Minimizing risks in wastewater reuse: proposed operational principles and guidelines for South Africa

J. R. Adewumi, A. A. Ilemobade and J. E. van Zyl

ABSTRACT

Treated wastewater represents a significant potential source of reclaimed water for some beneficial reuses. However, public concern over the risks/health-related hazards of wastewater reuse has limited the general acceptability of reuse systems in many countries. It is important to manage the operation of recycled water systems in such a way that it will not adversely affect public health and the environment. Management of recycled water involves process control and compliance monitoring. This paper presents proposed unit process monitoring guidelines to classify the performances of treatment units according to the pollutant removal efficiencies and frequency of sampling to test for effluent quality suitable for reuse. The paper also highlights the procedure for proper inspection of treatment facilities to ensure optimum performances. It proposes minimum quality requirements for different reuse activities in South Africa such as domestic (toilet flushing, watering private gardens), irrigation (crops, landscape, public parks and golf courses, cemeteries), industrial (system cooling and process water) and other activities (construction works, street cleaning, fire protection, groundwater recharge). By employing the wastewater treatment monitoring and sampling procedures proposed in this paper, health-related hazards can be minimized while public confidence in reuse schemes will be enhanced.

Key words | guidelines, monitoring, risks and health hazards, sampling, wastewater reuse

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INTRODUCTION

Water demand already exceeds supply in many parts of the world, and many more areas are expected to experience this imbalance in the near future. In order to meet an ever-increasing demand for freshwater, past efforts have centred on the development of additional water resources schemes, i.e. water supply interventions such as the exploitation of distant surface water and deeper groundwater sources, construction of new dams and desalination (Friedler & Hadari 2006). However, implementation of these measures usually requires significant capital investment (planning, construction, operation, maintenance and replacement) and is frequently accompanied by negative long-term environmental effects, such as the depletion of renewable water resources, deterioration of water quality, seawater intrusion and alteration of ecosystem dynamics.

Wastewater reuse for irrigation to crop plants was evaluated in a laboratory-scale experiment to assess growth and water-saving potential from natural resources by Jimenez *et al.* (2011). Their results shows that plant growth was visibly greater in treated wastewater from a suspended growth sequencing batch bioreactor than from an attached growth sequencing batch bioreactor because of less nutrient removal. Abdel-Shafy *et al.* (2011) evaluated the upgrading of a pond system for municipal wastewater treatment in a decentralized area for restricted reuse. Their results indicated that remarkable improvement in the treated effluent was achieved after upgrading the pond system via aeration.

Efficient and sustainable water use involves wastewater reuse. The main benefits of wastewater reuse are: protection of water resources, prevention of coastal pollution, recovery of water and nutrients for agriculture, savings in clear water

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use and wastewater treatment costs (Capra & Scicolone 2007; Saba *et al.* 2011). Wastewater reuse may expose the public to a variety of disease-causing pathogens, such as bacteria, viruses, protozoa or helminths. The factors influencing the transmission of these diseases in wastewater reuse are: degree of wastewater treatment, reuse applications and degree of contact with wastewater. To reduce potential risks to public health and promote public acceptance, there is a well-established guideline for water reuse in agricultural irrigation by the World Health Organization (WHO 2006) while the US Environmental Protection Agency (USEPA 2004) has standards for various non-potable applications. Also, there are standards available in many developed (e.g. USEPA 2004) and developing (e.g. Mexico and Indonesia; Blumenthal *et al.* 2000) countries. In Europe, some member states or autonomous regions have their own standards/guidelines/regulations (Bixio *et al.* 2005). Salgot *et al.* (2003) highlight pollutants of importance in water reuse and the need to develop a better tool for risk assessment and management while economic analysis of pollutants in wastewater for reuse are reported in Salgot *et al.* (2006).

In South Africa, there are no clear guidelines specifically targeted at the use of wastewater. However, the existing regulation that partially addresses the use of wastewater was produced by the Department of National Health and Population Development (DNHPD 1978). This guideline is outdated and needs to be revisited in light of the current local and international experience (Ilemobade *et al.* 2009). This paper presents proposed unit process monitoring guidelines to classify the performances of treatment units according to the pollutant removal efficiencies (i.e. minimum, average and maximum) and frequency of sampling to test for effluent quality suitable for reuse. The paper also presents a procedure for proper inspection of treatment facilities to ensure optimum performances.

OVERVIEW OF WASTEWATER TREATMENT PERFORMANCE IN SOUTH AFRICA

The quality of discharges from wastewater treatment plants in South Africa has become a matter of national importance and priority. The National Water Services Regulation Strategy (DWAF 2008) provides a clear statement of strategic intent to regulate the water and wastewater services sector in South Africa. The driving force of this strategy is the mitigation of risk associated with the management of water and wastewater facilities and the development of more comprehensive and effective regulation for the country. The three main programmes identified to mitigate risks are (DWAF 2008):

- concentrated regulatory efforts to address compliance and performance problems in priority municipalities, particularly where risks pose threats to health and the environment;
- a national drinking water quality regulatory initiative to manage potentially serious risks associated with unsafe drinking water; and
- a national wastewater discharge regulation initiative to manage potentially serious risks to health and the environment.

In line with international good practice, the Department of Water Affairs and Environment (DWAE) (formerly the Department of Water Affairs and Forestry (DWAF)) embarked on the assessment of all wastewater treatment plants in South Africa in 2008 (Manus & van der Merwe-Botha 2010). This assessment is aimed at developing the following two-pronged regulatory approach to raise the performance of wastewater treatment plants and effluent quality:

- an approach that is based on a risk profile of all wastewater treatment plants and that targets the plants that have the greatest impacts on the receiving environment;
- an incentive-based approach that recognizes excellence in the wastewater industry and that encourages service providers (i.e. municipalities) to work towards the achievement of Green Drop Certification which acknowledges the state of excellence in wastewater services. A Purple Drop Certification is issued if a service provider fails to comply with a predetermined level of green drop.

This approach to wastewater treatment plant assessment allows for incentive, punitive or assisted measures to be taken depending on the specific circumstances of non-compliance by the service provider. Manus & van der Merwe-Botha (2010) reported findings on the assessment of wastewater treatment plants in the nine provinces of South Africa from November 2008 to August 2009. The report clearly indicated that the general situation in the operation and management of wastewater treatment works

(WWTWs) in South Africa demands urgent attention. Hence, there must be a paradigm shift in the operation and management of WWTWs in order to guarantee the sustainable implementation of recycled water.

SUGGESTED OPERATIONAL GUIDELINES FOR WASTEWATER REUSE

Different hazards could occur due to WWTWs failures. From the public health and environmental standpoint, it is reasonable that a high standard of reliability should be required for a system producing reclaimed water for uses where direct or indirect human contact is likely. Therefore, water reuse requires strict conformity to all applicable water quality standards.

Several elements are combined together to make up a reclaimed water system's treatment and distribution. These include the power supply, individual treatment units, the maintenance programme and the operating personnel. Backup systems are important in maintaining reliability in the event of failure of vital components. Critical units within this system include the disinfection system, power supply and various treatment unit processes (USEPA 2004).

For reclaimed water production, EPA Class I reliability is recommended as a minimum criterion. EPA Class I reliability requires redundant facilities to prevent treatment abnormality during power and equipment failures, flooding, peak loads and maintenance shutdowns. Reliability for water reuse should also consider the following (USEPA 2004):

- operator certification to ensure that qualified personnel operate the water reclamation and reclaimed water distribution systems;
- instrumentation and control systems for on-line monitoring of treatment process performance and alarms for process malfunctions;
- a comprehensive quality assurance programme to ensure accurate sampling and laboratory analysis protocol;
- adequate emergency storage to retain reclaimed water of unacceptable quality for re-treatment or alternative disposal and supplemental storage to ensure that the supply can match user demands;
- a strict industrial pre-treatment programme and strong enforcement to prevent the illicit disposal of hazardous or other similar material that may interfere with the treatment and intended use of the reclaimed water.

Based on the above points and additional references, suggested guidelines for the operation of non-potable reuse are presented below.

Operator training and competence

No matter how sophisticated the automation of a plant is, mechanical equipment is subject to breakdown. Hence, qualified and well-trained operators are necessary to ensure the production of reclaimed water of the required quality. Plant operators are considered to be the most critical technical personnel in the wastewater treatment and reuse systems.

The knowledge, skills and abilities that an operator must possess vary considerably depending on the complexity of the plant. In general, an operator must be familiar with the following:

- the function of each unit in the plant;
- how each unit accomplishes its function;
- how to evaluate the operation of each function; and
- how each unit fits into the overall plant process.

The National Water Act (Gazette 28557 of 24/02/2006) requires operator certification as a reasonable means to expect competent operation. Frequent training via continuing education courses or other means enhances operator competence. Since actions of the system operator have the potential to adversely or positively affect reclaimed water quality, a knowledgeable and well-trained operator is critical to the sustainable generation of good reclaimed water quality. Consideration should be given to provide special training and certification for reclaimed water operations staff.

Instrumentation and control

According to USEPA (2004), major considerations in developing an instrumentation/control system for a reclamation facility include:

- ability to analyse appropriate quality parameters;
- ability to maintain, calibrate and verify accuracy of on-line instruments;

- monitoring and control of treatment process performance;
- monitoring and control of reclaimed water distribution.

In a water reuse system, the potential uses of the reclaimed water determine the degree of instrument sophistication and operator attention required. Each water reclamation plant is unique, with its own requirements for an integrated monitoring and control instrumentation system. The process of selecting monitoring instrumentation should address aspects such as frequency of reporting, parameters to be measured, sample point locations, sensing techniques, future requirements, availability of trained staff, frequency of maintenance, availability of spare parts and instrument reliability. Bourgeois *et al.* (2001) and Olsson *et al.* (2003) presented a review of available methods for monitoring the above-mentioned parameters. Such systems should be designed to detect operational problems during both routine and emergency operations. If an operating problem arises, activation of a signal or alarm permits personnel to correct the problem before an undesirable situation is created.

Effluent quality assurance and monitoring

An effluent quality assurance for a reclaimed water project involves the selection of appropriate parameters to monitor and handling of the necessary sampling and analysis in an acceptable manner. Standard procedures for sample analysis may be found in the 'Handbook for the Operation of Wastewater Treatment Works' (Pybus 2002). Sampling techniques, frequency and location are critical elements of monitoring and quality assurance.

A sample is a part or piece taken from a larger entity and presented as being representative of the whole. Samples can be collected manually or automatically. Process control sampling and testing is used to evaluate the performance of the unit process. During testing, turbidity, total suspended solids, biochemical oxygen demand, chemical oxygen demand, pH, total nitrogen, total phosphorus, faecal coliforms and total coliforms testing are routinely accomplished. Figure 1 shows typical sampling points in a treatment plant.

The recommended volume of sample to be taken, frequency and test to be carried out at each sample point are shown in Table 1.

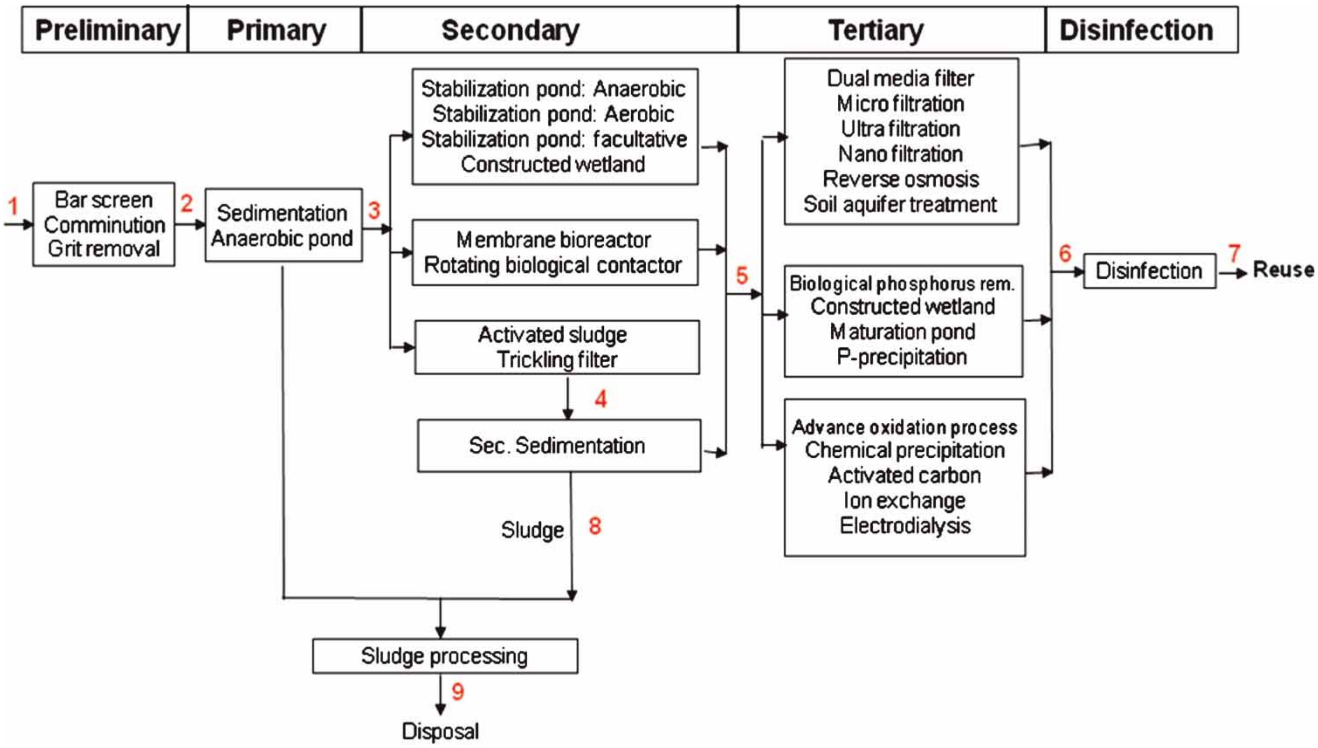

Figure 1 | Typical sampling locations for the treatment plants.

Table 1 | Sample volume, tests and frequency of test at each sample point of Figure 1 (USEPA 2004; Dettrick & Gallagher 2002)

Sample points	Sample volume (ml)	Tests to be carried out	Frequency of tests
1	100–500	Turbidity (Turb)	Continuous
	100–500	Total suspended solids (TSS)	Daily
	100–500	Biochemical oxygen demand (BOD)	Daily
	50–100	Chemical oxygen demand (COD)	Weekly
	50–100	pH	Daily
	50–100	Total nitrogen (TN)	Weekly
	50–100	Total phosphorus (TP)	Weekly
	50–100	Faecal coliforms (FC)	Weekly
	50–100	Total coliforms (TC)	Weekly
2	100–500	TSS	Bi-monthly
3	100–500	TSS	Weekly
	50–100	BOD	Weekly
	50–100	COD	Weekly
4	100–500	TSS	Daily
	100–500	BOD	Daily
	50–100	COD	Weekly
	50–100	pH	Daily
	50–100	TN	Weekly
	50–100	TP	Weekly
	50–100	FC	Weekly
	50–100	TC	Weekly
5	100–500	Turb	Continuous
	100–500	TSS	Weekly
	50–100	BOD	Weekly
	50–100	COD	Weekly
	50–100	pH	Daily
	50–100	TN	Weekly
	50–100	TP	Weekly
	50–100	FC	Daily
	50–100	TC	Daily
6	100–500	Turb	Continuous
	100–500	TSS	Weekly
	50–100	BOD	Weekly
	50–100	COD	Weekly
	50–100	pH	Daily
	50–100	TN	Weekly
	50–100	TP	Weekly
	50–100	FC	Daily
	50–100	TC	Daily
	200	Residual chlorine	Continuous

As stated earlier, tests conducted on the sample at each sampling point can be used to assess the performance of each unit process. As a guide to judge the performance of each unit process, Table 2 shows the percentage pollutant removal (minimum, average or maximum) of each unit process classified as preliminary, primary, secondary, tertiary and disinfection.

The general requirements of any reuse permit should ideally specify minimum sampling and testing that must be performed on the plant discharge. The permit should also specify the frequency of sampling, sample type and length of time for composite samples. Unless a specific method is required by the permit, all sample preservation and analysis must be in compliance.

EMERGENCY/SUPPLEMENTAL STORAGE FACILITIES

Wastewater is continuously generated through residential and industrial activities. Hence, treatment plants also treat wastewater continuously unless there is a breakdown. In case of a breakdown of major component(s) of a treatment plant, there is need to provide emergency storage to retain reclaimed water of unacceptable quality for re-treatment in order to safeguard public health and the environment. Usually, piping within a treatment plant is done in such a way that an emergency diversion is provided to convey reclaimed water of unacceptable quality to a temporary storage. At a later time, the diverted wastewaters are pumped back to the treatment plant for re-treatment.

Also, reclaimed water that cannot be used immediately may be stored or disposed of. Supplemental storage is provided to ensure that the reclaimed water supply can match users' seasonal demands. Reclaimed water must be treated and preserved to maintain its quality during storage. Storing reclaimed water can result in a change in quality, particularly microbiological quality. Therefore, if reclaimed water is stored, the quality should be tested regularly and any hazards managed accordingly. The frequency of testing and need for subsequent treatment will have to be decided on the basis of the level of risk at each site. Reclaimed water to be stored should have adequate chlorine residual and the circulation process to minimize stagnation and to maximize the distribution of the disinfection process.

Table 2 | Unit process pollutant removal efficiencies (Cheremisinoff 2002; Ahmed *et al.* 2002; ESCWA 2003; Joksimovic 2006)

	Unit process pollutant removal efficiencies (%)																							
	Turb			**TSS**			**BOD**			**COD**			**TN**			**TP**			**FC**			**TC**		
Unit process	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**
Bar screen	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Coarse screen	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Grit chamber	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pond: anaerobic	<15	15–50	>50	<30	30–45	>45	<40	40–65	>65	<30	30–60	>60	>30	30–50	>50	<5	5–7	>7	<30	30–50	>60	<20	20–35	>35
Pond: aerobic	<50	50–60	>60	<30	30–45	>45	<40	40–60	>60	<35	35–40	>40	<25	25–45	>45	<20	20–40	>40	<10	10–15	>15	<5	15–10	>10
Pond: facultative	<40	40–50	>50	<50	50–70	>85	<50	50–70	>70	<60	60–80	>80	<20	20–40	>40	<25	25–50	>50	<10	10–15	>15	<5	5–10	>10
Equalization basin	–	–	–	<5	5–10	>15	<4	4–12	>12	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sedimentation	<50	50–70	>70	<60	60–70	>70	<40	40–50	>50	<40	40–50	>50	<3	3–15	>15	<60	60–70	>70	<10	10–15	>15	<5	5–10	>10
Activated sludge + Secondary sedimentation	<10	10–40	>40	<50	50–70	>70	<50	50–70	>70	<60	60–80	>80	<10	10–30	>30	<10	10–23	>23	<20	20–35	>35	<15	15–30	>30
Trickling filter + Sec. sedimentation	<20	20–30	>30	<50	50–70	>70	<50	50–70	>70	<65	65–80	>80	<20	20–30	>30	<20	20–30	>30	<60	60–80	>80	<50	50–60	>60
Rotary biological contactor	<50	50–70	>70	<35	35–60	>60	<35	35–60	>60	<65	65–70	>70	<20	20–30	>30	<20	20–30	>30	<60	60–80	>80	<50	50–60	>60
Membrane bioreactor	<90	90–92	>92	<90	90–92	>92	<90	90–92	>92	>90	90–92	>92	<30	30–40	>40	<60	60–70	>70	<80	80–85	>90	<70	70–75	>75
Biological removal	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<90	90–95	>95	–	–	–	–	–	–
Phosphorus precipitation	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<90	90–95	>95	–	–	–	–	–	–
Chemical precipitation	<20	20–30	>30	<40	40–60	>60	<20	20–30	>30	<15	15–35	>35	<5	5–8	>8	<10	10–15	>15	<10	10–20	>30	<5	5–15	>15
Denitrification	–	–	–	–	–	–	–	–	–	–	–	–	<90	90–95	>95	–	–	–	–	–	–	–	–	–
Constructed wetland	<10	10–15	>15	<60	60–75	>75	<25	25–35	>35	<10	10–15	>15	<50	50–60	>60	<80	80–85	>85	–	–	–	–	–	–
Maturation pond	<30	30–45	>45	<15	15–25	>25	<8	8–13	>13	<10	10–20	>20	<30	30–40	>40	<20	20–30	>30	<30	30–50	>50	<20	20–35	>35
Dual medial filter	<80	80–90	>90	<80	80–90	>90	<65	65–75	>75	<60	60–70	>70	<5	5–10	>10	<5	5–10	>10	<90	90–93	>93	<80	80–85	>85
Micro filtration	<80	80–90	>90	<80	80–90	>90	<65	65–75	>75	<60	60–70	>70	<5	5–10	>10	<5	5–10	>10	<90	90–93	>95	<80	80–85	>85
Ultra filtration	<80	80–90	>90	<80	80–90	>90	<65	65–75	>75	<60	60–70	>70	<5	5–10	>10	<5	5–10	>10	<90	90–93	>95	<80	80–85	>85
Nano filtration	<30	30–50	>50	<80	80–90	>90	<20	20–35	>35	<60	60–70	>70	<40	40	>40	<80	80–90	>90	<90	90–95	>95	<90	90–93	>93
Reverse osmosis	<30	30–50	>50	<80	80–90	>90	<20	20–35	>35	<60	60–70	>70	<40	40	>40	<80	80–90	>90	<90	90–95	>95	<90	90–93	>93
Soil aquifer treatment	<85	85	>85	<80	80–90	>95	<85	85	>85	<85	85	>85	<85	85	>85	<80	80–90	>90	<70	70–75	>80	<65	65–70	>75
Activated carbon	<20	20–40	>20	<40	40–45	>45	<40	40–45	>45	<20	30–30	>40	0	0	0	<8	8–15	>15	<15	15–30	>30	<10	10–20	>20
Ion exchange	<10	10–20	>20	<40	40–45	>45	<10	10–20	>20	0	0	0	<60	60–70	>70	<70	70–80	>80	0	0	0	0	0	0
Advanced oxidation ponds	<70	70–80	>90	0	0	0	<70	70–80	>90	<70	70–80	>80	0	0	0	0	0	0	<60	60–70	>80	<55	55–65	>65
Electrodialysis	<70	70–80	>80	0	0	0	0	0	0	0	0	0	<40	40–50	>50	<40	40–50	>50	<60	60–70	>70	<55	55–65	>65
Chlorine gas	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	100	100	100	100	100
Chlorine dioxide	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	100	100	100	100	100
Ozone	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<90	90–95	>95	<90	90–95	>95
UV radiation	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	<60	60–70	>70	<55	55–65	>65

Table 3 | Inspection procedure for wastewater treatment plants (Boyd & Mbelu 2009)

Classification	Facilities for inspection	What to look for
WWTW configuration	*Flow diagram* – this is necessary in order to understand how the WWTW has been structured and should be operated. It must be drawn and make available on site.	• A flow diagram for the WWTW.
	Design capacity – this enables plans to be made for future development. It answers question of how much wastewater can still be accommodated.	• Confirm the design capacity.
Screen	*Manual/automatic screens* – these are used to remove debris from raw wastewater.	• Screens that are free of debris • Hand rake and wheelbarrow that are easily accessible and in working condition • Unusual sounds or vibrations • Maintenance schedule • Screening that are washed and return to WWTW.
Grit removal	*Manual/automatic operated grit removal* – grit material can include sand, silt, glass, small stones as well as other large-sized organic and inorganic substances. It is essential to protect moving mechanical equipment and pumps from abrasion.	• Channels that are clean of grit • Channels that are in working order, e.g. one that can be used while the other is closed for grit removal • A spade and container that are easily accessible.
	Automated degritters – a pump is required to remove a slurry of grit.	• A pump in working order.
	Screenings and grit disposal – if left lying around these will cause nuisance conditions such as odours and will encourage fly breeding.	• Non-nuisance conditions (odours and flies) • Grit or screenings lying around • Covered bins that are used for storage of grit • Proof that grit and screenings buried on site are covered daily.
Flow	*Flow metering* – a WWTW is designed to treat a specific volume of wastewater per day. It is important to know how much wastewater is entering so as not to overload the plant.	• Flow measurement • Knowledge of flow in relation to design capacity • The flow mechanism and determine whether it is in working order and is calibrated.
	Flow balancing – this is used to overcome the operational problems caused by flow rate variations and to improve the performance of the downstream unit processes; also called flow equalization.	• Mixers – are they working? • Aerators – are they working if in place? • Pumps – are they working? • Odours – are odours controlled?
Primary sedimentation	*Primary sedimentation tank (PST)* – the main purpose of primary sedimentation is to allow separation of the solid and liquid phase fractions in the wastewater.	• Inflow that should be light grey in colour • Overflow at the weirs that is similar where more than one PST is present • Weirs in good condition • Scum or floating sludge layer • Layer of fats/grease/oil • A schedule for desludging and check that it is implemented • Records of process sampling.
Pond systems	*0xidation ponds* – pond systems are relatively shallow bodies of wastewater in which the self-purification of processes of water are used under controlled conditions to purify raw or settled wastewater.	• Ponds operated in series • The presence of short-circuiting (water is flowing through a course; this means the detention time is inadequate) • Aerators – are they working if present? • Evidence of desludging – is it done periodically to a schedule and is sludge correctly disposed of? • Area around the ponds – is it well maintained? • Visible erosion around the ponds.

(*continued*)

Table 3 | continued

Classification	Facilities for inspection	What to look for
Trickling filter (TF)	*Trickling filters* – these utilize microorganisms that grow on a medium (e.g. stones) to remove organic matter found in wastewater.	• Access to the top of the filter • Movement of the rotating distributor arm – is it smooth? • Distribution of wastewater to the filter media through the rotating distributor arm – is it even? • Filter media – is it free of ponding? • Underdrains – are they clear of any obstructions?
Rotating biological contactors	*Rotating biological contactors* – these utilize microorganisms that grow on the disc system to remove organic matter found in wastewater.	• The motor – is it working? • The disc system – does it rotate freely at a steady rate? • The sludge return pump – is it working? • The ammeter – does it fluctuate as the disc turns? • Is there floating sludge in the final settling tank?
Activated sludge (ASP)	*Activated sludge* – this is a biological process of developing an activated mass of microorganisms capable of stabilizing waste aerobically. Visual observation of the ASP is very important. The colour, smell and appearance of the biomass give a good indication of whether the ASP is working well.	• Records of the sludge age • Scum on the surface • Records of the Mixed Liquid Suspended Solid (mg/l) • Records of the dissolved oxygen • Dark brown biomass (colour) • An earthy smell • Clean chemical dosing area • Records of daily process monitoring as appropriate to the ASP • On-line equipment – is it in working order and calibrated and are calibration certificates available? • Aerators – are they in working order? • Recycling – is it taking place and is a record of the correct ratio of inflow to sludge recycle maintained?
Secondary sedimentation	*Secondary sedimentation* – this is used after the TF and ASP. Sludge from TF and ASP is in suspension and must be settled out in the clarifier to produce two streams, i.e. the sludge and the clear effluent.	• Trends of the sludge volume index test • Clean effluent weirs/channel clean launders • Operational desludging equipment • Limited scum on the surface of the clarifier • An operational scum draw-off system • Clear overflow.
Constructed wetlands	*Constructed wetlands* – artificial or constructed wetlands consist of a bed of granular material through which the effluent can flow without too much hydraulic resistance.	• Reeds are planted • Reed growth is controlled using a schedule • Selective seeding and planting is undertaken periodically • Samples are taken according to relevant authorization • Herbicidal and insecticidal treatment is practised.
Maturation ponds	*Maturation ponds* – these give a final 'polish' to effluents. They are used to improve the bacteriological quality of the final effluent and can also act as a buffer in the event of a breakdown at the works.	• Overflow is clear • No erosion is observed • The banks of the ponds are protected against erosion.

(*continued*)

Table 3 | continued

Classification	Facilities for inspection	What to look for
Membrane filtrations	*Membrane filtration* – these are used to remove dissolved organic and inorganic compounds from secondary effluent.	• Permeate flows uniformly through the membrane • Records of membrane cleaning • Pumps are working perfectly • Methods of concentrate management and disposal.
Chemical disinfection	*Chemical disinfection* – the goal of disinfection is to remove pathogenic microorganisms	• The dosing equipment is in working order • No chlorine can be smelled • Relevant training has been given to the process controller/s • Residual chlorine level is being measured in the final effluent • The contact tank is clean (i.e. not sludged up) and free of algae • Final effluent samples are taken in accordance with water use authorization.

INSPECTION AND APPROVAL OF RECYCLED WATER FACILITIES

The DWAE has the responsibility for issuing permits to operate and periodically to inspect wastewater treatment plants (National Water Act 1998). The inspection of WWTWs by the DWAE is to ensure compliance with the DWAE standards for effluent discharge in order to protect public health and the ecosystem of the receiving watercourse. Therefore, the main concerns in the inspection of WWTWs are influent hydraulic and organic loadings, quality of effluent and proper disposal of sludge solids. The inspection of recycled water facilities should, in addition, include the assessment of both the recycled water service provider's facilities and user's facilities. The inspection of service provider's facilities should include a detail examination of each unit process, its operation and how the process functions in the overall treatment scheme. In the user's facilities, the inspector should look out for improper connections, unclear markings, insufficient depths of pipe installation and possible overloading (e.g. altering soil permeability, pH, electrical conductivity, cation exchange capacity) of the irrigated land. Follow-up inspections are routine, and in some cases, fixed interval inspections and random inspections are planned as explained in Salgot *et al.* (2006).

Inspection of recycled water service provider's facility

In order to undertake an inspection of a recycled water service provider's facility, it is imperative that the inspector must understand the complex nature of various unit processes involved in the treatment of wastewater. The inspector must be trained in flow measurement, sampling, laboratory testing and record keeping. A summary of an inspection procedure for WWTWs producing recycled water is shown in Table 3.

The primary purpose of regulatory inspections is to verify compliance with the DWAE standards. During inspection, water samples must be taken at sampling points 1, 5, 6 and 7 (see Figure 1) for laboratory analysis to determine the operation efficiency by monitoring unit processes listed in Table 2. These points give a good representative of influent wastewater, secondary treatment, tertiary treatment and final effluent (after disinfection).

Beyond the final treatment effluent is the management of sludge produced. In most cases, the aerobic digestion method is used in treating the sludge produced from wastewater. The purpose of anaerobic sludge digestion is to stabilize bulky, odourous raw sludge to relatively inert materials that can be readily dewatered without obnoxious odours. Overall performance of a sludge digester is determined by volatile solid reduction, gas production and composition. Operational controls include temperature of the digesting sludge, mixing in high rate digesters, rate of raw sludge feed, and solid retention time. Careful consideration is given to all unit operations that discharge flow back to the head of the plant.

Wastewater reuse quality for different non-potable uses

Table 4 shows the authors' suggested guidelines for reclaimed water quality for various types of water reuse in South Africa based on the best international practice.

In addition to the recommendations in Table 4, the recommended guidelines for the maximum concentration of trace elements in soils under natural conditions are presented in Table 5. It suggested that for monitoring purposes, the soil and vegetation is sampled and analysed. The only satisfactory safeguard is the sampling and analysis of soil and vegetation before irrigation

Table 4 | Suggested guidelines for water reuse in South Africa

Types of reuse	Reclaimed water quality	Reclaimed water monitoring
Domestic uses *(toilet flushing, watering private gardens, water use fixtures)*	• pH = 6–9 • TSS ≤5 mg/l • Turb ≤1 TNU • BOD ≤5 mg/l • COD ≤10 mg/l • TN ≤5 mg/l • TP ≤0.2 mg/l • FC ≤0 • TC ≤ 0 • Cl_2 residual ≤1 mg/l	• pH – weekly • BOD – weekly • TSS – weekly • Disinfection – daily • Turbidity – continuous • Cl_2 residual – continuous • Coliforms – daily • Nutrient, toxicant and salinity – regularly
Irrigation uses *(agricultural, crops, landscape, parks, golf courses, cemeteries, green belt land)*	• pH = 6–9 • TSS ≤10 mg/l • Turb ≤5 TNU • BOD ≤10 mg/l • COD ≤30 mg/l • TN ≤10 mg/l • TP ≤2 mg/l • FC ≤0 • TC ≤0 • Cl_2 residual ≤1 mg/l	• pH – weekly • BOD – weekly • TSS – weekly • Turbidity – continuous • Cl_2 residual – continuous • Coliforms – daily • Nutrient, toxicant and salinity – regularly
Industrial uses *(system cooling, boiler feed and process water)*	• pH = 6–9 • TSS ≤10 mg/l • Turb ≤5 TNU • BOD ≤20 mg/l • COD ≤10 mg/l • TN ≤5 mg/l • TP ≤0.2 mg/l • FC ≤200 cfu/100 ml • TC ≤200 cfu/100 ml • Cl_2 residual ≤1 mg/l	• pH – weekly • BOD – weekly • TSS – weekly • Turbidity – continuous • Cl_2 residual – continuous • Coliforms – weekly • Nutrient, toxicant and salinity – regularly
Other activities *(construction works, street cleaning, fire protection and groundwater recharge)*	• pH = 6–9 • TSS ≤10 mg/l • Turb ≤10 TNU • BOD ≤20 mg/l • COD ≤70 mg/l • TN ≤10 mg/l • TP ≤0.2 mg/l • FC ≤200 cfu/100 ml • TC ≤200 cfu/100 ml • Cl_2 residual ≤1 mg/l	• pH – weekly • BOD – weekly • TSS – weekly • Turbidity – continuous • Cl_2 residual – continuous • Coliforms – weekly • Nutrient, toxicant and salinity – regularly

Table 5 | Recommended maximum concentrations of metals in irrigation waters (Dettrick & Gallagher 2002)

Elements	Suggested soil CCL[a] (kg/ha)	LTV[b] over 100 years mg/l	STV[c] over 20 years mg/l	Plant effects
Aluminium (Al)	ND[d]	5	20	Toxic at pH <5.5
Arsenic (As)	20	0.1	2	Toxicity varies depending on species
Beryllium (Be)	ND	0.1	0.5	Toxicity varies depending on species
Boron (B)	ND	0.5	<0.5–15	Toxicity varies depending on species
Cadmium (Cd)	2	0.01	0.05	Toxic at low concentration; Bio-accumulation issues
Chromium (CrVI)	ND	0.1	1	Low toxicity
Cobalt Co)	ND	0.05	0.1	Toxic at high concentration
Copper (Cu)	140	0.2	5	Toxic at high concentration
Fluoride (F)	ND	1	2	Not active in neutral to alkaline soils
Iron (Fe)	ND	0.2	10	Not toxic in aerated soils
Lead (Pb)	260	5	2	Low toxicity; inhibits growth at high conc.
Lithium (Li)	ND	2.5	2.5	0.075 mg/l if used on citrus crops
Manganese (Mg)	ND	0.2	10	Toxicity depends on Fe/Mn ration and soil pH
Mercury (Hg)	2	0.002	0.002	No guideline at the time
Molybdenum (Mo)	ND	0.01	0.05	Low toxicity to plants, toxic to animals fed crops grown on high avail. Mo
Nickel (Ni)	85	0.2	2	Toxicity increases with soil pH <7
Selenium (Se)	10	0.02	0.05	Toxic to plants; toxic to animals fed on high Se pasture
Uranium (U)	ND	0.01	0.1	
Vanadium (Vn)	ND	0.1	0.5	Toxic to plants
Zinc (Zn)	300	2	5	pH dependent. Greater toxicity above pH 7

[a] CCL: Cumulative contaminant loading limit – the maximum contaminant loading in soil, defined in kg/ha, above which site specific risk assessment is required if contaminant addition is planned (assuming application rate of 1,000 mm/year, inorganic contaminants in top 150 mm of soil profile and soil bulk density is 1,300 kg/m^3).

[b] LTV: Long-term trigger value – the maximum concentration (mg/l) of contaminant in irrigation water which can be tolerated given 100 years of irrigation, using the same annual irrigation loading assumptions as CCL.

[c] STV: Short-term trigger value – the maximum concentration of contaminant that can be tolerated over 20 years using the same annual irrigation loading assumptions as CCL.

[d] ND: Not determined – insufficient background data to calculate CCL.

commences and regular monitoring during the life of the irrigation scheme.

CONCLUSION

Conventional water resources have been seriously depleted due to increasing water demand in various sectors. As a result, wastewater reclamation and reuse is increasingly being integrated in the planning and development of sustainable water resources. For any reuse project to be successful and well embraced by all users, it must operate within a regulated framework. This paper provides suggested guidelines for the operation, inspection and regulation of reuse water facilities in South Africa. This will minimize potential human risks and environmental pollution.

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REFERENCES

Abdel-Shafy, H. I., Hobus, I. & Hegemann, W. 2011 Upgrading of decentralized ponds for municipal wastewater treatment and restricted reuse. *J. Water Reuse Desalination* **1**, 141–151.

Ahmed, S. A., Tewfik, S. R. & Talaat, H. A. 2002 Development and verification of a decision support system for the selection of optimum water reuse schemes. *Desalination* **152**, 339–352.

Bixio, D., De Koning, J., Savic, D., Wintgens, T., Melin, T. & Thoeye, C. 2005 Wastewater reuse in Europe. In: *Proceeding of International Conference Integrated Concepts in Water Recycling*, Wollongong, NSW, Australia, 14–17 February 2005.

Blumenthal, U. J., Peasey, A., Ruiz-Palacious, G. & Mara, D. 2000 *Guidelines For Wastewater Reuse in Agriculture and Aquaculture: Recommended Revisions Based on New Research Evidence*. WELL Study, Task No 68, Part I. Water and Environmental Health at London and Loughborough, London, UK. Available from: http://www.lboro.ac.uk/well/resources/well-studies/well-studies.htm (accessed 15 May 2007).

Bourgeois, W., Burgess, J. E. & Stuetz, R. M. 2001 On-line monitoring of wastewater quality: a review. *J. Chem. Technol. Biotechnol.* **76**, 337–348.

Boyd, L. A. & Mbelu, A. M. 2009 *Guideline for the Inspection of Wastewater Treatment Works*. Water Research Commission report. WRC Report No TT 375/08.

Capra, A. & Scicolone, B. 2007 Recycling of poor quality urban wastewater by drip irrigation systems. *J. Cleaner Prod.* **15**, 1529–1534.

Cheremisinoff, N. P. 2002 *Handbook of Water and Wastewater Treatment Technologies*. Butterworth-Heinemann, USA.

Dettrick, D. & Gallagher, S. 2002 *Environmental Guidelines for the Use of Recycled Water in Tasmania*. Department of Primary Industries, Water and Environment, Tasmania, Australia. Available from: http://epa.tas.gov.au/Documents/Use_of_Recycled_Water_December_2002.pdf (accessed 23 August 2012).

DNHPD (Department of National Health and Population Development) 1978 Guide: Permissible utilization and disposal of treated sewage effluent. Report No. 11/2/5/3.

DWAF (Department of Water Affairs and Forestry) 1998 National Water Act. Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry) 2008 National Water Service Regulation Strategy: Protecting the interest of the consumer and public through the effective regulation of water supply and sanitation services.

ESCWA (Economic and Social Commission for Western Asia) 2003 *Waste-water Treatment Technologies: A General Review*. Publication of United Nations, New York.

Friedler, E. & Hadari, M. 2006 Economic feasibility of on-site greywater reuse in multi-story buildings. *Desalination* **190**, 221–234.

Ilemobade, A. A., Adewumi, J. R. & van Zyl, J. E. 2009 Framework for assessing the viability of implementing dual water reticulation systems in South Africa. *Water SA* **35** (2), 216–227.

Jimenez, B., Carranza, F. & Medina, N. 2011 Agricultural water reuse in Nicaragua: extent, actual practices, perception and perspectives. *J. Water Reuse Desalination* **1**, 185–201.

Joksimovic, D. 2006 Decision Support System for Planning of Integrated Water Reuse Project. PhD thesis, University of Exeter, UK.

Manus, L. & van der Merwe-Botha, M 2010 Raising wastewater treatment performance through incentive and risk-based targeted regulation. *Proceedings, Water Institute of South Africa (WISA) 2010*, Durban, South Africa, 18–22 April.

Olsson, G., Nielsen, M., Yuan, Z., Jeensen, A. L. & Steyer, J. 2003 *Instrumentation, Control, and Automation in Wastewater Systems*. IWA Publishing, London, UK.

Pybus, P. 2002 *Handbook for the Operation of Wastewater Treatment Works*. Water Institute of Southern Africa, Midrand.

Saba, B., Mahmood, T., Zaman, B. & Hashmi, I. 2011 Reuse of treated wastewater using sequencing batch bioreactor for the improvement of wheat growth. *J. Water Reuse Desalination* **1**, 179–184.

Salgot, M., Huertas, E., Weber, S., Dott, W. & Hollender 2006 Wastewater reuse and risk: definition of key objectives. *Desalination* **187**, 29–40.

Salgot, M., Verges, C. & Angelakis, A. N. 2003 Risk assessment in wastewater recycling and reuse. *Water Sci. Technol. Water Supply* **3**, 301–309.

USEPA (United State Environmental protection Agency) 2004 Guidelines for Water Reuse. EPA/625/R-04/108.

WHO (World Health Organization) 2006 *Guidelines for the Safe Use of Wastewater, Excreta and Greywater-Policy and Regulatory Aspects Vol. 1*, Geneva, Switzerland.

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