Water Science & Technology **Vol 55 No 1–2 pp 441–448** © IWA Publishing 2007

Water management in Windhoek, Namibia

J. Lahnsteiner* and G. Lempert**

*VA TECH WABAG GmbH, Siemensstrasse 89, 1210 Vienna, Austria
(E-mail: *josef.lahnsteiner@wabag.com*)

**Aqua Services and Engineering (Pty) Ltd, PO Box 20714, Windhoek, Namibia

Abstract For decades, the city of Windhoek in Namibia succeeded in stretching their limited potable water resources through strict water management, latterly including wastewater reclamation and direct potable reuse. An integrated approach was followed and proper policies were put in place. This was followed up with appropriate legislation, education, policing and technical and financial measures with the result that extreme water shortages were overcome even in times of severe droughts.

Keywords Direct potable reuse; wastewater reclamation; water demand management; Windhoek

Introduction

Namibia is amongst the most arid countries in the world as two deserts flank it, the Namib desert in the west and Kalahari desert in the east. More than 80% of the country consists of desert or semi-desert. Windhoek, the capital, is located in the Central Highlands approximately 1,540 m above mean sea level. The annual rainfall in Windhoek is approximately 370 mm, while the potential surface evaporation rate is in the range of 3,200–3,400 mm/a (Department of Water Affairs, 1988). The distance to the closest perennial river, the Okavango River, is 750 km and to the ocean approximately 300 km from Windhoek. The population of Windhoek is approximately 240,000 with a growth rate of 5% per year (natural population growth 1.5%, migration from rural areas 3.5%) (Van der Merwe, 2000).

The city's water supply is based on the use of surface and groundwater. All potable water resources within a radius of 500 km have been fully exploited. The rainfall is uncertain and long spells of severe droughts are frequently encountered. Therefore, the supply of water from the central Namibian reservoirs and wells cannot be guaranteed in the near future. Forced by this prediction, the city council of Windhoek approved an integrated water demand management programme in 1994 that included policy matters, legislation, education, technical and financial measures (Van der Merwe, 1994).

Water demand management in Windhoek

Van der Merwe (2000) studied Windhoek's water demand over many years and was fundamental in developing an integrated water demand management programme for the city. Total annual water consumption for the city is approximately 21 million m^3 per year, i.e. an average demand of 57,500 m^3/d. There are four main sources of water supply to the central area of Windhoek: surface water obtained from the Von Bach, Swakoppoort and Omatako dams; groundwater abstracted from 50 municipal production boreholes; reclaimed water recovered by suitable treatment from both the New Goreangab Water Reclamation Plant (NGWRP) and the Old Goreangab Water Reclamation Plant (OGWRP). Figure 1 shows water supply and utilisation for the city's overall water supply scheme, including wastewater reclamation and reuse.

doi: 10.2166/wst.2007.022

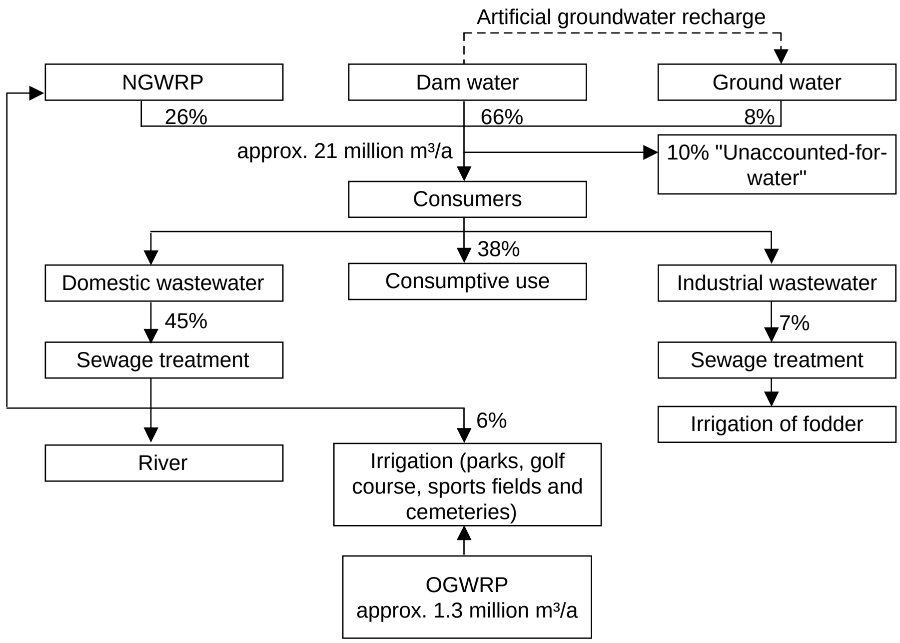

Figure 1 Water sources and water supply to Windhoek (modified for 2004 after Van der Merwe, 2000)

In years of average to good rainfall, surface water runoff from the catchment areas suffices to satisfy the potable water demand for Windhoek. During continuing years of dry spells 4 million m^3 potable water could be abstracted from the municipal boreholes over a period of 4 consecutive years.

The capacity of the NGWRP is 7.5 million m^3/a. Currently, the city uses 5.5 million m^3/a of this water, i.e. almost a quarter of the total water demand is supplied by the NGWRP. Treated water from the OGWRP is unsuitable for human consumption and is used for irrigation (5,000 m^3/d mainly for sport fields and a golf course). OGWRP is treating polluted Goreangab dam water and the treatment process consists of flocculation, dissolved air flotation, rapid sand filtration, granular activated carbon filtration and chlorine disinfection.

Industrial wastewater (1.5 million m^3/a), discharged mainly from a small food and beverage industry, is treated in anaerobic followed by aerobic ponds and reused for irrigation of pastures.

Municipal wastewater is treated in the Gammams Water Care Works. This is a nutrient removal plant comprising primary treatment followed by secondary treatment with biological nitrogen and phosphorus removal. Biological treatment consists of both an activated sludge process and trickling filters in parallel. Subsequently, the secondary effluent with a COD of approximately 60 mg/L is discharged into maturation ponds. These ponds have a retention time between 2 and 4 days and further COD reduction to approximately 30 to 40 mg/L takes place here. The final effluent of these ponds serves as raw water for the New Goreangab Water Reclamation Plant (NGWRP).

Borehole water, especially after a drought, needs to be artificially augmented and one of the options under investigation is to recharge the groundwater aquifer. Treated surface water with an additional granular activated carbon filtration step to mainly remove organic constituents, trihalomethanes and chlorine will be injected into the boreholes. Facilities to recharge groundwater have already been installed around the city and will be used in times of good rains and low water demand. Windhoek's estimated aquifer uptake capacity is at least 15 to 25 million m^3 and an annual recharge of 6–10 million m^3 should be possible. Underground, as opposed to surface water storage, will be very beneficial as the evaporation of millions of cubic metres from the surface reservoirs can be avoided resulting in higher water availability. Furthermore, the recovery period of an aquifer is substantially shortened by artificial recharge and this provides a higher security of water supply. This is especially important after severe droughts when too much water has to be abstracted from the aquifer.

The major policy issues within the integrated water demand management programme are maximum wastewater reuse and saving of water. Therefore, additionally to wastewater reclamation, the city of Windhoek has introduced special measures for the latter through municipal bylaws for water saving. During times of severe droughts, these measures are rigorously enforced. Table 1 summarises both the requirements of the water supply regulations and the method of implementation (Van der Merwe, 1999).

Consumption-related, progressive water pricing also played an important role towards achieving ambitiously set water-saving targets. As a typical example, water in 2004 was charged for as follows: $0\text{–}0.2\,m^3$ per day $= 0.58$ €/m^3; $0.201\text{–}1.8\,m^3$ per day $= 0.96$ €/m^3; $>1.8\,m^3$ per day $= 1.8$ €/m^3 (Municipality of Windhoek, 2004). Water savings achieved by households have been counterbalanced by population growth. This latter was mainly due to an above average influx to the capital of approximately 5% per year over the last 15 years, brought about by urbanisation. Per capita consumption has already been reduced to a minimum by technical improvements and exemplary public relation activities.

Technical measures implemented are mainly with regard to leakage control (lowering of "unaccounted-for-water") and proper watering of gardens. In order to reduce water losses both leakage detection and water audits are being done on a continuous basis. Additionally, repairs as well as systematic pipe replacement programmes have been

Table 1 Requirements of the water supply regulations and method of implementation (Van der Merwe, 1999)

Regulation requirement	Method of implementation
Prevention of undue water consumption on private properties	Wastage of water on a private property can be addressed immediately. Windhoek is the only city in Southern Africa with a water control officer
Water efficient equipment	As from 16 December 1996, the following is compulsory in new developments in the city: Metering taps must be used in hostels. Taps outside non-residential buildings must be self-closing or lockable. Only low flow showers are allowed. Toilet cisterns must be 6/3 L dual flush units. Automatic flushing devices without activation by the user are prohibited. Retrofitting of existing inefficient water devices is compulsory within 3 years.
Groundwater	Groundwater abstraction from private boreholes and groundwater levels is controlled.
Gardens	Watering may not be done during high evaporation times, i.e. between the hours of 10:00 and 16:00.
Swimming pools	Swimming pools must be covered when not in use.
Prevention of water pollution	Regular testing of groundwater fuel tanks is mandatory. All tanks were registered.

implemented and a proper management of water meters is done. Due to these measures, water losses in Windhoek are only 10%, which represents the lowest comparable value in Southern Africa. Even for cities in highly developed regions such as Western Europe, this represents a very low figure.

The new Goreangab water reclamation plant (NGWRP)

Regular droughts in Namibia and a continuous shortage of potable water to Windhoek have necessitated the municipality to investigate alternative sources of raw water supply. The most viable option proved to be reuse of municipal wastewater from the largest sewage treatment plant in Windhoek, the Gammams Water Care Works, with augmentation from a surface water source on the outskirts of the city, the Goreangab Dam. The orginal (now "Old") Goreangab Water Reclamation Plant was built over 30 years ago to reclaim municipal effluent for potable water purposes. This plant was upgraded and extended several times during the last 30 years but reached the end of its viable life span in the late 1990s and was also technologically no longer up to date. It was therefore decided to build a new, larger reclamation plant, the NGWRP, using the "multiple barrier" approach (see below). This plant was put into operation in mid-2002 and will now be further elucidated on.

The NGWRP produces 21,000 m^3/d of drinking water, safe for human consumption, at all times. To achieve the latter, a "multiple barrier" approach was taken during final selection of the process technology. This means that the treatment processes employed ensure that at least 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. For example, complete and/or partial barriers for one of the most resistant pathogens, *Cryptosporidium,* include ozonation, enhanced coagulation, dissolved air flotation (DAF), dual media filtration, ultrafiltration and chlorination. Similarly, five barriers have been included for organic substances, viz. enhanced coagulation, ozonation, biologically active carbon (BAC), granular active carbon (GAC) adsorption and ultrafiltration. This ensures both micropollutant removal and degradation and results in a substantial reduction of the THM formation potential (Table 2).

The following unit processes have been included in the final plant design (Figure 2) Powdered activated carbon (PAC) dosing, pre-oxidation and pre-ozonation, flash mixing, enhanced coagulation and flocculation, dissolved air flotation, dual media rapid gravity sand filtration, ozonation, BAC filtration, GAC filtration, ultra-filtration (UF), disinfection and stabilisation.

Guarantee values that the final water produced by the plant must adhere to were based on WHO Guidelines (1993), Rand Water (South Africa) Potable Water Quality Criteria (1996) and the Namibian Guidelines for Group A water (NamWater, 1998). Water samples are taken every 4 h at various points throughout the plant and analysed in the plant laboratory for basic quality control purposes. Refrigerated composite samples are taken twice per week and used for extensive analyses of all major water quality parameters as defined for guarantee values.

The process is fully automated based on a monitoring supervisory control and data acquisition (SCADA) system. Plant operation shows that the specified guarantee parameters can be easily met and a high quality drinking water is provided (Table 2). Blending the reclaimed water with treated surface water and/or groundwater provides additional safety. The maximum portion of reclaimed water fed into the distribution system is 50% in times of water scarcity and low water demand (winter season). Originally, it was decided to limit the maximum percentage of reclaimed water to 35% of the total potable water released into the distribution network (Du Pisani, 2006). This decision was based on a DOC value of approximately 5 mg/L for the final water produced in the

Table 2 Major quality parameters for NGWRP water

Parameters	Units	Raw water (design value)	Treated water (guarantee value)	WHO guidelines	EU directive	Commissioning results[a]	Current operating values[b]
Physical and chemical							
Turbidity	NTU	53	0.1	0.1[c]	[d]	0.08	0.11
DOC	mg/L	15	5			1.0	2.6
COD (dichromate)	mg/L	43	20			12.6	
THM	μg/L	169	20	[e]	100	11	34
Microbiological							
Giardia	per 100 mL	214	0 or log 6 removal			0	
Cryptosporidium	per 100 mL	334	0 or log 6 removal			0	
E. coli	per 100 mL	20,347	0		0	0	
Heterotrophic Plate Count	per 1 mL	332,150	80			8	
Elements							
Iron	mg/L	2.8	0.05		0.2	<0.05	0.06
Manganese	mg/L	0.9	0.005	0.4	0.05	<0.005	0.015

[a]Median at performance test
[b]City of Windhoek, 2005
[c]Recommendation for effective disinfection
[d]No abnormal change
[e]Guideline values: chloroform 0.2 mg/L, bromoform 0.1 mg/L, dibromochloromethane 0.1 mg/L, bromodichloromethane 0.06 mg/L

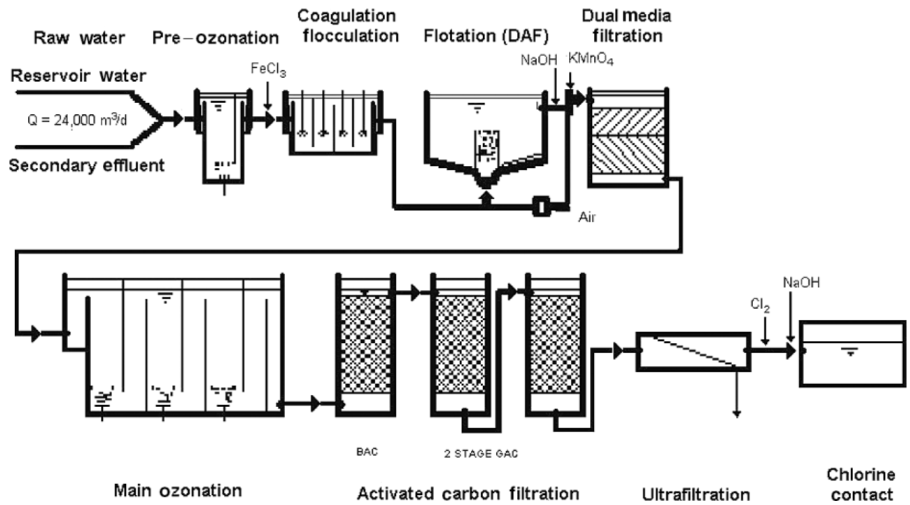

Figure 2 NGWRP process flow diagram

OGWRP and the corresponding THM formation potential in the distribution network after blending. Because the NGWRP constantly achieves DOC values ≤ 2.6 mg/L (City of Windhoek, 2005), the maximum ratio of reclaimed water to total potable water released into the distribution system was increased to 50%. Currently, the plant produces on average about 25% of total potable water demand for Windhoek.

The project has been financed by the Kreditanstalt für Wiederaufbau (40%), the European Investment Bank (55%) and the City of Windhoek (5%). Consultants were GFJ (South Africa), Multi Consult (Namibia) and Fichtner (Germany). The project was bid on a turnkey-basis with the final contractor consisting of a consortium between DB Thermal (at that stage representing WABAG Technology in Southern Africa) and Stocks Structures. The contractor had to take full process responsibility and the technology that was incorporated into the plant was based on WABAG technology.

The New Goreangab Water Reclamation Plant was started up in May 2002, with final hand-over on 2002 August 5 (DB Thermal, 2002). The plant was officially inaugurated on 2002 December 2.

Initially, raw water fed to the New Goreangab Water Reclamation Plant consisted of 50% secondary effluent and 50% surface runoff water from the Goreangab Dam. Currently, the portion of secondary effluent feeding the plant constitutes 90% secondary effluent, because the quality of Goreangab Dam water has deteriorated to a point where the raw water design parameters are far exceeded and usage thereof in the plant results in exceeding the final water specifications. Goreangab Dam water is currently only abstracted for treatment in the OGWRP and used for irrigation.

A 20-year operation and maintenance (O&M) contract has been concluded between the city of Windhoek and the Windhoek Goreangab Operating Company Ltd (WINGOC). In order to include as much specialist process and operating know-how, WINGOC is made up of three major international water treatment contractors: Berlinwasser International, VA TECH WABAG and Veolia Water.

The investment costs for the reclamation plant were approximately €12.5 million (2002): electrical and mechanical equipment, €8.3 million; civil works, €4.2 million. Total water production costs (2002/3) were €0.63/m^3 of which €0.25/m^3 constituted capital costs and €0.38/m^3 operational costs (from Du Pisani, 2006). This is slightly higher than the €0.61/m^3 that the national bulk water supplier charged for treated surface water during the same period, but certainly much lower than other options for importing water to Windhoek (e.g. transport from the Okavango River) would have cost.

With technology improving, designs should become simpler in future and a cost reduction can be expected. Also, other processes could be considered that may further reduce costs such as a two-stage membrane process, viz. ultrafiltration followed by reverse osmosis.

Partial desalination is also considered as a future process step for the NGWRP to stop or even reverse the ever-increasing salinity observed in the potable water supply to consumers in the city. The existing UF in the NGWRP consists of five trains and can be extended to six trains. An option would be, for example, to put 20 to 30% of the UF permeate additionally through RO membranes. If the permeate produced by the RO membranes is then blended with UF permeate, the final water salinity would be substantially reduced. Over time, this would also reverse the currently observed slowly increasing salinity of the potable water supplied to the consumers. (Potable water salinity has shown an approximate 50% increase over the past 50 years.)

Public awareness of water saving and acceptance of direct potable reuse

To increase both the level of awareness of water savings and the acceptance of direct potable reuse, the city of Windhoek has arranged adequate education programmes in schools, radio and television, as well as in the printed media. Evaluation of these programmes showed that the biggest benefit would be accomplished if water awareness forms part of the normal curriculum in schools.

Reclaiming drinking water from municipal secondary effluent is not generally acceptable to the public and psychological barriers have to be broken down first. However, with persistent and good marketing as done in the above-mentioned education programmes, this perception can be changed. The people of Windhoek have even derived some pride from the fact that they are the only city worldwide where direct potable water reuse is practised.

Since the beginning of potable reuse in 1968 in Windhoek, no outbreak of waterborne disease has been experienced and no negative health effects have been attributed to the use of reclaimed water. This forms a prerequisite for acceptance by the population and an indication for the trust by the latter in potable reuse is the fact that less than 5% of the population uses additional point source treatment in their homes.

Conclusion

Summarising the experience of Windhoek, it can be said that careful water management including direct potable reuse is required to secure the water supply to the city. With proper process design and quality management, water meeting stringent standards can be produced by reclamation and direct potable reuse can be practised. The public will accept such schemes if properly informed, despite initial health and aesthetic concerns. The operation of the New Goreangab Water Reclamation Plant represents a milestone for further similar projects. The Windhoek Water Management policy is exemplary and should be considered as a model for other arid regions.

References

City of Windhoek (2005). Advertisement by the Windhoek Goreangab Operating Company (Pty) Ltd. City of Windhoek Diary 2006.

DB Thermal Pty Ltd (2002). Goreangab Water Reclamation Plant Taking Over Certificate. City of Windhoek, 5 August 2002

Department of Water Affairs (1988). *Evaporation map for Namibia*. Report No: 11/1/8/1/H1, October 1988, p.11.

Du Pisani, P.L. (2006). Direct reclamation of potable water at Windhoek's Goreangab reclamation plant. In: *Desalination.* Elsevier.

Municipality of Windhoek (2004). Department of Infrastructure Water and Technical Services Division: Bulk and Waste Water, Government Gazette No. 3228, 1 July 2004.
NamWater (1998). Guidelines for the evaluation of drinking-water for human consumption with regard to chemical, physical and bacteriological quality. Namibia Water Corporation Ltd., Namibia.
Van der Merwe, B.F. (1994). Water demand management in Windhoek, Namibia. Internal Report, City Engineer's Department, Windhoek Municipality.
Van der Merwe, B.F. (1999). Report of the Namibian Ministry of Agriculture, Water and Rural Development and City Engineer (Water Services) City of Windhoek to the International Conservation Union on Water Demand Management, Country Study Namibia, edited by Ben van der Merwe, Namibia.
Van der Merwe, B.F. (2000). Integrated water resource management in Windhoek, Namibia. *Water Supply*, **18**(1), 376–380.