid a raw water surcharge, based on the actual additional cost of treatment. The manager would furthermore pay for raw water consumed or wasted, and would pay a charge for the treatment of effluents emanating from the treatment process. This is very strong motivation to reduce waste and to optimize the processes for maximum recovery.

The payment due to the manager would then be computed as follows:

Treated water toll for the day = (availability toll for the day) + (volumetric toll for the day) + (raw water surcharge) − (raw water consumption) − (wastewater treatment)

During the first year of operation, the plant produced 5,955,347 m^3 of high-quality water at an average treatment cost per m^3 of N$2.76 (equal to US $0.46). If one the cost of capital is added, it would add a further N$1.84 to the price of water from the plant. The average price would then be N$4.69 or US $0.77/m^3. During the same period, the cost of water from the national bulk water supplier (surface water), was on average N$4.36 (US $0.73).

In the case of Windhoek, however, the value of water is not calculated in financial terms only, but in the value of security of supply. If one looks at the cost of alternatives, such as bringing water from the perennial rivers on the border, the cost of water increases fourfold. The investment in reclamation is therefore economically, financially and environmentally a sound one. What is evident, however, is that the cost of water is very sensitive to the quantity produced, and the City strives to have maximum production whenever possible.

9. Conclusions

The new plant went into operation in August 2002, and is being operated by WINGOC on a 20-year operation and maintenance contract. The plant is currently shut down due to a failure of the oxygen generation system but has delivered water of excellent quality over its first year of commercial operation.

From the Windhoek experience it is evident that treated domestic sewage can be successfully re-used for potable purposes. In the case of Windhoek, a combination of factors, with the lack of alternatives probably the most notable, makes direct potable reclamation a viable option, even in financial terms. It is furthermore evident that the technology exists to produce water which meets all drinking water guidelines and standards and to provide the user with an acceptable level of confidence as to the risk of potable re-use.

The main obstacle to newly introducing potable reclamation will, however, be public perception. It is the perception of the author that only in cases where no viable alternatives exist will it be possible to consider the introduction of direct potable reclamation. The use of reclaimed water to replace the use of potable water in non-drinking water uses such as industry, agriculture or artificial recharge of aquifers, should however be rigorously pursued.

The old Goreangab plant, on a reduced process train, provides reclaimed water for the irrigation of all sports fields and public parks in the city. In the very near future, all excess reclaimed water will be used to artificially recharge the Windhoek aquifer, albeit under very strong quality constraints.

Goreangab is an excellent example of one of the innovations practiced in a country with few resources, both natural and financial. Direct potable reclamation has proven in Windhoek that, if it is possible to overcome public prejudice, it is a viable option for arid countries and fits in very well into the concept of integrated water resources management.

Bibliography

[1] J. Haarhof, C.J. van der Walt and B.F. van der Merwe, Process design considerations for the Windhoek water reclamation plant, unpublished report, 1999.

[2] FMG–Joint Venture, Goreangab water reclamation plant, Design report to the City of Windhoek, 1998, unpublished.

[3] K Wolz, Reclamation of waste water at the new Goreangab water reclamation plant, Presented at the 4th Biennial Congress of the African Division of the International Association of Hydraulic Research, Windhoek, Namibia.

[4] I.B. Law, Advanced Reuse — From Windhoek to Singapore and Beyond, Water, May 2003, p. 44.