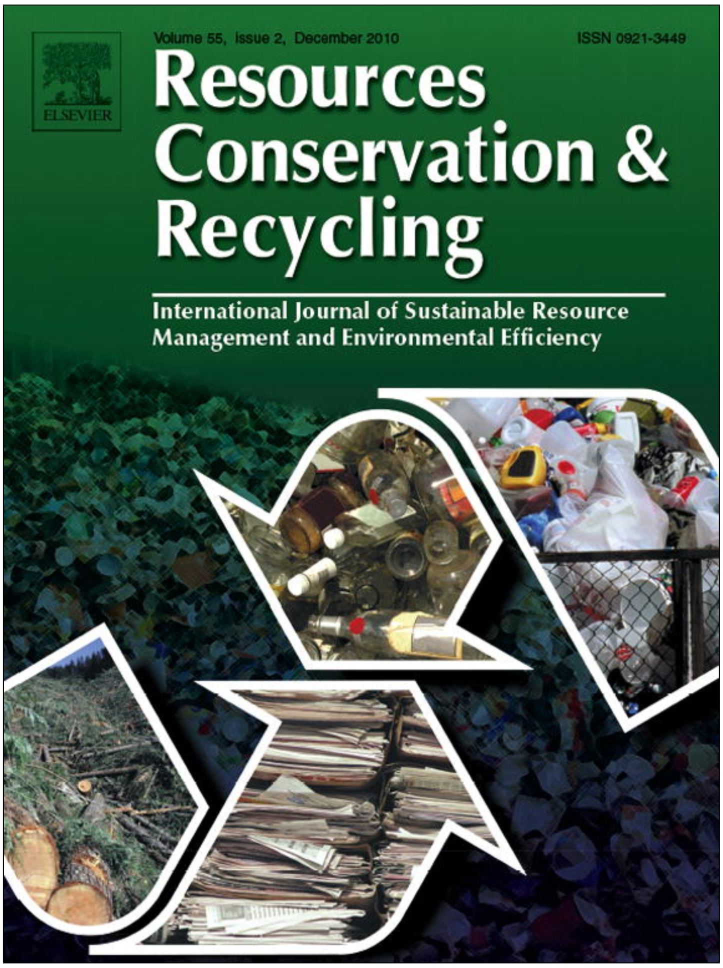
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Treated wastewater reuse in South Africa: Overview, potential and challenges

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ABSTRACT

Many communities in South Africa struggle to access reliable and adequate quantities of potable water for diverse water requirements. This is against the backdrop of decreasing freshwater availability and increasing water demands. Currently, interest in the reuse of wastewater for non-drinking water requirements is increasing. This paper therefore provides an overview of the South African water resources situation and wastewater[1] generation in order to put the need for wastewater reuse into perspective. Potential for broader implementation and parameters influencing wastewater reuse based on local attitudes and experience were discussed with recommendations to facilitate broader implementation of wastewater reuse. This paper concludes that significant potential exists for implementing wastewater reuse for large non-drinking applications (e.g. landscape irrigation and industrial processes) in arid areas of South Africa especially Western Cape Province. Parameters highlighted from local attitudes and experience to influence broader implementation in addition to aridity include distance from source, retrofitting versus new installations, quantity of reuse, tariffs, source quality, public health, willingness, public trust and knowledge, and regulations and guidelines for reuse. Prior to implementation, it is recommended that these parameters be addressed.

1. Background and motivation

South Africa is a semi-arid country with high water stress (40–60%) due to the low volumes of rainfall (average of 500 mm per annum) and high evaporation (average of 1700 mm per annum) (Eberhard and Robinson, 2003). The highly variable and spatial distribution of rainfall across the country adds to the scarcity of fresh water. South Africa depends on surface water for most of its urban, industrial, and agricultural requirements with about 320 dams providing a total capacity of about 32,412 × 10^6 m^3 (DWAF, 2004a). Groundwater plays an important role but mostly in rural water supply schemes, with only a few groundwater aquifers that can be utilised on a large scale due to groundwater salinity in especially the coastal areas of the country (Mukheirbir, 2005). To manage existing water resources therefore, the country's hydrological basins have been divided into 19 water management areas (Fig. 1) with mean annual runoff of approximately 49,040 × 10^6 m^3/a. This includes water inflows of about 4800 × 10^6 m^3/a and 700 × 10^6 m^3/a originating from Lesotho and Swaziland respectively (DWAF, 2004a).

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[1] Wastewater refers to domestic, institutional, and industrial liquid waste products collected through networks of pipes (sewers) into treatment plant.

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1.1. Current water yield and requirements

Surface water yield in rivers as shown in Table 1 was computed as 10,240 × 106 m^3/a using mass curve analysis of the available reservoirs (dams) at 98% assurance of supply. To satisfy ecological flow requirements, 20% of the flow is assumed to remain in rivers to maintain a healthy biophysical environment. The Annual groundwater harvest potential is derived from an evaluation of the mean annual recharge of groundwater (adjusted for drought period rainfall). This gives an indication of the maximum volume of groundwater that may be abstracted without depleting the aquifers as 1088 × 106 m^3/a. The numerical data given in Table 1 with respect to yield and available water is therefore accepted as being of relatively high reliability. However, the figures are subject to review in future as some of the influencing factors change and as new extreme climatic events are observed over time (DWAF, 2004a).

The difference between the mean annual runoff (49,040 × 10^6 m^3/a) and the total freshwater yield from surface and groundwater sources (11,328 × 10^6 m^3/a) (Table 1) shows the significant effect that river losses (due to evaporation and seepage) have on freshwater availability in South Africa. The negative yields from surface water in the Middle Vaal, Lower Vaal and Lower Orange water management areas reflect the fact that river losses are greater than the additional yield contributed by local runoff in these areas. Usable return flows (i.e. treated wastewater),

Table 1
Available yield from water management areas in 2000 (DWAF, 2004a).

Water management area	Freshwater source (million m^3/a)		Usable return flows (million m^3/a)			Total local yield (million m^3/a)
	Surface water	Ground water	Irrigation	Urban	Mining and bulk industrial	
Limpopo	160	98	8	15	0	281
Luvuvhu/Letaba	244	43	19	4	0	310
Crocodile West and Marico	203	146	44	282	41	716
Olifants	410	99	44	42	14	609
Inkomati	816	9	53	8	11	897
Usutu to Mhlatuze	1019	39	42	9	1	1110
Thukela	666	15	23	24	9	737
Upper Vaal	598	32	11	343	146	1130
Middle Vaal	(67)	54	16	29	18	50
Lower Vaal	(54)	126	52	0	2	126
Mvoti to Umzimkulu	433	6	21	57	6	523
Mzimvubu to Keiskamma	777	21	17	39	0	854
Upper Orange	4311	65	34	37	0	4447
Lower Orange	(1083)	24	96	1	0	(962)
Fish to Tsitsikamma	260	36	103	19	0	418
Gouritz	191	64	8	6	6	275
Olifants/Doring	266	45	22	2	0	335
Breede	687	109	54	16	0	866
Berg	403	57	08	37	0	505
Overall	10,240	1088	675	970	254	13,227

which comprise about 14% of the overall yield and approximately double the groundwater yield, are indirectly reused for potable supply i.e. extracted by drinking water treatment works from surface waters after discharge from wastewater treatment works (WWTWs) a distance upstream. With the aridity of the region and the substantial quantities of usable return flows generated daily, this paper argues for the direct reuse of these return flows for some non-drinking applications.

In relation to water use, six broad categories totalling $12{,}871 \times 10^6$ m^3/a (Table 2) were published by DWAF (2004a) i.e. rural (domestic and stock watering), urban (domestic, commercial and public), mining and industry, power generation, irrigation and afforestation. Irrigation makes up approximately 62% of the total water used and hence, any water savings in this sector will be beneficial to other needy sectors. Total water requirement of $12{,}871 \times 10^6$ m^3/a (Table 2) is noticeably close to the estimated overall yield of $13{,}227 \times 10^6$ m^3/a (Table 1) with water deficits existing in more than half of the water management areas, whilst a surplus still exists for the country as a whole (Table 3). In several cases, the deficits shown do not imply that present use exceeds available yield, but rather that the ecological reserve is not fully met (DWAF, 2004a). Also, inter basin transfers are often employed to address water supply shortfalls (Mukheirbir, 2005).

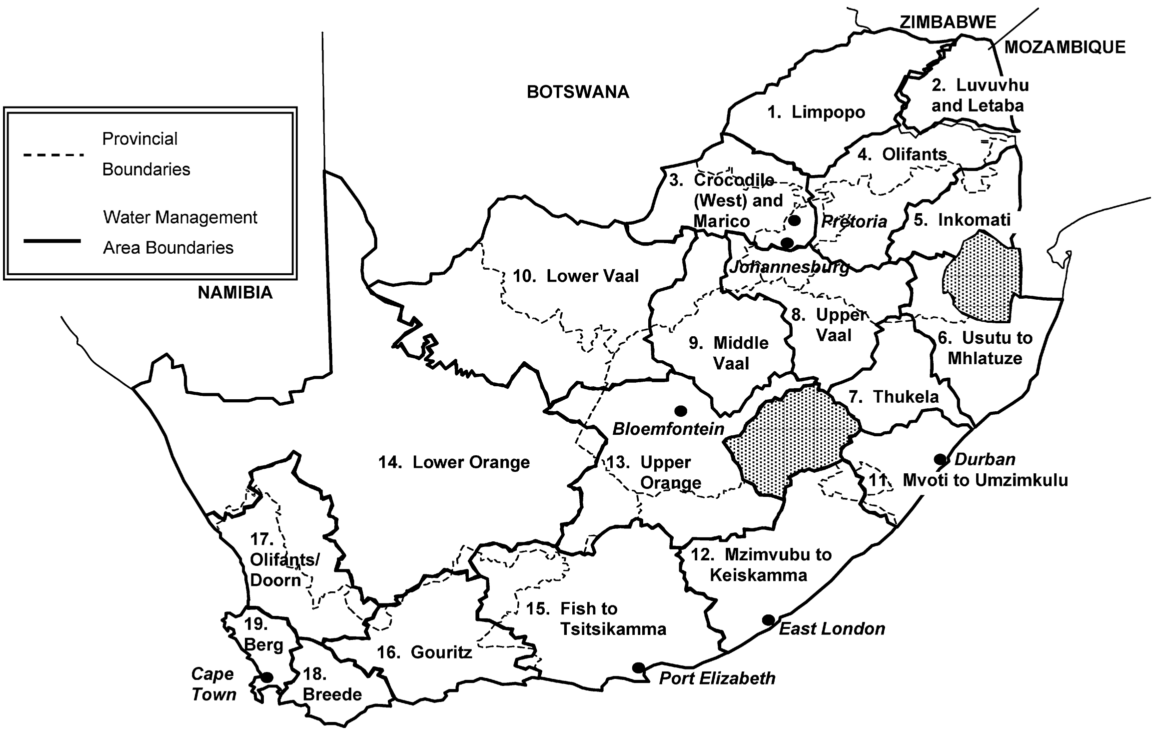

Fig. 1. Map of South Africa showing water management areas (DWAF, 2004a).

Table 2
Water requirement (million m^3/a) in the various sectors in 2000 (DWAF, 2004a).

Water management area	Irrigation	Urban	Rural	Mining and industry	Power generation	Afforestation	Total requirement
Limpopo	238	34	28	14	7	1	322
Luvuvhu/Letaba	248	10	31	1	0	432	333
Crocodile West and Marico	445	547	37	127	28	0	1184
Olifants	557	88	44	94	181	3	967
Inkomati	593	63	26	24	0	138	844
Usutu to Mhlatuze	432	50	40	91	0	104	717
Thukela	204	52	31	46	1	0	334
Upper Vaal	114	635	43	173	80	0	1045
Middle Vaal	159	93	32	85	0	0	369
Lower Vaal	525	68	44	6	0	0	643
Mvoti to Umzimkulu	207	408	44	74	0	65	798
Mzimvubu to Keiskamma	190	99	39	0	0	46	374
Upper Orange	780	126	60	2	0	0	968
Lower Orange	977	25	17	9	0	0	1028
Fish to Tsitsikamma	763	112	16	0	0	7	898
Gouritz	254	52	11	6	0	14	337
Olifants/Doring	356	7	6	3	0	1	373
Breede	577	39	11	0	0	6	633
Berg	301	389	14	0	0	0	704
Total for country	7920	2897	574	755	297	428	12,871
	62%	23%	4%	6%	2%	3%	100%

1.2. Future water requirements

Many factor such as climate, economic growth (i.e. irrigated agriculture and industrialization) and standards of living influence the requirements for water in South Africa. The major changes in national policies since 1994 have influenced migration into urban area and decline in population of rural areas. However, negative impact of HIV/AIDS on the country is a clear indication that future population cannot be a simple extension of the past. Detailed study of the demographic and socio-economic changes in the country shows that there is lower population growth rate than previous years (DWAF, 2004a). Estimation of future water demand was based on the division of the entire country into smaller geographic units with great attention given towards urbanisation and the expected stronger economic growth in the major urban and industrial estate. Low and high economic growth scenarios for different geographic regions of the country were developed and analysed. The result (Table 4) shows an upper scenario of average growth in GDP of over 4% per year for the period up to 2025, and a less favourable low growth scenario of 1.5% per year (DWAF, 2004a). Climate variability due to global warming could lead to reduction in stream flow by as much as 10% by 2025 in South Africa (Mukheirbir, 2005). Whilst the effect of climate change has been observed and acknowledged internationally, the effect of likely changes in climate on water resource is yet to be fully established in South Africa, hence, it was not included in the future water requirements estimation. However, in anticipation of possible climatic change, special attention has been given to it in catchment monitoring program of DWAF (DWAF, 2004a).

With the aridity of the region, water use approaching water yield and the incessant pollution of surface and groundwater resources, municipalities are challenged to explore alternative sources and efficiently manage water use and supply. Few municipalities have been proactive in these initiatives. However, some municipalities, for instance in the Western Cape Province, have implemented several demand management mechanisms to curb growing demands in the face of declining freshwater availability. These include water restrictions, pressure management, monitoring of water usage,

Table 3
Available yield versus water requirement from water management areas in 2000 (DWAF, 2004a).

Water management area	Total local yield (million m^3/a)	Total requirement (million m^3/a)	Differences (million m^3/a)	
			Surplus	Deficit
Limpopo	281	322		41
Luvuvhu/Letaba	310	333		23
Crocodile West and Marico	716	1184		468
Olifants	609	967		358
Inkomati	897	844	53	
Usutu to Mhlatuze	1110	717	393	
Thukela	737	334	403	
Upper Vaal	1130	1045	85	
Middle Vaal	50	369		319
Lower Vaal	126	643		517
Mvoti to Umzimkulu	523	798		275
Mzimvubu to Keiskamma	854	374	480	
Upper Orange	4447	968	3479	
Lower Orange	(962)	1028		1990
Fish to Tsitsikamma	418	898		480
Gouritz	275	337		62
Olifants/Doring	335	373		38
Breede	866	633	233	
Berg	505	704		199
Overall	13,227	12,871	5126	4770

Table 4
Future water requirements and available total local yield (including potential for further development) for the year 2025 (DWAF, 2004a).

Water management area	Total local yield including further development (million m^3/a)	Low growth scenario (million m^3/a)	High growth scenario (million m^3/a)
Limpopo	295	347	379
Luvuvhu/Letaba	405	349	351
Crocodile West and Marico	1084	1438	1898
Olifants	665	1075	1143
Inkomati	1036	914	957
Usutu to Mhlatuze	1124	728	812
Thukela	776	347	420
Upper Vaal	1486	1269	1742
Middle Vaal	67	381	415
Lower Vaal	127	641	703
Mvoti to Umzimkulu	614	1012	1436
Mzimvubu to Keiskamma	886	413	449
Upper Orange	4755	1059	1122
Lower Orange	(956)	1079	1102
Fish to Tsitsikamma	452	988	1053
Gouritz	288	353	444
Olifants/Doring	337	370	380
Breede	897	638	704
Berg	602	829	1304
Overall	14,940	14,230	16,814

water meter management, installation of water efficient devices, the planting of water efficient vegetation, promoting retrofitting, communication and education, and the promotion of wastewater reuse (CoCT, 2006).

The quality of water needed for some non-drinking applications such as landscape irrigation, toilet and urinal flushing, and a variety of industrial processes, need not be of the same quality required for drinking applications. However in practice in South Africa, drinking water of the highest quality is often used for these non-drinking applications. This practice is unsustainable considering the overview above and hence, wastewater reuse for some non-drinking water requirements presents a promising alternative. In light of the overview of the South African water resources situation presented above and the need for wastewater reuse, this paper is therefore aimed at:

(i) providing an overview of wastewater reuse in South Africa and the potential that exists for broader implementation;
(ii) highlighting the parameters influencing wastewater reuse based on local attitudes and experiences; and
(iii) providing recommendations to facilitate broader implementation of wastewater reuse in South Africa.

2. Wastewater reuse in South Africa

Wastewater reuse involves the collection and treatment of wastewater so that it may be used for certain applications. Wastewater reuse can form an important component of both wastewater management and water resource management and can offer an environmentally sound option for managing wastewater that dramatically reduces environmental impacts associated with the discharge of wastewater to surface waters. In addition, reuse can provide an alternative water supply for many activities that do not require drinking water quality and as such, permit the saved drinking water to be used elsewhere. Costly projects for drinking water supply may also be delayed due to the reduced demand for drinking as a result of reuse. Lastly, reuse is attractive in many communities because the cost of producing treated wastewater has been found to be lower than the cost of producing drinking water. These reasons form the major drivers for wastewater reuse in many communities across the world. The most significant restraints to reuse include the potential risks to public health, and the potential for reduced sewer or stream flows. If implemented under uncontrolled or unregulated circumstances, treated wastewater can be harmful to living beings (if ingested directly or through irrigated crops) and irrigated soil (due to the chemicals and potential bacteria within the effluent). Reduced sewer flows can result in blocked sewers whilst reduced stream flows can be detrimental to activities extracting certain flow quantities downstream (Ilemobade et al., 2008; IWA, 2008).

Wastewater reuse has formed an essential component of water demand management (WDM) in many countries like Jordan, Kuwait, Israel, Spain, Australia, Namibia, Germany, United Kingdom, and the United States of America (IWA, 2008). With the broad range of effective wastewater treatment technologies that exist and records of successful wastewater reuse implementation in many of these countries, it has become imperative to evaluate the potential of wastewater reuse as a viable alternative in the drive towards overcoming the challenges of current and future water shortages in South Africa. Although there has been limited uptake of this alternative in many communities within South Africa, a few reuse schemes have been identified. Brief overviews of these schemes are presented below using the categories of reuse published by Dimitriadis (2005) and Mckenzie et al. (2003) i.e. household, district, wide-area urban/agricultural and industrial reuse.

2.1. Household wastewater reuse

This category of reuse involves the collection of wastewater which is processed and used for non-drinking requirements within the same building (single- or multiple-dwellings) that generated the wastewater. Examples of this category in South Africa are found in Carnarvon, the Northern Province and Hull Street in Kimberly, the Free State Province:

Carnarvon is a village. Before 2005, the management of domestic wastewater (bath, shower and kitchen water) had placed a heavy financial and environmental burden on the municipality and residents. At the time, 800 of the households within the community collected and stored their wastewater in containers on a daily basis, as infrastructure for the discarding of wastewater did not exist. Municipal workers then collected this wastewater twice a week using a truck, and dumped the wastewater at the existing WWTWs. Different wastewater recycling systems were then investigated. The preferred system requires residents to convey their household wastewater into a 50 L drum via a filter trap and sump. A submersible pump in the drum kicks in automatically as the sump fills up. The water is then pumped through a hose and sprinkler

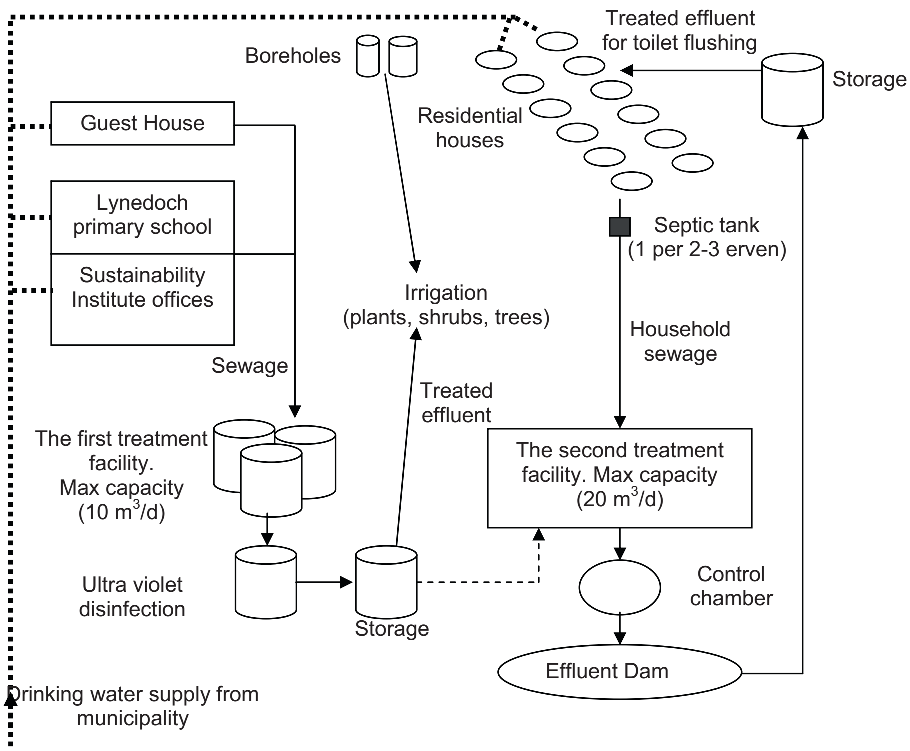

Fig. 2. Schematic of the drinking water and wastewater reuse system within the Lynedoch Eco-village.

onto the garden for irrigation. When the sump is almost empty, the pump turns itself off. After the pilot phase, awareness workshops on operation and maintenance of the wastewater recycling units were conducted with households committing themselves to operating and maintaining the systems (Ilemobade et al., 2008).

In Hull Street, Kimberly, each double-storey house is equipped with a dual water reticulation system (a system consisting of separate pipes that supply drinking and treated wastewater to separate uses). Wastewater from washing machines is channelled using PVC pipes to irrigate lawns above the ground surface whilst wastewater from kitchen sinks is channelled using rock-filled trenches to irrigate lawns below the surface. Each rock-filled trench contains fat traps, a mulch layer made from gravel, sisal and saw dust, removable plastic baskets to catch large particles, and geotextile material (WASE Africa, 2006).

The dual systems were implemented in such a manner that each household could easily carry out operation and maintenance tasks. Where regular maintenance was neglected, many of the systems failed. In Carnavon, the indiscriminate use of filtered wastewater poses a threat to especially children and pets that regularly use the irrigated lawns, and may have negative long term environmental consequences due to the accumulation of undesirable chemicals within the irrigated soil.

2.2. District wastewater reuse

This category of reuse involves the collection of wastewater at a central location from multiple buildings. The effluent is then processed and used for non-drinking uses within the same or other buildings. This may include large housing developments. An example of this category of reuse in South Africa is found in the Lynedoch Eco-village, Western Cape Province. The Lynedoch Eco-village is a pilot sustainability project with 'zero waste' as one of its targets. It was founded in 1999 and is managed by a non-profit company, the Lynedoch Development Company (LDC).

According to Dowling (2007), the dual water reticulation system at the Lynedoch Eco-village was designed in response to the following:

(i) the scarcity of future water supplies to the Western Cape Province;
(ii) the increasing tariffs of drinking water over the next 20 years due to the need to introduce new dams, ground water aquifers or desalination;
(iii) the necessity to achieve eco-efficiency through the recycling of wastewater. Nutrients present in wastewater are beneficial and can adequately replace chemical fertilizers (Panichsakpatana, 2007).

To achieve the objective of wastewater reuse in Lynedoch, two WWTWs were implemented (Fig. 2).

The first treatment facility is an engineered micro-ecology consisting of a peat filter inoculated with earth worms to deal with the effluent solids within an aerobic environment. This is intended at turning the wastewater into a viable resource (i.e. treated wastewater loaded with nitrogen and phosphorus) for irrigation. The second treatment facility (a Vertically Integrated Wetland) produces treated wastewater that is low in nutrients (nitrogen and phosphorus) to be used for household toilet flushing. About 54% savings in drinking water has resulted from wastewater reuse in all the households for the months of April 2006 to January 2007 as is shown in Table 5.

Operation and maintenance of the dual system is carried out by employees of the Development Company and this has facilitated system sustainability. However, overall costs of producing the effluent were about 400% (for the first treatment facility) and 300% (for the second treatment facility) above the drinking water tariff. Hence, although the system may not have been economically viable, it achieved the goals of supplementing drinking water supply (by 54% over 10 months) and promoting eco-efficiency.

Table 5
Drinking water savings due to wastewater reuse in the Lynedoch Eco-village (Dowling, 2007).

Month	Recycled wastewater (L)	Municipal water (L)	Total water (L)	Drinking water Savings (%)
April 2006	42,204	32,361	74,565	57
May 2006	50,445	23,145	73,590	69
June 2006	36,816	97,990	134,806	27
July 2006	76,058	109,619	185,677	41
August 2006	81,655	68,199	149,854	54
September 2006	97,455	63,103	142,558	56
October 2006	54,404	43,996	98,400	55
November 2006–January 2007	376,405	243,114	619,519	61
Total	815,442	681,527	1,496,969	54

Table 6
Formal wastewater reuse within the City of Cape Town (CoCT, 2007).

Wastewater treatment works	Volume of treated wastewater reused (Ml/d)	Reuse activities (%)		
		Sport field/landscape irrigation	Industries	Agriculture
Bellville	4.10	28	71	
Kraaifontein	2.10	100		
Macassar	2.00	100		
Parow	1.50	100		
Potsdam	27.60	9	48	43
Scottsdene	0.70	100		
Wesfleur (Atlantis)	0.30	100		
Total	39.90			

Table 7
Informal wastewater reuse within the City of Cape Town (CoCT, 2007).

Wastewater treatment works	Volume of wastewater reused (Ml/d)	Reuse activities (%)		
		Sport field/landscape irrigation	Industries	Agriculture
Athlone	3.00	100		
Borcherds Quarry	2.00	100		
Cape Flats	4.60	100		
Gordonsbay	0.50	100		
Kraaifontein	5.50			100
Melkobs Strands	2.00	100		
Potsdam	2.40	100		
Scottsdene	5.00			100
Total	25.00			

2.3. Wide-area urban/agricultural reuse

This category of reuse involves the collection of wastewater at a central location from domestic and non-domestic sources within an urban/agricultural area. The effluent is then processed and used for non-drinking requirements at the sources of generation or elsewhere. This category of reuse in South Africa is found in the eThekwini metropolitan authority, the Kwazulu-Natal Province and the CoCT, the Western Cape Province:

In the KwaZulu-Natal Province, a Public-Private Partnership exists between the eThekwini Unicity Council and private investors in the production of treated wastewater for industrial applications. The WWTWs is designed to treat 47.5 Ml/d of domestic and industrial wastewater with about 74% of the treated wastewater supplied to MONDI Paper.[2] The treated wastewater produced meets or exceeds the South African drinking water standards (DWAF, 2004b) in 95% of the parameters measured. Significant benefits of this project have included:

- delayed capital investment for increased marine outfall pipeline;
- delayed capital investment for future bulk potable water supply infrastructure;
- creation of long-term revenue from a levy raised on the production of recycled water;
- reduced cost of water services to Durban's citizens; and
- a 44% reduction in the 2001 water bill for MONDI Paper.

In the Western Cape Province, the CoCT stands out as one of the very few local authorities in South Africa that has operated a wastewater reuse system for several decades. Reuse has therefore become a vital component of the city's integrated water management plan. Treated wastewater is supplied from participating WWTWs to several large scale irrigation and industrial users. Wastewater reuse in the CoCT is grouped as follows:

(i) Formal (direct) reusers of wastewater: this group of users are connected to a treated wastewater pipe network of 2527 km from seven WWTWs. The pipe network is funded and operated by the local authority (Table 6).
(ii) Private (direct) users of wastewater: these are users who privately fund and operate the treated wastewater pipe networks from the participating WWTWs (e.g. Century City and Steenberg golf estate from the Cape Flats WWTWs). These schemes withdraw approximately 14.5 Ml/d of treated wastewater.

[2] Integrated packaging and business paper producing company.

Table 8
Potential for wastewater reuse in the City of Cape Town (CoCT, 2007).

Wastewater treatment works	Plant capacity (Ml/d)	Current reuse (Ml/d)	Potential reuse (Ml/d)			Total potential reuse (Ml/d)
			Sport field/landscape irrigation	Industry	Agriculture	
Athlone	120.00	3.00	10.68	2.33	0.00	13.00
Bellville	56.00	5.70	9.99	3.99	0.00	13.99
Borcherds Quarry	30.00	2.00	n/a	n/a	n/a	n/a
Cape Flats	200.00	4.60	8.62	0.00	0.00	8.62
Gordonsbay	3.50	0.50	1.306	0.00	0.00	1.31
Kraainfontein	18.80	7.60	0.33	0.00	0.00	0.33
Macassar	35.00	2.00	7.56	0.00	0.00	7.56
Melkbos Strands	3.10	2.00	2.00	0.00	0.00	0.00
Mitchells Plain	37.50	0.00	6.06	0.00	0.00	6.06
Parow	1.50	1.50	0.38	0.00	0.00	0.38
Philadelphia	0.08	0.00	0	n/a	n/a	n/a
Potsdam	32.00	30.00	4.35	0.12	15.00	19.47
Scottsdene	7.50	5.70	2.05	0.00	0.00	2.05
Wesfleur (Atlantis)	14.00	0.30	1.56	0.00	0.00	1.56
Wildevoelvlei	14.00	0.00	4.75	0.00	0.00	4.75
Zandvlet	55.00	0.00	4.47	0	0.00	4.47
Total	627.98	64.90	64.12	6.44	15.00	83.55

(iii) Informal (indirect) users of wastewater: a significant number of these users are unregulated and withdraw treated wastewater from downstream points along a surface water source after discharge from the participating WWTWs. These include some golf courses from the Athlone treatment works and agricultural users from Kraaifontein and Scottsdene (Table 7).

(iv) Groundwater recharge: in Atlantis, drinking water is supplied primarily from the Atlantis aquifer with extensive recharge occurring using treated domestic wastewater. Two large infiltration basins, covering an area of approximately 500,000 m^2 exist some 500 m upstream of the drinking water extraction point. These basins recharge to the order of about 200 Ml/a (Murray et al., 2007).

The CoCT supplies treated wastewater to only large non-domestic consumers. Public safety and costs of retrofitting are the major reasons why domestic consumers are not allowed access to the effluent. Tariffs for treated wastewater in the city are on average, 50% less than drinking water tariffs and hence, financially attractive for large non-drinking water consumers.

2.4. Industrial wastewater reuse

This category of reuse involves the on-site collection, processing and non-drinking use of wastewater from industrial processes. This category of reuse in South Africa is found in especially mining communities e.g. the Gold Fields gold mine in Driefontein. The Gold Fields gold mine is located at the outskirts of Carletonville, Gauteng province, south west of Johannesburg. It has four WWTWs that produce about 10.36 Ml/d of treated wastewater. 1 Ml/d of this effluent is used for flushing communal toilets at one of the high density residences and for landscape irrigation. This practice has existed for a number of years and proven to be successful with no recorded incidents of compromised public health (Ilemobade et al., 2008).

2.5. Potential for wastewater reuse in South Africa

The overview of wastewater reuse above shows some valuable experience of wastewater reuse in South Africa that presents a strong argument for the broader implementation in many arid South African communities. Table 1 also shows that significant quantities of usable return flows from the different water management areas may be exploited for reuse thereby reducing their pollution effects on the existing rivers. For this reason, several studies have been commissioned to investigate the potential for wastewater reuse in many areas. An extract for a study undertaken for the CoCT is shown in Table 8 (CoCT, 2007). The study concludes that significant opportunities exist within the CoCT for extending current reuse to other large non-domestic consumers of water for non-drinking applications.

Table 9
Spread of questionnaire respondents.

Type of institution	Number of questionnaires administered	Number of responses
Private landscape irrigation (i.e. educational institutions and professional sports clubs)	19	9
Public landscape irrigation	4	2
Crop growing irrigation	1[a]	1[a]
Petroleum refining	2	1[b]
Pulp and paper manufacturing	3	1
Textile manufacturing	1	0
Construction	2	2
Mining	2	1
Total	34	17

[a] A group representing about 30 farmers.
[b] The only respondent not located within the CoCT.

3. Parameters influencing the potential for wastewater reuse in the City of Cape Town in Western Cape Province

In addition to the survey of existing reuse schemes presented above, a questionnaire was developed and administered to several large users of treated wastewater in order to determine parameters which influence the potential for wastewater reuse in South Africa. A significant number of the questionnaires were administered within the CoCT due to the large number of users located within the City. Sixteen of the seventeen questionnaires returned were from the CoCT (Table 9). Participation in the survey was severely limited by potential respondents who either felt the information requested was confidential or could be misinterpreted. Twelve of the seventeen respondents reuse wastewater for mainly irrigation.

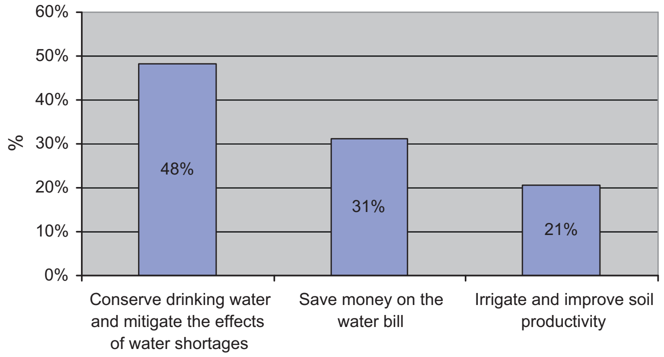

Fig. 3. Drivers for wastewater reuse amongst respondents.

For each of the parameters highlighted below, a brief discussion follows on their influence (positive or negative) on reuse implementation.

3.1. *Aridity and growing water demands*

The South African water resources situation in many areas is characterised by water requirements approaching available yield (Tables 1 and 2). This, as explained earlier, is caused by climatic conditions, which negatively influence freshwater water yields in the face of growing water demands. This situation has therefore stimulated a willingness in many arid areas (e.g. in the Western Cape, Northern Cape and Limpopo provinces) to reuse wastewater. Forty-eight percent of the respondents indicated that the extent of aridity predominantly drove their need to reuse wastewater (Fig. 3). An implication of this is that communities more likely to embrace wastewater reuse are communities in arid areas that typically experience drinking water restrictions, limited access to drinking water, and high drinking water tariffs.

3.2. *Distance from source*

For wide-area urban reuse, the capital costs of laying pipelines to convey treated wastewater from WWTWs to potential users is significant. In the CoCT for instance, as distance from the treated wastewater source increased beyond 500 m, less and less respondents were willing to use the resource (Fig. 4)—thus indicating that distance from the WWTWs played a role in large consumers choosing to (or not to) reuse wastewater via a wide-area urban reuse system.

3.3. *Retrofitting versus new installations*

In new developments, wide-area urban reuse may be implemented from project inception thus lowering installation costs (in comparison to retrofitting)—drinking water pipes would generally be smaller since an integrated design involving drinking and

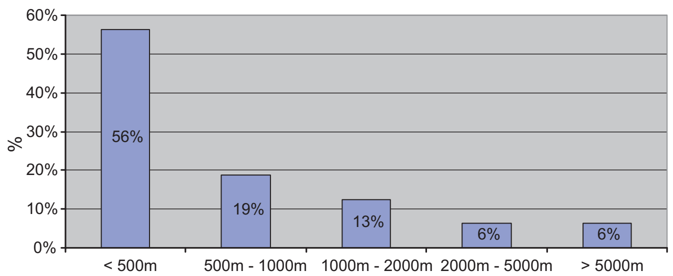

Fig. 4. Distance of wastewater treatment works from respondents.

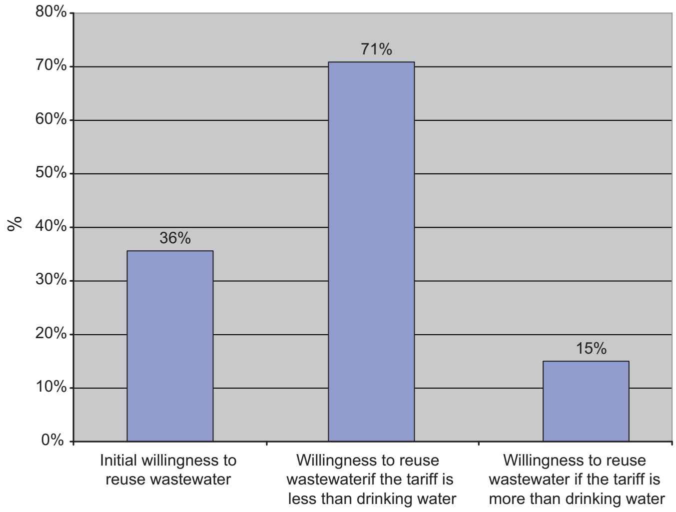

Fig. 5. Willingness to reuse wastewater based on tariff difference.

wastewater pipe networks would be undertaken, costs of installing two pipes in new installations would be cheaper than retrofitting as these costs will be incorporated into the total costs of installing other infrastructure, and the size of the WWTWs would be smaller (Okun, 2007). The high population densities common to many arid South African urban areas is a significant deterrent (due to retrofitting costs) to the implementation of especially wide-area urban reuse schemes.

3.4. *Quantity of reuse*

Primarily supplying large quantity users with treated wastewater can significantly reduce installation and operational costs (due to economies of scale), and to a large extent, guarantee system sustainability. Once the large users are supplied, the system may then be extended to smaller quantity users (USEPA and USAID, 1992). This priority scale is similarly adopted by most local authorities involved in wide-area urban reuse with little or no supply of treated wastewater to domestic consumers. Local authorities thus benefit from the economies of scale employed in this arrangement and reduce the potential risks to public health (by not supplying domestic consumers).

3.5. *Tariffs for drinking water versus treated wastewater*

Tariffs are generally used as a tool in managing drinking water demand—as tariffs increase, consumers decide whether to use less or pay more, and vice-versa. In the survey, if the tariff for treated wastewater is lower than the tariff for drinking water, 71% of respondents indicated willingness to reuse wastewater (Fig. 5). On the other hand, if the treated wastewater tariff is higher, only 15% of respondents were willing. The difficulty is that often times, the cost of supplying treated wastewater may be within proximity, or substantially higher than the cost for supplying drinking water (such as the Lynedoch Eco-village experience). Reasons for this include expensive wastewater treatment technology and the drinking water tariff excluding one or more items such as (Hassan et al., 1996):

(i) the recurrent costs of utilising bulk infrastructure (collection, treatment, storage and distribution);
(ii) the marginal costs of new drinking water supplies;

(iii) variable tariffs, as opposed to flat rates, to provide for periods of scarcity and peak demands;
(iv) the opportunity cost of water;
(v) property rights and tradable permit systems in water; and
(vi) lifeline tariffs and equity.

To be sustainable, tariffs must be inclusive of all costs. Only then will the true differences between drinking water and treated wastewater tariffs be evident.

3.6. Source quality, public health and willingness

For treated wastewater to be suitable for the potential reuses without endangering public health (DWAF, 1996), the effluent quality must be as specified in the DWAF (2001) and DWAF (2004b) standards. The quality of treated wastewater is largely determined by the efficiency of the WWTWs and influent qualities. Due to highly toxic influents (especially from industrial sewage) and sub-optimal WWTWs efficiencies, some WWTWs regularly fail to produce wastewater of the prescribed quality. Table 10 depicts the level of compliance to DWAF (2004b) standards in the CoCT (CoCT, 2006). Many inefficient WWTWs in the city have resulted from the historical lack of financial investment due to the high demand on capital throughout the city and this has affected essential maintenance and upgrading (CoCT, 2006). For this reason, many respondents undertake further on-site treatment before reuse.

Related to the quality of treated wastewater is public health. Protecting public health is achieved by reducing pathogenic micro-organisms, controlling the quantities of different chemical constituents within the treated wastewater, and limiting the public's exposure (physical contact, inhalation and ingestion) to the treated wastewater. The CoCT only supplies large institutional users with treated wastewater for primarily non-drinking water requirements. This thus reduces the potential risks to public health as domestic consumers are not connected to the treated wastewater pipe networks.

Public exposure to the wastewater directly influences willingness to reuse (Friedler et al., 2006)—where physical contact is likely, willingness to reuse is generally low. Willingness to reuse wastewater has determined the success of many reuse projects with some schemes failing because decision-makers underestimated the need to engage the benefitting community (Okun, 2002; Po et al., 2004). Willingness to reuse is also influenced by political will and the perceptions of risk associated with reuse. In the survey, 88% of respondents perceived the risks associated with wastewater reuse to be low. This perception thus encouraged reuse amongst respondents.

Table 10
Wastewater treatment works in the City of Cape Town (CoCT, 2006).

Treatment works	Level of compliance to standards (DWAF, 2004b) (%)
Athlone	83.00
Bellville	76.70
Borcherds Quarry	97.45
Cape Flats	66.67
Gordonsbay	96.70
Kraainfontein	86.75
Llandudno	83.00
Macassar	85.50
Melkbosstrand	99.40
Miller's Point	77.00
Mitchells Plain	93.00
Oudekraal	87.90
Parow	88.00
Potsdam	52.50
Scottsdene	93.35
Simon's Town	58.80
Wesfleur (Atlantis)	99.51
Wildevoelvlei	96.50
Zandvliet	97.00

3.7. Public trust in the service provider and knowledge of reuse

Service providers of drinking water are continually faced with the challenges pertaining to uninterrupted drinking water supply. Interruptions encourage apathy and negate consumers' trust in a service provider's ability to provide reliable service irrespective of whether it is drinking water supply or treated wastewater. Perception surveys conducted by Po et al. (2004) showed that trust in the Water Corporation of Western Australia to provide safe and reliable treated wastewater was critical to why residents were willing to reuse wastewater. Respondents' trust in the service provider to supply the appropriate quality of treated wastewater was 48%. This response is poor and likely influenced by the poor qualities of treated wastewater that have been supplied these respondents over time prompting further on-site treatment of the effluent.

Closely related to trust is knowledge of reuse. The more knowledgeable potential users are, the better empowered they are in deciding to (or not to) embrace reuse. Knowledge involves an awareness of local drinking water supply problems and the potential for treated wastewater to satisfy some water requirements, an understanding of the quality of treated wastewater that can be produced using the available technology, and an assurance that the treated wastewater system will involve minimal risk to the public. When potential consumers are educated about reuse, the decision to (or not to) embrace reuse is usually clearly articulated.

3.8. Regulations and guidelines for reuse

National regulations that briefly address reuse can be found in the documents below:

(i) the latest revision of the Water Services Act of 1997 relating to greywater and treated wastewater (DWAF, 2001); and
(ii) the latest revision of the National Water Act of 1998, 37(1) relating to irrigation of any land with waste or water containing waste generated through any industrial activity or by a water works (DWAF, 2004b).

In these documents, there is no objection to the reuse of wastewater for different non-drinking water requirements. However, reuse must be permitted and monitored by the relevant Water Services Authority using rigorously developed By-Laws. The CoCT appears to be the only local government authority in South Africa with detailed By-Laws for wastewater reuse within the city (CoCT, 2007).

There are no current national guidelines on wastewater reuse in South Africa. The existing guideline—the South African guide for the permissible utilisation and disposal of treated effluent (DNHPD, 1978), is currently 30 years-old and promotes the concept of 'No potential risk' to public health when reusing wastewater. For this guideline to be employed, expensive technology and processes are often required. This therefore makes the DNHPD (Ibid) guideline unaffordable when implementing wastewater reuse in typical South African developing communities.

4. Recommendations

To facilitate broader implementation of wastewater reuse, the recommendations below are proffered:

(i) there is urgent need for the DWAF to develop a national guideline document that presents a consistent technical guide for the implementation of wastewater reuse and reuse systems. The DNHPD (1978) guideline is outdated but may, with the CoCT By-Laws (CoCT, 2006), provide some input into the new guideline. The proposed guideline should include wastewater quality criteria for different non-drinking applications, uniquely designed and standardised engineering materials (e.g. pipes, meter boxes, valves, taps and tanks) and specifications (e.g. sizes, thickness, colour, labelling) for wastewater reuse systems (unique features of a reuse system would be valuable in preventing cross-connections with drinking net-works);

(ii) in order to ensure the economic feasibility of wastewater reuse, a careful life cycle cost-benefit analysis needs to be carried out within the context of other water resource alternatives and a full appreciation of the true costs of drinking water supply provision. There are potentially large savings that may be realised in avoiding treating water to drinking standards for non-drinking uses;

(iii) tariffs have been shown to significantly influence potential consumers' willingness to embrace wastewater reuse. Incentives to achieve wastewater tariffs lower than drinking water tariffs may include subsidies to consumers for wastewater reuse, utilisation of existing infrastructure (e.g. WWTWs), and/or the installation of a reuse system during the construction of new buildings;

(iv) to guarantee a high level of service for wastewater reuse, a program of regular control and monitoring of influent from various sources (especially industries) should be implemented by local authorities. In addition, many local authorities need to be equipped with qualified personnel that will undertake control and monitoring tasks and enforce By-Laws. Wastewater reuse must not be implemented where the qualified institutional capacity is deficient;

(v) willingness to reuse by potential users is critical prior to implementation. Decision-makers must also understand the conditions under which potential users will be willing to reuse wastewater. From the study, it was clear that non-drinking water requirements that involved minimal human contact (e.g. landscape irrigation) were preferred. Hence, it would be wise for decision-makers to target these uses when reuse is to be implemented;

(vi) if wide-area urban systems are to be implemented, local authorities must first consistently perform well in the services rendered to communities. This will increase consumers' trust in the local authority's ability to implement reuse systems and therefore reduce any potential risks to public health and safety. It is fruitless for local authorities to consider implementing wastewater reuse when existing service levels are low; and

(vii) the general awareness of decision-makers, builders, plumbers, product manufacturers, architects, etc. to the potential of wastewater reuse will be beneficial for a better understanding and broader implementation of wastewater reuse. Also, an integrated water reuse education/awareness programme would be beneficial for potential consumers to understand wastewater reuse. This programme can be enhanced using case studies of wastewater reuse in other communities.

5. Conclusion

South Africa is a semi-arid country with many communities struggling to access reliable and adequate quantities of water for diverse water requirements. Wastewater reuse for non-drinking water requirements has been, for many years, a promising option for supplementing municipal water supply despite the limited implementation in many parts of the country. With increasing demands on existing freshwater resources and pressures on existing municipal supplies, the need to implement wastewater reuse has increased. This paper therefore presents an overview of the South African water resources situation in order to put the need for wastewater reuse into perspective, an overview of wastewater reuse and the potential for broader implementation, a discussion on the parameters influencing wastewater reuse based on local attitudes and experience, and recommendations to facilitate broader implementation of wastewater reuse in South Africa. Significant potential exists for implementing wastewater reuse for large non-drinking applications (e.g. landscape irrigation and industrial processes) and arid areas of South Africa especially provide ample opportunities for implementation of reuse. Parameters highlighted to influence broader implementation of reuse in addition to aridity include distance from source, retrofitting versus new installations, quantity of reuse, pricing, source quality, public health, willingness, public trust and knowledge, and regulations and guidelines for reuse. It is therefore recommended that these parameters be considered prior to implementation.

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