Technical Support Document to the Development of: *Guidelines for the Utilization and Disposal of Water Treatment Residues*

Report to the
Water Research Commission

by

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WRC Report No. 1723/1/13
ISBN 978-1-4312-0410-6

APRIL 2013

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EXECUTIVE SUMMARY

Water treatment residue (WTR) is defined as '*the accumulated solids or precipitate removed from a sedimentation basin, settling tank, or clarifier in a water treatment plant*'. The term 'water treatment residue' (WTR) replaces the previous term 'water treatment sludge' to avoid confusion with wastewater sludge, from which if differs completely.

The solid particles accumulated in the WTR are the result of chemical coagulation, flocculation and sedimentation of raw water. Aluminium sulphate, ferric salts, lime and poly-electrolytes are among the chemicals added to promote flocculation. The type and concentration of chemical(s) present in the WTR depend on the quality of the raw water, added chemicals and the purification process.

WTRs are produced on a daily basis and should be managed. Therefore guidelines for the use and disposal of these residues are important. This Guideline has been developed, although there are still knowledge gaps, to ultimately allow regulatory bodies to distinguish between wastewater sludge and WTR in their land disposal requirements and should enable water treatment works to dispose of their residues onto nearby land thus saving on transport and landfill costs.

The objectives of the study were to:

- Conduct a national survey of a range of WTRs to obtain an indication of spatial variability in the inorganic characteristics of all types of WTR produced from different raw water sources, different water treatment processes and their variability;
- Develop Guidelines that describe the requirements for the disposal and/or use of WTR; and
- Gain acceptance for the document through public participation and scientific peer review.

The approach to the development of WTR Guidelines is based on international and local research as established during the literature survey, an assessment and review of legislation governing WTR use and disposal and a risk assessment process. The risk assessment was similar to that followed during the development of the Sludge Guidelines. The risk assessment is based on the consequence that the source (in this case WTR) may have for a certain receptor and the probability of that consequence occurring along a specific pathway. The risk assessment included 11 receptors and 67 possible pathways that use and disposal of WTR could impact the environment. This is perceived to be the best way in which to develop guidelines to protect human health as well as the environment. Mitigating factors for high risk areas have been recommended where applicable.

The development process also included Stakeholder consultation with the regulating authorities and key stakeholders to test the feasibility of the implementation of the guidelines as well as the acceptability of the rationale and the limitations proposed for the guideline. The comments and concerns raised at these workshops are included in this document as well as notes on how they were addressed.

The different types of WTP (chemical treatment plants, softening plants, inorganic removal plants) and its associated WTR are discussed in detail. WTR include naturally occurring, colloidal/particulate matter (e.g. clay, silt, algae) removed from raw water by sedimentation, filtration, membranes or other processes and inert material in treatment chemicals (e.g. grit in lime); naturally occurring, soluble substances (e.g. iron, manganese, calcium, and magnesium) converted to their insoluble precipitate forms by oxidation or pH adjustment; precipitates formed (e.g. $Al(OH)_3$, $Fe(OH)_3$) when chemicals are added to water; and spent materials (e.g. granular activated carbon (GAC), powdered activated carbon (PAC), filter media, resins) periodically removed from unit treatment processes after exceeding their useful lives.

The characteristics of South African WTR can be summarised as follows:

- Physical characteristics:
  - Physical consistency – If the raw water source has a high concentration of total suspended solids (TSS) the alum/iron coagulant residue will contain a high percentage of viscous hydroxide precipitates (e.g. $Al(OH)_3$, $Fe(OH)_3$) and will exhibit the physical consistency indicated in Table 3 (ASCE/AWWA, 1990). Chemical softening WTRs primarily consist of crystalline calcium carbonate ($CaCO_3$), with the magnesium hydroxide ($Mg(OH)_2$) portion of the solids increasing as the magnesium content of the raw water increases. Because of the structured, crystalline nature of the $CaCO_3$ precipitate, the relationship between solids content and the physical consistency of chemical softening residues is different from that for coagulant and iron/manganese residues;
  - Particle size distribution – It might be expected that, in general, residues would exhibit high clay and silt fractions. However, the residues are formed by coagulation of fine particles into larger, stable aggregates. Depending on the treatment process, the WTR may exhibit pozzolanic (cementitious) properties. The particle size distribution of the WTR samples was variable depending on the degree of dispersion attained. The particle sizes featuring most prominent in all the WTR samples are coarse sand (0.5-2 mm), silt (0.002-0.05 mm) and clay (<0.002 mm) fractions;
- Chemical characteristics:
  - The pH of the WTR will influence the mobility of elements in the soil profile after application and the availability of elements to plants. The pH(H_2O) values of South African WTRs range from 6.2 to 9.2;
  - The organic carbon content ranges from 0.5 to 16.7% and will have a positive impact on soils;
  - Nitrate-N ranged from 9.7 to 94.2 mg kg^{-1} and NH_4-N from 26.3 to 358.4 mg kg^{-1};
  - The extractable P in WTR is generally low;
  - Total trace elements and metals – An aqua regia digestion was used to determine the total trace metal concentration of the WTR and the data then compared to the Pollutant Class A classification for wastewater sludge according to the Sludge Guidelines. It was concluded that

the trace metal concentrations for all the WTR samples were lower than the Pollutant Class A limits (unrestricted use) and that the beneficial use of WTR on soils is a viable option. However, to ensure protection of the receiving environment and receptors, certain restrictions will apply. The only elements with elevated concentrations were Mn and Fe which is due to the chemicals added during the treatment process. These elements are macro elements and building blocks of soils and are naturally present in all soils.

- Potentially plant available metal fractions – The DTPA extractable fraction gives an indication of the concentration of elements that could be available for uptake by plants. If the WTR has high plant available concentrations of potentially toxic elements it would indicate that it would be unsuitable for land application due to potential phytotoxicity or food-chain contamination. DTPA extractable metal concentrations of metals in South African WTR were generally low, although Fe and Mn concentrations were elevated in most of the WTRs.

- Ammonium nitrate (NH_4NO_3) metal extractions can be used to determine the available fraction of elements in soils. The NH_4NO_3 extractable concentrations of selected elements indicate that the extractable concentrations of the majority of elements were <1.5 mg/kg.

- TCLP and acid rain extraction for metals was developed in the USA by the Environmental Protection Agency to measure a waste's leachability and hence the risk it poses to groundwater. Since not all of a potentially toxic element in a waste stream will necessarily leach out, the TCLP extraction can be used to determine the mobility and hence concentration of a potentially toxic element that will probably leach from the waste stream. The acid Rain test can also be used to determine the mobility and hence concentration of a hazardous substance that will probably leach from the waste stream. It can be used to determine the mobility of organics and inorganics in liquid, solid and multiphase wastes including volatile and semi-volatile organic compounds. The TCLP and acid rain extractable Mn concentration in all the WTR samples exceeded the acceptable risk level (ARL) for Mn. It is therefore likely that under the recommendations of the Minimum Requirements most of these WTRs would be considered as hazardous material.

- Organic pollutants – There were no data available in South Africa on the organic pollutants in WTR. The literature review also indicated that these constituents in WTR are not monitored internationally. The WTR consists primarily of residues from the first stages of water treatment i.e. coagulation/flocculation/granular media filtration. During these processes none of the volatile or semi-volatile organic compounds, synthetic organics and pesticides would be removed from the raw water. These are removed during the granulated active carbon stage of the water treatment process where the little residue produced is not added to the rest of the WTR. Analytical results of a pesticide screening of selected WTR show that no pesticides were detected in any of the samples.

- Infectious substances – There were no data available in South Africa on the infectious substances in WTR. The literature review also indicated that these constituents in WTR are not monitored internationally. The concentration of infectious substances in WTR would be dependent on the quality of the raw water. The water treatment process removes the infectious substances from the water and they would then be present in the residues. It is possible that the initial chlorination of the raw water would kill such organisms but since these are potentially constituents of concern. The results of a pesticide screening and infectious substances (pathogen) analyses on six SA WTRs are indicate that the WTRs contain no pesticides or nematodes and low total aerobic plate counts.

Initial characterization of WTR is essential to enable selection of applicable management options and to determine the feasibility of these options. However, the initial characterization is based on the total metal content (aqua regia digestion) of the WTR and further investigation and analyses will be required once a management option is selected. It is recommended that the **Pollutant Class A** classification for wastewater sludge, detailed in the Sludge Guidelines, be used for this characterization. Only 8 metals of concern are included in this classification. However, other elements might also be of concern to the receiving environment (Mn, Al, Fe, and U) and it is recommended the WTR be analysed for these elements as well before a management option is selected.

The potential management options for WTR discussed in this document include:

- Land application (agriculture, forestry and land reclamation);
- Disposal (on0site and off-site disposal on landfill);
- Discharge to WWTP; and
- Potential reuse options.

There are several restrictions and requirements for all of the management options to ensure that the environment will be protected against any adverse effects of the management option. These include site selection and investigation, areas where WTR use and disposal is not allowed that should be considered, buffer zones to be introduced between the waste body and surface and groundwater (for disposal sites). Management requirements may include run-off collection, surface water protection measures, groundwater protection measures, soil quality requirements, restrictions on crop production, grazing animals and public access restrictions.

Monitoring requirements for all the management options are introduced to determine variability in WTR quality over time and to serve as early warning systems of when land application or disposal should be terminated due to its potential negative effect. The monitoring requirements include WTR monitoring, groundwater monitoring, surface water monitoring and soil monitoring. These monitoring results can also serve to improve our current knowledge base and fill the gaps which still exist.

Closure and remediation plans for disposal site should be developed and implemented if the monitoring data indicates any environmental degradation. Records should be kept at the land disposal site including records on all the above requirements.

Although there are still limited information on the characteristics of WTR and its impact on soil, surface- and groundwater, these guidelines will serve as a first step to ensure responsible handling, application and/or disposal of WTR into the environment. The guideline lean heavily on the approach and methodology followed during the development of the South African Sludge Guidelines.

This Guideline document was developed to assist the WTR producer to decide on an appropriate management option for WTR. It informs the reader regarding the legal requirements for each management option as well as restrictions and requirements applicable to the different options. Monitoring programmes are introduced to collect data on the variability of WTR quality as well as to determine the potential impact of the management options on the receiving environment.

It is recognized that new information will be generated through future research and monitoring and it is recommended that these Guidelines be updated every 5 to 10 years. This will allow the South African water industry sufficient time to implement the Guidelines and highlight shortcomings and constraints. Through the introduced record keeping process, case specific data will be generated that will enrich the local knowledge base.

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AE	Acceptable Exposure
ARL	Acceptable risk level
BOD	Biological oxygen demand
CARA	Conservation of Agricultural Resources Act (Act No. 43 of 1983
COD	Chemical oxygen demand
DEAT	Department of Environmental Affairs and Tourism
DWAF	Department of Water Affairs and Forestry
ECA	Environment Conservation Act 73 of 1989
EEC	Estimated Environmental Concentration
EIA	Environmental Impact Assessment
GAC	Granular activated carbon
HR	Hazard rating
MAT	Maximum available threshold
MPL	Maximum permissible level
NEMA	National Environmental Act, No. 107 of 1998
NWA	National Water Act 36 of 1998
OSH	Occupational Health and Safety Act
PAC	Powdered activated carbon
PPE	Personal protective equipment
RoD	Record of Decision
TCLP	Toxicity Characteristic Leaching Procedure
TIL	Total investigative level
TMT	Total maximum threshold
TTV	Total trigger values
WSA	Water services authorities
WSP	Water services providers
WTP	Water treatment plant
WTR	Water treatment residues
WWTP	Wastewater treatment plant

1 INTRODUCTION

Water treatment residue (WTR) is defined as '*the accumulated solids or precipitate removed from a sedimentation basin, settling tank, or clarifier in a water treatment plant*' (Pandit & Das, 1998). The term 'water treatment residue' (WTR) replaces the previous term 'water treatment sludge' to avoid confusion with wastewater sludge, from which if differs completely (Hughes et al., 2005).

The solid particles accumulated in the WTR are the result of chemical coagulation, flocculation and sedimentation of raw water. Aluminium sulphate, ferric salts, lime and poly-electrolytes are among the chemicals added to promote flocculation. The type and concentration of chemical(s) present in the WTR depend on the quality of the raw water, added chemicals and the purification process.

Traditionally, WTR has been sent to landfill for disposal but an option gaining acceptance internationally is land application or land treatment where WTR is applied directly onto land. The reasoning behind this approach is that physical, chemical and biological properties of the soil can be used to digest the applied waste without inducing negative effects on soil quality, groundwater or plant growth (Rengasamy *et al.* 1980; Elliott and Singer, 1988; Ahmed *et al.*, 1997; Basta *et al.*, 2000; Dayton and Basta, 2001). To validate this principle with regard to WTR requires rigorous scientific information since, given the wide variety and therefore the different characteristics of WTR produced, it is inappropriate and potentially risky to transfer recommendations across waste disposal systems (Cameron et al., 1997). A study conducted by Hughes *et al*. (2005) found that land application of WTR can have a number of positive effects on soils and can reduce the possibility of pollution by heavy metals.

A resent gap analyses conducted by UKZN and Golder Associates entitled: A scoping report on the development of guidelines for the disposal of water treatment residue to land (Hughes *et. al*., 2007) identified the following knowledge gaps that should be addressed in order to develop guidelines: (1) limited information on the characteristics of all types of WTR produced nationally from different raw water sources with different water treatment processes; (2) insufficient information on the impact of different types of WTR on soil properties, surface and groundwater; and (3) lack of information on the organic pollutant and infectious substance contents of sufficient representative samples of the variety of WTRs produced nationally. However, WTRs are produced on a daily bases and should be disposed of. Therefore guidelines for the use and disposal of these residues are important. It was decided that guidelines be developed although there are still knowledge gaps. Such guidelines will ultimately allow regulatory bodies to distinguish between wastewater sludge and WTR in their land disposal requirements and should enable water treatment works to dispose of their residues onto nearby land thus saving on transport and landfill costs. Both agricultural land application (and other beneficial uses) and disposal were addressed.

1.1 Objectives

The objectives of the study were to:

- Conduct a national survey of a range of WTRs to obtain an indication of spatial variability in the inorganic characteristics of all types of WTR produced from different raw water sources, different water treatment processes and their variability;

- Develop Guidelines that describe the requirements for the disposal and/or use of WTR; and

- Gain acceptance for the document through public participation and scientific peer review.

1.2 General project approach

The approach to the development of WTR Guideline is based on international and local research as established during the literature survey, an assessment and review of legislation governing WTR use and disposal and a risk assessment process.

1.2.1 Literature review

A literature review was conducted to gain information on international experience about approaches that have been adopted to develop guidelines for WTR use and disposal. The rationale behind limitations and restrictions that were implemented were determined and the unique local considerations and practices that could affect the South African Guideline evaluated.

1.2.2 Legal review

An assessment and review of the legislation governing the specific WTR disposal/use practice under consideration was conducted in order to determine the legal requirements that need to be met. This includes a critical assessment of the appropriateness of existing legal requirements for South African conditions.

1.2.3 National survey of Water Treatment plants

A national survey of SA WTPs will supply information on the status quo on WTR management. WTR were collected at selected plants and analysed for several constituents to determine the variability in the characteristics of the different types of WTR and could also serve as benchmark values.

1.2.4 Risk assessment

The Sludge Guidelines (Snyman & Herselman, 2007) were developed by following a similar risk assessment protocol as was followed during the development of the USEPA Part 503 Rule for the land application of wastewater sludge. The risk assessment is based on the consequence that the source (in this case WTR) may have for a certain receptor and the probability of that consequence occurring along a specific pathway. The risk assessment included 11 receptors and 67 possible pathways that land application of WTR could impact the environment. This is perceived to be the best way in which to develop guidelines to protect human health as well as the environment.

1.2.5 Development of Guideline- and Technical Support documents

The Technical Support Document will record the assessment and review of the legislation governing the utilization and disposal of WTR, the international and local literature that assisted in the development of the Guideline and the rationale that was followed to develop the South African WTR Guideline, the associated limits for South African conditions and the outcomes of the risk assessments. It will also record the rationale followed to develop the Guideline and the origin of all limitations placed on the use and disposal of WTR, management systems to be implemented to reduce the risks and limits for constituents of concern relevant to South African conditions.

The Guideline for the utilization and disposal of WTR describe good management practices and guide the responsible use and disposal of WTR. The impact on the groundwater, surface water, soil and the public were addressed as well as monitoring requirements for these sites. If land disposal is applied the user is guided to minimize the risk of contaminating surface and groundwater and possible remediation strategies are described. In terms of landfilling the interaction and use of the DWAF Minimum Requirements and the relevant regulations and acts were included. Guidance will also be supplied for good management practices for the responsible use of WTR for agricultural purposes.

1.2.6 Stakeholder consultation

Comprehensive consultation with the regulating authorities and key stakeholders were conducted to test the feasibility of the implementation of the guideline as well as the acceptability of the rationale and the limitations proposed for the guideline. The consultation process included workshops in Gauteng, Western Cape, KwaZulu-Natal and the Eastern Cape. The purpose of the consultations was to get buy-in from the regulating authorities and key stakeholders. As the Guideline has a specific target audience, the general public was not included in this process. The stakeholders forming part of the consultation process was identified through the WISA database and through regulatory personnel at the DWAF Head office and Regional offices as well as the DEAT, DoA and DoH offices.

1.3 Deliverables

The following deliverables were expected of this project:

- Report on the national survey of WTR;
- Technical Support Document;
- Draft Guideline;
- Report on the consultation process; and
- Final Guideline.

2 METHODOLOGY

2.1 National survey of Water Treatment Plants

The DWAF database of WTPs in South Africa supplied information on location and contact details of WTPs which were used for this study. Several WTPs in all the provinces were contacted telephonically to determine the different WTR management options used in South Africa. Twenty plants were selected where samples of WTR were obtained for analyses at the University of KwaZulu-Natal, which included:

- Particle size distribution;
- pH H_2O, EC, Organic carbon;
- Nutrients: Total N, NO_3, NH_4, P, SO_4, and the extractable K, Na, Mg and Na;
- CEC;
- NH_4NO_3 extractable trace elements (a ICP Scan after extraction);
- A 1:20 acid rain extract with an ICP Scan.

During the scoping study on the disposal of WTR to land (Hughes *et.al*, 2007), it was concluded that organic constituents and infectious substances are not constituents of concern in WTR and these analyses were not included in this project.

2.2 Risk assessment methodology

2.2.1 Source characterisation

The potential pollution source (WTR) were characterised by using existing South African data as well as results derived from the national survey. The following parameters were considered:

- Physical characteristics (density, bulk density, particle size, odours, etc.)
- Chemical characteristics (CEC, organic carbon)
    - Macro nutrients (N, P, K, etc.)
    - Micro nutrients (Zn, Cu, Mn, Fe, Mo, etc.)
    - Metals (Cd, Cr, As, Pb, etc.)
    - Organic pollutants (Volatile Organic Compounds, Semi Volatile Organic Compounds, Pesticides, Endocrine disruptors, Polychlorinated biphenyls (PCB))
    - Infectious substances (Total plate count, Faecal coliforms, E. coli, Specific pathogens)

2.2.2 Receptors

The following eight receptors were identified that could be impacted by the application of WTR to land.

- General public – The general public can be either directly or indirectly exposed to WTR. Direct exposure includes the workers and members of public present at or near to the land application sites where the WTR are applied to land. They may either be in direct contact with the WTR during application and/or inhale air-borne dust and volatile pollutants during land application. The general public can also be indirectly exposed to at or near the land application site via ingestion of plants grown on WTR, ingestion of meat of animals that grazed on land application sites, drinking of surface and/or groundwater impacted by WTR and eating fish from impacted surface water. Direct contact with surface and groundwater impacted by WTR are also included as indirect contact.

- Soil – The effects of land application of WTR have been studied extensively internationally. Most of the studies indicated that land application of WTR can have positive effects on the soil (Hughes *et al*., 2005). However, the application of WTR to soil may negatively affect the physical soil structure, soil chemical properties and fertility as well as the soil microbiological characteristics, depending on the constituents in the WTR.

- Vegetation – International studies indicated that land application of WTR, when managed properly, will not have negative effects on vegetation. Constituents in the WTR, especially phytotoxic elements, may have negative effects on natural vegetation, commercial crops as well as grazing crops cultivated at land application sites. The high levels of Mn in South African WTR would appear to represent a major concern. These negative effects should be identified and mitigated/managed.

- Air – The residues are formed by the coagulation of fine particles into larger aggregates and may exhibit a coarse texture when dried. However, the fine particles may lead to excessive dust during application and may have negative effects on air quality during and after land application. This may also include volatile pollutants in the WTR which may, when present, lead to negative impacts on the receiving environment.

- Surface water – Surface water bodies at land application sites may be impacted negatively to run-off after application of WTR or due to direct run-off from WTR while it is stored before application. WTR may cause turbidity of surface water due to fine particles transported to the surface water during rainstorms or the chemical quality can be impacted by dissolved elements from the WTR.

- Groundwater – Constituents of concern in WTR may migrate through the soil and negatively impact the groundwater resource. Hughes *et al*. (2005) conducted a five-step fractionation of WTR which gives an indication of how mobile or available metals may be. This showed that generally most metals are not readily exchangeable. Extraction with a weak acid, however, showed increases in the concentration of most metals from all samples. This indicates that these elements may become mobile under acid conditions. The high levels of Mn in South African WTR would appear to represent a major concern.

- Grazing animals – Grazing animals can be impacted via direct ingestion of WTR and soil at application sites or through ingestion of vegetation at application sites and inhalation of air-borne dust and volatile pollutants. The intake of negatively impacted surface and groundwater may also have negative effects on grazing animals.

- Fauna – Fauna can also, like grazing animals, be impacted via direct ingestion of WTR and soil at application sites or through ingestion of vegetation at application sites and inhalation of air-borne dust and volatile pollutants. The intake of negatively impacted surface and groundwater may also have negative effects on grazing animals.

2.2.3 Exposure Pathways

The identified receptors may be impacted by WTR land application through various pathways. Table 1 show all the pathways that were considered for the risk matrix (total of 36). Some of these pathways are very long (3 receptors before the final receptor) and the negative impact to the final receptors may be very small. An example is the ingestion of meat of animals that grazed on WTR applied soil by the general public: WTR → Soil → Plant → Animal → Human. The negative effect of the WTR would be on the plant (if phytotoxic) or on the animal (zootoxic) and would most probably not get to the human.

Table 1: Exposure pathways considered during the risk assessment

Receptors	Potential exposure pathways
Workers	WTR → Ingestion/Dermal absorption of toxic constituents
	WTR → Dust → Inhalation
	WTR → Air → Inhalation
General population	WTR → Ingestion/Dermal absorption of toxic constituents
	WTR → Dust → Inhalation
	WTR → Air → Inhalation
	WTR → Soil → Plant → Human
	WTR → Soil → Plant → Animal → Human
	WTR → Soil → Surface water → Human
	WTR → Soil → Surface water → Fish → Human
	WTR → Soil → Surface water → Human
	WTR → Soil → Groundwater → Human
	WTR → Soil → Groundwater → Human
Soil	WTR → Soil physical properties
	WTR → Soil chemical and fertility
	WTR → Soil microbiological characteristics

Receptors	Potential exposure pathways
Vegetation	WTR → Soil → Natural vegetation
	WTR → Soil → Commercial crops
	WTR → Soil → Grazing crops
Air	WTR → Air
	WTR → Soil → Air
Surface water	WTR → Soil → Surface water
	WTR → Surface water
Groundwater	WTR → Soil → Groundwater
Grazing animals	WTR → Soil → Plant → Animal
	WTR → Soil → Animal
	WTR → Soil → Surface water → Animal
	WTR → Soil → Groundwater → Animal
	WTR → Soil → Animal
	WTR → Animal
Fauna	WTR → Soil → Plant → Animal
	WTR → Soil → Animal
	WTR → Soil → Surface water → Animal
	WTR → Soil → Groundwater → Animal
	WTR → Soil → Animal
	WTR → Animal

2.2.4 Population of risk ranking matrix

The risk ranking matrix is based on the probability/frequency that a specific consequence will occur (frequent to highly unlikely; see Figure 1) and the consequence that the source may have for a given receptor (very severe to neutral; see Table 2). The consequence and probability should be determined for each pathway that may impact a receptor (see Tabnle 2).

The risk ranking matrix was populated for each of the receptors and the pathways, concentrating on the information that is available on the source (WTR). A separate matrix was developed for physical properties, nutrients, macro-elements, micro-elements, metals, organic pollutants and pathogens. Mitigating factors, for agricultural land application and disposal, were identified for high risks and medium-high risks. These mitigation measures were included in the guideline document.

	1	2	3	4	5	6		Consequence Class
5	5	10	15	20	25	30	5	Very Severe
4	4	8	12	16	20	24	4	Severe
3	3	6	9	12	15	18	3	Moderate
2	2	4	6	8	10	12	2	Low
1	1	2	3	4	5	6	1	Neutral
	1	2	3	4	5	6		
Frequency Class	Highly Unlikely	Rare	Low Likelihood	Possible/ Probable	Can Occur	Frequent		
Probability	Not Expected to Happen	Not During Life	Could Happen	Possibly Will Happen	Could Happen Regularly	Expected to Occur		
Frequency (Lifetime)	1:1 000 000	1:100 000	1:10 000	1:1 000	1:100	1:10		
	Probability							

KEY

- High Risk
- Medium to High Risk
- Low to Medium Risk
- No risk

Figure 1: Generic risk ranking matrix and probability classes

Table 2: Consequence classes and descriptions

Consequence Class	Receptors		
	Workers	**General population**	**Soil**
Very Severe	Severe negative health condition to multiple parties requiring hospitalisation	Severe negative health condition to multiple parties requiring hospitalisation	Irreparable damage
Severe	Isolated negative health conditions requiring hospitalisation	Isolated negative health conditions requiring hospitalisation	Extensive intervention and remediation required
Moderate	Recoverable condition	Recoverable condition	Intervention required to rehabilitate soil
Low	Self-treatable conditions	Self-treatable conditions	Degradation impacts are manageable
Neutral	No impact	No impact	No impact
Consequence Class	**Vegetation**	**Air**	**Surface water**
Very Severe	Plants die	Severe toxic and dust pollution on a regional scale	Acute or Chronic effects at regional scale
Severe	Severe phytotoxic effects	Toxic and/or dust pollution impacting on the surrounding community	Long term impairment of fitness for use
Moderate	Deterioration in yield or biodiversity	Dust and/or odour nuisance confined to the working area	Recoverable impacts to fitness for use
Low	Some intervention required to maintain yield or biodiversity	Sporadic dust nuisance	Low intensity, temporary
Neutral	No impact	No impact	No impact
Consequence Class	**Groundwater**	**Grazing animals**	**Fauna**
Very Severe	Acute or Chronic effects at regional scale	Animal deaths	Animal deaths and loss of biodiversity
Severe	Long term impairment of fitness for use	Severe toxic effects observed	Severe toxic effects observed
Moderate	Recoverable impacts to fitness for use	Some intervention required to maintain viable animals	Biodiversity will recover after closure
Low	Low intensity, temporary	Recoverable effects	Some intervention required to maintain yield or biodiversity
Neutral	No impact	No impact	No impact

3 TYPES OF WATER TREATMENT PLANTS AND WTR

Metal salts or polymers are added to raw water during the treatment process to coagulate the suspended solids and dissolved contaminants. Most of these coagulants and the impurities they remove settle to the bottom of the settling tank / clarifier where they become part of the WTR. The quantity of WTR generated depends upon the raw water quality, dosage of chemicals, performance of the WTP and the method of residue removal. Figure 2 shows an overview of a typical WTP.

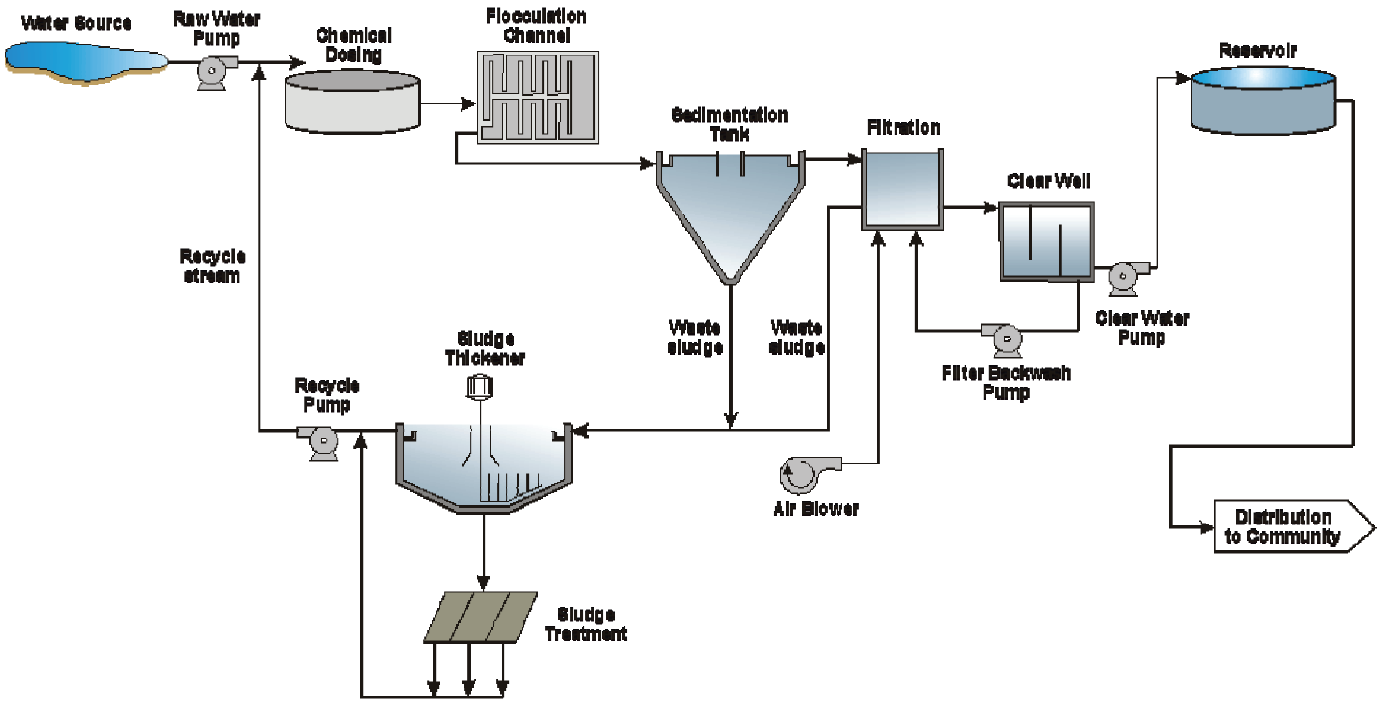

Figure 2: Overview of a typical water treatment plant

Water treatment plants can be divided into four general categories (Cornwell *et al.*, 1987) with different associated waste streams. These include the following:

3.1 Chemical treatment plants

Treatment plants that coagulate filter and oxidize surface water for removal of turbidity, colour, bacteria, algae and elements like iron and manganese. This is the most commonly used water treatment technology and this type of WTR for approximately 70% of the WTR produced (Cornwell *et al.*, 1987). These plants use alum or iron salts for coagulation. In addition other chemicals might be added such as powdered activated carbon, polymer, lime or activated silica. These elements are usually removed along with the solids in the raw water in a sedimentation tank or clarifier.

The waste streams include clarifier WTR and filter backwash wastes and the quantity of solids produced depends on the raw water quality and chemical addition. Typical contaminants present in the WTR may include metals, suspended solids, organics, pathogens and inorganics.

3.2 Softening plants

Treatment plants treating hard and alkaline water have to soften the water by removing calcium and magnesium from the raw water. These represent the second major waste product produced by water treatment plants. Softening is accomplished either by chemical precipitation of the Ca and Mg by adding lime, sodium hydroxide and/or soda ash or by the use of ion exchange resins.

These plants produce settled WTR from the clarifier and filter backwash. Some plants may also add polymer or metal slat to remove fine precipitates, colour or turbidity present in the raw water. This type of WTR account for another 25% of WTR produced (Cornwell *et al.*, 1987). Contaminants that may be present in these WTR are metals, suspended solids, organics and unreacted lime.

3.3 Inorganic removal plants

The removal of trace elements and metals from raw water is becoming more of a problem due to industrialization and pollution of surface water resources. Treatment plants specifically designed to remove trace inorganic substances (nitrate, fluoride, etc.) using processes like ion exchange, reverse osmosis or adsorption. These plants produce spent adsorption material as a waste. Depending on the concentrations of these elements in the raw water and the residue, the WTR may be classified as hazardous waste and may include metals, nitrates and TDS.

3.4 Stripping of volatile compounds

Treatment plants designed for stripping of volatile compound produce air phase wastes and are not common in SA.

3.5 Categories of WTR

According to the USEPA (1996), the majority of residuals from water treatment plants (WTPs) fall into one of four categories:

- Naturally occurring, colloidal/particulate matter (e.g. clay, silt, algae) removed from raw water by sedimentation, filtration, membranes or other processes and inert material in treatment chemicals (e.g. grit in lime);
- Naturally occurring, soluble substances (e.g. iron, manganese, calcium, and magnesium) converted to their insoluble precipitate forms by oxidation or pH adjustment;
- Precipitates formed (e.g. $Al(OH)_3$, $Fe(OH)_3$) when chemicals are added to water; and
- Spent materials (e.g. granular activated carbon (GAC), powdered activated carbon (PAC), filter media, resins) that must periodically be removed from unit treatment processes after exceeding their useful lives.

3.6 Residuals Handling Process Types

Some water treatment processes that may produce solids are grit collection, sedimentation, and filtration. These processes can include mechanisms for collection and concentration of solids before conveyance to disposal or to another unit process. These residuals can be handled through a variety of process types (USEPA, 1996). The process types are:

- Thickening: A process of concentrating the solids content of a residual stream to reduce the volume before disposal or further treatment.
- Coagulant recovery: A treatment technique for improving solids dewatering characteristics and lowering the concentration of metallic ions in the residuals.
- Conditioning: Adding a chemical to a residual or physically altering its nature. Conditioning is traditionally used as a method to optimize the dewatering process.
- Dewatering: Similar to thickening in that both processes involve a liquid-solids separation approach with a goal of minimizing the amount of residuals for disposal. Dewatering is defined as a process to increase the solids concentration of residuals (by weight) to greater than 8 percent, typically in the 10 to 20 percent range.
- Drying: An extension of the liquid-solids separation approach of thickening and dewatering. Drying is defined as a process to increase the solids concentration of residuals (by weight) to greater than 35 percent.
- Disposal and reuse: Removal of residuals from the WTP site or permanent storage of residuals at the WTP site. This category includes hauling to landfill, discharging to sanitary sewer or natural waterway, land application, and various reuse options (e.g. soil supplement, brick manufacture).
- Recovered and non-recovered water handling: Thickening, dewatering, and drying processes produce both liquid and solids components. The solids component may be further treated and disposed of. The liquid component is returned to the main WTP processes if it is recoverable, which means it has little impact on the main treatment process and no harmful effect on the finished water quality. Quality parameters that can affect the recoverable status of the water include the following:
    - Residuals metal concentrations.
    - Disinfectant by-product formation potential.
    - Use of unapproved polymers in the residuals handling processes

4 CHARACTERISTICS OF WTR

4.1 Physical characteristics

In terms of characterising South African WTR the only study conducted to date is that by Hughes *et al*. (2005) and one of its subsequent publications (Titshall and Hughes, 2005). Much of the following discussion therefore is taken from these documents and the reader is referred to them for more in-depth analysis (repeated reference to these documents will not be made). In addition, as part of the current project, additional laboratory analyses were conducted on WTR samples collected from different WTP in SA. These results are included in the discussions that follow.

4.1.1 Physical consistency

If the raw water source has a high concentration of total suspended solids (TSS) the alum/iron coagulant residue will contain a high percentage of viscous hydroxide precipitates (e.g. $Al(OH)_3$, $Fe(OH)_3$) and will exhibit the physical consistency indicated in Table 3 (ASCE/AWWA, 1990). Chemical softening WTRs primarily consist of crystalline calcium carbonate ($CaCO_3$), with the magnesium hydroxide ($Mg(OH)_2$) portion of the solids increasing as the magnesium content of the raw water increases. Because of the structured, crystalline nature of the $CaCO_3$ precipitate, the relationship between solids content and the physical consistency of chemical softening residues is different from that for coagulant and iron/manganese residues (see Table 3).

Table 3: Physical consistency of coagulant and chemical softening residues at different solids contents (ASCE/AWWA, 1990)

Coagulant Residue Characteristics		Chemical Softening Residue Characteristics	
Solids content	**Physical consistency**	**Solids content**	**Physical consistency**
0-5%	Liquid	0-10%	Liquid
8-12%	Spongy, semi-solid	25-35%	Viscous liquid
18-25%	Soft clay	40-50%	Semi-solid
40-50%	Stiff clay	60-70%	Crumbly cake

4.1.2 Particle size distribution

It might be expected that, in general, residues would exhibit high clay and silt fractions. However, the residues are formed by coagulation of fine particles into larger, stable aggregates. Depending on the treatment process, the WTR may exhibit pozzolanic (cementitious) properties. The majority of WTRs have an earthy smell but the odour can be influenced by the raw water source; WTR produced from eutrophic sources or when algal blooms affect the water source may smell bad (Dr A van Niekerk, Golder Associates, personal communication). Such bad odours may influence public perception and acceptance of land disposal. However, suitable treatment at the works can alleviate these problems to a large degree.

The particle size distribution of the WTR samples was variable depending on the degree of dispersion attained. The particle sizes featuring most prominent in all the WTR samples are coarse sand (0.5-2 mm), silt (0.002-0.05 mm) and clay (<0.002 mm) fractions.

4.1.3 Particle density

The particle densities of the dry WTRs ranged from 2.02 to 2.43 g/cm^3 and plant available water ranged considerably from 8.66 to 197.72 g/kg, but was generally low (Hughes *et al*., 2005). Cornwell *et al*. (1987) indicated that alum WTR had densities of 1.002-1.008 g/cm^3 while lime WTR had a density of 1.292 g/cm^3. Alum WTR can be dewatered to 7-19%.

4.1.4 Pozzolanic properties

Some types of WTR may display pozzolanic (self-cementing) properties i.e. the ability of a material to harden and gain strength in the presence of water. Such characteristics have resulted in WTRs being considered for a wide range of uses, such as making bricks and cement (Gonçalves *et al*., 2004; Carvalho and Antas, 2005). Many WTRs harden upon drying and these dry aggregates are resistant to water and appear to break down in soil only under conditions of alternate wetting and drying. A large thickness of wet WTR applied to the soil surface could theoretically result in a sealed soil surface that could impact on infiltration or penetration by plant shoots. In practice this may not occur since the WTR cracks on drying thus opening up channels through which water can enter the soil and plants could emerge. However, such risks can be completely eliminated by not applying such a thickness of wet material (Hughes *et al*., 2000).

4.1.5 Thickening and Dewatering

The major constituent of WTR is water. The water content of WTR can be divided into 4 categories:

- Free water which is not held to the WTR solids and can be removed by gravitational settling;
- Floc water / hydrogen bound water which is trapped/attracted in the flocs and can be removed by mechanical dewatering;
- Capillary water which is held to the solids by surface tension and can only be removed by compaction and deformation of the flocs; and
- Chemically bound water which is chemically bound to the individual floc particles and cannot be removed (Cornwell *et al*., 1987).

WTR from a coagulation process typically have 0.5-2% solids content and can be thickened with gravity to 3-4% solids. WTR resulting from a softening process with lime can be removed from the clarifier at 10% solids and may gravity thicken to 30% solids.

Table 4 presents a generalised range of final solids content that could be expected from different dewatering mechanisms for lime and coagulant residues (Cornwell *et al*., 1987).

Table 4: Range of solids contents obtainable with dewatering for lime and coagulant residues (Cornwell *et al*., 1987)

Dewatering mechanism	Lime residue	Coagulant residue
Gravity thickening	15-30%	3-4%
Belt filter press		10-15%
Drying beds	50%	20-25%
Long term storage lagoons	50-60%	7-15%

4.2 Chemical characteristics

The chemical characteristics of WTR that may have an impact on its environmental impact during and after land application and disposal are pH, nutrients, trace elements, organic pollutants and pathogens. These constituents will be discussed in the following sections, including their possible effects and whether it is a constituent of concern.

- The pH of the WTR will influence the mobility of elements in the soil profile after application and the availability of elements to plants. According to Titshall and Hughes (2005) the pH(H_2O) values of South African WTRs range from 6.2 to 9.2. The pH(H2O) of the WTR samples analysed during this study varied between 6.7 and 7.6. These pH ranges is not a characteristic that is of concern for land application of WTR.
- The organic carbon content ranges from 0.5 to 16.7% and will have a positive impact on soils. This is therefore not a constituent of concern.

4.2.1 Nutrients

The nutrient content of the WTR will determine whether it could substitute for, or be used as, a fertilizer. High concentrations of certain nutrients could also present a negative environmental impact due to surface and groundwater contamination.

- The N content of WTR may have positive (supplying N to plants) and negative (groundwater contamination due to leaching and surface water contamination due to runoff) impacts on the environment during and after land application. Nitrate-N ranged from 9.7 to 94.2 mg kg^{-1} and NH_4-N from 26.3 to 358.4 mg kg^{-1}. Although little information on the actual impact of N from WTR on groundwater and surface water is available, data from Umgeni Water (Hughes *et al*., 2005) suggests that at their disposal site leaching of N is not a problem.
- The extractable P in WTR is generally low. Phosphorus is not a constituent of concern since in most soils P does not leach due to being adsorbed on oxides of iron and aluminium under acid soil conditions and by calcium carbonate when the soil pH is alkaline. Furthermore many South African soils are deficient in P for crop growth. Most pollution of surface water by phosphorus is due to adsorbed P being removed with solid particles washed from the land surface. This might lead to eutrophication of water resources and has to be mitigated. This potential for erosion of WTR from its site of application is an aspect recommended for further research.

- The CEC gives an indication of the material's potential to hold plant nutrients and other cations. The CEC is determined by the type and amount of clay and/or organic material that is present. These two colloidal substances are essentially the cation warehouse or reservoir and are very important because they improve the nutrient and water holding capacity of the material. Sandy material with little organic matter (OM) has a low CEC (2-10 $cmol_c/kg$), but smectitic clay with high amounts of OM would have a much greater capacity to hold cations (20-40 $cmol_c/kg$). The disadvantages of a low CEC obviously include the limited availability of mineral nutrients to the plant and the WTR's inability to hold applied nutrients. The CEC of the WTRs ranged from 1.4-68.4 $cmol_c/kg$. The CEC of the WTR is not of concern since it has positive effects on the nutrient and water holding capacity of soils after application.

4.2.2 Trace and heavy metals

The trace element and metal content of WTR may have negative impacts on several receptors when present in high concentrations. Different extraction methods were used by Hughes *et al.* (2005) to determine the concentrations of different fractions of trace elements and metals in WTR. The plant available fraction was determined with DTPA extraction and the leachable fraction by TCLP. Additionally to these methods, aqua regia digestion as well as NH_4NO_3 and acid rain extraction were conducted during the current study.

Manganese, Cu, Ni, Co, As, F, B, and Zn are among a number of potentially phytotoxic elements. For the cations among the potentially phytotoxic elements (Zn, Cu, Ni, Co, Mn), soil pH and soil adsorption strongly affect plant uptake; plant species also differ in uptake from the same soil. These elements are usually adsorbed or precipitated in the soil and are commonly bound to Fe and Mn oxides or organic matter in the soil. Protons compete with the metal cations for the specific sorption by these surfaces, so as pH is reduced, metal ion solubility is increased and plant uptake is increased. Strongly acidic soils allow these elements to become phytotoxic, while adding enough lime to make the soil alkaline prevents phytotoxicity (Kabata-Pendias and Pendias, 2001). The high pH of the WTR and the amended soil allows the metal cations to be strongly bound by the soil or precipitated in the roots, so that the concentrations in edible plant tissues do not comprise a chronic ingestion risk.

Total trace metal concentrations

An aqua regia digestion was used to determine the total trace metal concentration of the WTR (Table 5). The data were then compared to the Pollutant Class A classification for wastewater sludge according to the Sludge Guidelines. It was concluded that the trace metal concentrations for all the WTR samples were lower than the Pollutant Class A limits (unrestricted use) and that the beneficial use of WTR on soils is a viable option. However, to ensure protection of the receiving environment and receptors, certain restrictions will apply.

The only elements with elevated concentrations were Mn and Fe which is due to the chemicals added during the treatment process. These elements are macro elements and building blocks of soils and are naturally present in all soils.

Table 5: Total trace metal concentrations (aqua regia) in South African WTR (mg/kg)

Sample number	WTP	Aqua regia extraction - (mg/kg)								
		Cd	Co	Cu	Cr	Ni	Pb	Zn	Fe	Mn
WTR 1	Randwater fresh	9.97	13.80	33.91	32.20	bd	1.00	33.26	25162	1543
WTR 2	Randwater stockpile	9.94	13.48	24.94	28.82	bd	9.53	30.77	23813	1341
WTR 3	Randwater stockpile 2	9.69	13.00	20.75	29.34	bd	6.67	28.56	35021	887
WTR 4	Bronkhorstspruit 1	9.83	14.59	22.98	30.84	3.39	1.32	28.25	20664	652
WTR 5	Bronkhorstspruit 2	10.17	16.75	34.59	68.90	30.12	22.90	45.15	23638	1271
WTR 6	Bronkhorstspruit 3	9.37	11.22	11.59	2.11	bd	bd	13.74	23045	107
WTR 7	Midvaal 1	13.51	9.98	54.15	71.87	53.35	120.37	54.09	69249	3323
WTR 8	Midvaal 2	11.98	12.10	43.08	70.73	43.55	71.33	60.98	52955	2614
WTR 9	Midvaal 3	12.26	14.27	46.99	107.52	49.91	86.01	76.60	63961	2567
WTR 10	Vaalkop	11.01	18.86	28.18	186.25	36.54	47.58	39.13	40269	450
WTR 11	Voelvlei	9.58	12.02	13.92	6.10	bd	bd	23.60	79136	136
WTR 12	Faure	15.07	0.31	26.16	53.56	bd	168.29	335.03	143933	942
WTR 13	Blackheath	11.13	10.29	25.06	25.74	bd	49.84	44.73	29282	387
WTR 14	Elandsjagt	9.96	12.43	14.62	13.80	bd	8.27	21.22	22215	189
WTR 15	Loerie	10.21	13.40	27.12	44.22	bd	39.97	47.11	21977	184
WTR 16	Churchill	10.22	12.53	15.43	13.47	bd	7.78	22.06	36355	219
WTR 17	Noditgedagt	10.66	12.39	22.12	32.99	bd	37.18	54.28	35426	445
WTR 18	Balkfontein	11.00	13.97	28.17	38.20	5.96	35.73	37.21	58623	1807
WTR 19	Nelspruit	11.90	22.85	59.50	47.37	4.20	85.53	86.91	43982	1436
WTR 20	Midmar	11.69	15.75	37.29	68.00	3.71	77.16	56.23	41231	3656
WTR 21	Bloemfontein	11.16	14.14	51.17	75.90	5.64	53.24	68.77	6476	889
WTR 22	Nahoon	10.22	15.25	21.59	32.84	bd	28.27	37.06	32907	703
WTR 23	Klein Brak	14.21	9.69	62.52	102.27	41.24	163.48	57.24	124255	1292
WTR 24	Friemersheim	9.46	12.06	13.74	4.18	bd	bd	31.26	10881	95
WTR 25	Sandhoogte	10.49	9.41	27.46	24.40	bd	27.11	15.30	6021	124
	Sludge Guidelines: Pollutant class a	40	--	1500	1200	420	300	2800	--	--

bd = below detection

Potentially plant available fractions

The DTPA extractable fraction gives an indication of the concentration of elements that could be available for uptake by plants. If the WTR has high plant available concentrations of potentially toxic elements it would indicate that it would be unsuitable for land application due to potential phytotoxicity or food-chain contamination. Hughes *et al*. (2005) found the DTPA extractable metal concentrations to be generally low (Table 6), although Fe and Mn concentrations were elevated in most of the WTRs (420-725 mg/kg Mn) due to the Mn concentration in the treatment chemicals. The Midvaal and Faure WTRs also had elevated concentrations of Zn, possibly from the Fe-salts used to treat the raw water. Nickel concentrations in the Midvaal WTR were slightly elevated, again probably due to contamination from the Fe-salt used for water purification. Copper concentrations were elevated in the Midvaal and Midmar samples.

Table 6: DTPA extractable metals (mg/kg) from six South African WTR

Element	Rand	Midmar	Amatola	Midvaal	Faure 1	Faure 2
Cd	0.66	0.42	0.45	0.50	bd	0.30
Co	0.42	0.63	0.70	1.06	1.82	2.59
Cr	1.16	1.18	1.45	1.86	bd	bd
Cu	1.76	5.78	1.39	7.16	0.41	0.29
Fe	48.70	87.70	63.30	246	65.00	42.70
Mn	38.80	88.90	13.23	22.10	725	420
Ni	0.56	1.34	0.61	3.39	bd	bd
Pb	0.20	1.07	2.67	1.43	0.79	1.64
Zn	1.48	3.01	2.04	8.64	10.27	10.89

bd – below detection (0.1 mg/kg)

Ammonium nitrate (NH_4NO_3) extractions

The NH_4NO_3 (DIN 19730) extraction method can be used to determine the available fraction of elements in soils. Since WTR majorly consist of soil particles, this method can also be used for WTR. The NH_4NO_3 extractable concentrations of selected elements are presented in Table 7. These results indicate that the extractable concentrations of the majority of elements were <1.5 mg/kg. In the New Sludge Guidelines (Snyman & Herselman, 2006) the maximum available threshold (MAT) for metals in agricultural soils receiving wastewater sludge are as follows: Cd – 0.1 mg/kg, Cr – 0.1 mg/kg, Cu – 1.2 mg/kg, Ni – 1.2 mg/kg, Pb – 3.5 mg/kg and Zn – 5 mg/kg. The NH_4NO_3 extractable Cd and Cr in the WTR exceeded the MAT for agricultural soils. Since edible crops for human consumption will not be cultivated in WTR alone, this concentration will not pose a problem.

Table 7: Concentration of selected elements in NH_4NO_3 extractions of South African WTR

WTP	Ammonium nitrate extraction (mg/kg)								
	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Randwater fresh	0.10	0.04	0.07	0.45	0.32	5.94	0.27	0.45	0.12
Randwater stockpile	0.11	0.01	0.12	0.05	0.13	0.17	0.03	0.40	0.13
Randwater stockpile 2	0.11	bd	0.13	0.06	0.10	0.19	bd	0.53	0.12
Bronkhorstspruit 1	0.09	0.24	0.17	0.78	30.60	7.15	1.24	0.20	0.12
Bronkhorstspruit 2	0.10	0.08	0.20	0.74	23.55	5.11	0.94	bd	bd
Bronkhorstspruit 3	0.10	bd	0.21	0.51	16.94	5.76	0.65	bd	bd
Midvaal 1	0.17	0.02	0.20	0.64	2.04	14.79	0.78	bd	bd
Midvaal 2	0.19	0.07	0.23	0.20	0.82	1.35	0.38	bd	bd
Midvaal 3	0.18	bd	0.25	0.08	0.52	1.38	0.10	bd	bd
Vaalkop	0.15	bd	0.24	bd	0.21	4.35	0.04	bd	bd
Voelvlei	0.14	bd	0.26	bd	0.22	0.59	bd	bd	bd
Faure	0.14	bd	0.28	bd	0.18	40.38	bd	bd	bd
Blackheath	0.11	bd	0.30	bd	0.91	37.30	bd	bd	bd
Elandsjagt	0.11	bd	0.31	bd	0.71	4.63	bd	bd	bd
Loerie	0.11	bd	0.32	bd	7.39	42.58	bd	bd	bd
Churchill	0.08	bd	0.36	bd	0.85	10.51	bd	bd	bd
Nooitgedagt	0.12	bd	0.41	bd	0.35	9.95	bd	bd	bd
Balkfontein	0.15	0.10	0.50	0.56	1.40	6.59	0.33	bd	bd
Nelspruit	0.09	bd	0.42	bd	0.28	4.68	bd	bd	bd
Midmar	0.09	bd	0.49	0.13	0.82	5.66	bd	bd	bd
Bloemfontein	0.10	bd	0.82	0.21	0.35	2.76	bd	bd	bd
Nahoon	0.08	bd	0.51	bd	0.47	0.61	bd	bd	bd
Klein Brak	0.13	bd	0.57	0.02	1.78	75.25	bd	bd	bd
Friemersheim	0.07	bd	0.54	bd	3.80	2.95	bd	bd	bd
Sandhoogte	0.11	bd	0.62	bd	17.96	2.64	bd	bd	bd

bd - below detection (<0.01mg/kg)

TCLP and acid rain extraction

The TCLP was developed in the USA by the Environmental Protection Agency to measure a waste's leachability and hence the risk it poses to groundwater. Since not all of a potentially toxic element in a waste stream will necessarily leach out, the TCLP extraction can be used to determine the mobility and concentration of a potentially toxic element that will probably leach from the waste stream. The acid Rain test can also be used to determine the mobility and hence concentration of a hazardous substance that will probably leach from the waste stream. It can be used to determine the mobility of organics and inorganics in liquid, solid and multiphase wastes including volatile and semi-volatile organic compounds (DWAF, 1998). However, importantly, it takes no account of any re-adsorption of the 'leached' elements that may occur as a result of interaction with the soil.

According to the Minimum Requirements (DWAF, 1998) the TCLP and acid rain extractable metal concentrations represent the estimated environmental concentration (EEC). The EEC must be compared to the acceptable exposure level (AE) to determine the hazard rating of the waste sample. The AE values refer to the LC_{50} x 0.1 with the LC_{50} being the concentration at which a substance would kill 50% of organisms if it were disposed of directly into a water body. The EEC represents "*the concentration of a substance in the aquatic environment when introduced under worst case scenario conditions i.e. directly into a body of water. It is used to indicate possible risk, by comparison with the minimum concentration estimated to adversely affect aquatic organisms or to produce unacceptable concentrations in biota, water or sediment.*" (DWAF, 1998). The 3rd Edition of the Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste is currently being reviewed before implementation. In previous editions, requirements were set to ensure safe disposal to the aquatic environment, an ecosystem recognized for its sensitivity and vulnerability. Although such requirements also provide adequate protection to human health for some contaminants in wastes, protection has also to be more adequately ascertained according to the risk it poses to human health. In the Third Edition, necessary provisions are included to ensure safe disposal to protect human health, in addition to the environment. A systemic acceptable exposure for human health is proposed i.e. the concentration of a contaminant in water, calculated from a reference dose or "*tolerance daily intake*" as derived from chronic toxicity studies and a person of 70 kg mass drinking two litres of water per day.

The acid rain extractable Mn concentration in all the WTR samples exceeded the AE for Mn. The concentrations of all the other elements were lower than the AE for these elements (Table 8). The TCLP extractable Mn concentration in the majority of WTR samples also exceeded the AE levels, as well as the Fe concentration in selected samples (Table 9). When the acid rain and TCLP extractable concentrations of elements is compared, it is clear that acid rain extracts more Mn, Cu, Ni and Zn than the TCLP extract and less Fe and Pb.

It is likely that under the recommendations of the Minimum Requirements (DWAF, 1998) most of these WTRs would be considered as hazardous material. The Minimum Requirements, however, are excessively stringent for purposes of land disposal, as they do not consider either existing soil background conditions or, perhaps most importantly, the ability of soil to buffer additions of heavy metals. When one considers limits set by other environmental organisations, specifically for soil, then the levels reported here for these WTRs are generally not excessive, especially if the effects of dilution when land disposing such waste are considered.

Table 8: Concentration of selected elements in acid rain extractions

WTP	Acid rain extraction (mg/l)								
	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Acceptable exposure*	**0.03**	**0.97**	**4.7**	**0.13**	**9**	**0.3**	**0.75**	**0.12**	**0.69**
Randwater fresh	bd	bd	bd	0.04	0.18	3.78	0.02	0.01	0.11
Randwater stockpile	bd	bd	bd	0.01	0.39	0.49	0.01	bd	0.09
Randwater stockpile 2	bd	bd	bd	0.01	0.36	0.55	0.01	bd	0.05
Bronkhorstspruit 1	bd	bd	bd	0.04	3.12	27.77	0.09	bd	0.10
Bronkhorstspruit 2	bd	bd	bd	0.03	2.10	19.42	0.08	bd	0.08
Bronkhorstspruit 3	bd	bd	bd	0.03	1.91	18.90	0.09	bd	0.08
Midvaal 1	bd	bd	bd	0.09	2.72	7.76	0.12	bd	0.14
Midvaal 2	bd	bd	bd	0.04	1.76	4.09	0.08	0.02	0.12
Midvaal 3	bd	bd	bd	0.02	0.89	5.12	0.05	bd	0.09
Vaalkop	bd	bd	bd	0.01	0.23	2.04	0.10	bd	0.08
Voelvlei	bd	bd	bd	0.01	0.78	2.09	0.02	bd	0.17
Faure	bd	bd	bd	bd	5.57	11.61	0.03	0.01	0.55
Blackheath	bd	bd	bd	0.02	0.95	4.74	0.02	0.01	0.13
Elandsjagt	bd	bd	bd	bd	0.19	1.73	0.02	bd	0.06
Loerie	bd	bd	bd	bd	0.83	2.27	0.02	bd	0.15
Churchill	bd	bd	bd	bd	0.63	1.04	0.03	bd	0.18
Nooitgedagt	bd	bd	bd	0.01	0.17	6.63	0.03	bd	0.07
Balkfontein	bd	bd	bd	0.04	0.86	4.09	0.09	bd	0.05
Nelspruit	bd	bd	bd	0.01	0.28	2.27	0.03	bd	0.10
Midmar	bd	bd	bd	0.01	0.12	14.47	0.03	bd	0.30
Bloemfontein	bd	bd	bd	0.04	0.16	1.68	0.03	bd	0.12
Nahoon	bd	bd	bd	0.01	0.19	1.59	0.02	bd	0.10
Klein Brak	bd	bd	bd	0.04	2.47	15.40	0.10	bd	0.10
Sandhoogte	bd	bd	bd	bd	1.46	1.63	0.05	bd	0.21

*Minimum Requirements bd - below detection limit (<0.01mg/kg)

Table 9: Concentration of selected elements in TCLP extractions

WTP	TCLP extraction (mg/l)								
	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Acceptable exposure*	**0.03**	**0.97**	**4.7**	**0.13**	**9**	**0.3**	**0.75**	**0.12**	**0.69**
Randwater fresh	bd	bd	bd	0.03	0.17	0.98	0.03	0.02	0.05
Randwater stockpile	bd	bd	0.01	0.01	0.13	0.19	0.01	0.06	0.06
Randwater stockpile 2	bd	bd	bd	0.01	0.11	0.19	0.01	0.04	0.05
Bronkhorstspruit 1	bd	bd	bd	0.03	1.17	3.54	0.04	bd	0.25
Bronkhorstspruit 2	bd	bd	bd	0.02	0.68	2.29	0.03	0.02	0.05
Bronkhorstspruit 3	bd	bd	bd	0.02	0.44	3.37	0.03	0.01	0.04
Midvaal 1	bd	bd	bd	0.06	6.07	2.98	0.11	0.02	0.05
Midvaal 2	bd	bd	bd	0.03	1.02	0.75	0.06	0.02	0.05
Midvaal 3	bd	bd	bd	0.02	0.47	0.52	0.03	0.02	0.04
Vaalkop	bd	bd	bd	0.01	0.15	0.82	0.02	0.01	0.06
Voelvlei	bd	bd	bd	bd	0.26	0.22	0.01	bd	0.07
Faure	bd	bd	0.02	0.04	77.85	2.25	0.03	0.03	0.31
Blackheath	bd	bd	bd	0.02	0.55	2.08	0.01	0.01	0.07
Elandsjagt	bd	bd	bd	0.01	0.26	0.59	0.01	bd	0.08
Loerie	bd	bd	bd	0.01	0.62	2.67	0.01	bd	0.07
Churchill	bd	bd	bd	0.02	0.51	1.00	0.02	bd	0.08
Nooitgedagt	bd	bd	bd	0.02	0.40	1.20	0.01	bd	0.07
Balkfontein	bd	bd	bd	0.04	0.49	1.92	0.08	0.20	0.05
Nelspruit	bd	bd	bd	0.01	1.06	0.66	0.01	bd	0.08
Midmar	bd	bd	bd	0.01	0.20	1.39	0.01	bd	0.06
Bloemfontein	bd	bd	bd	0.04	0.17	0.48	0.01	0.04	0.06
Nahoon	bd	bd	bd	0.01	0.20	0.22	0.02	bd	0.05
Klein Brak	bd	bd	bd	0.06	11.93	3.48	0.01	0.02	0.07
Sandhoogte	bd	bd	bd	0.02	18.94	0.46	0.02	bd	0.06

*Minimum Requirements bd - below detection limit (<0.01mg/kg)

Manganese

The major constituent of concern in the WTR seems to be Mn. Manganese is an essential element for invertebrates, birds and mammals, and is required for growth and reproduction in animals, and in plants manganese is essential for nitrogen and inorganic acid metabolism and photosynthesis. Mn^{2+}, Mn^{3+}, and Mn^{4+} are the common valence states found in most soils with Mn^{2+} being the primary form absorbed by plants. The concentration of Mn^{2+} in the soil is affected by soil pH, redox status, water tension, microbial activity, and temperature. Its solubility decreases 100 fold as soil pH increases by one unit (Kongchum, 2005). Manganese toxicity is normally associated with soils of pH 5.5 or lowers (Eastern Research Group, 2001). As the main reason for the elevated concentrations is likely the high concentrations of these constituents in the chemicals used during the treatment process of the raw water, a change at the water treatment plants to cleaner chemicals could alleviate or remove this problem altogether, although there may be a cost implication to such a change. Furthermore, the application of WTR to soils with certain pH and redox properties would prevent Mn leaching.

The Mn content of South African WTR stands out to be the main reason for concern for land application and disposal of WTR. Although the total Mn content of the WTR are elevated, the pH of the WTR (>6.2) would render it insoluble since Mn is soluble at pH < 5.5. Internationally, Mn is handled as a non-issue since the risk to the environment is perceived to be minimal. However, all the elements were considered in the risk assessment because it adds to the worst-case scenario.

According to Kabata-Pendias and Mukherjee (2007) the range of Mn in natural soils is 0.01-0.9% with a mean concentration of 500 mg/kg. The soluble fraction of normal soils can be as high as 10 mg/L.

Aluminium

Aluminium is one of the main constituents of the earth’s crust. Total Al content of soils is inherited from parent material and range between 0.5 and 10%, but only a fraction of the total Al are soluble. Mobility of Al sharply increase at pH <5.5 and also at pH >8. The mean soluble Al concentration in neutral soils is 0.4 mg/L and can be as high as 5 mg/L in acid soils (Kabata-Pendias and Mukherjee, 2007). The mobile Al in acid soils can be taken up rapidly by plants. The main mitigation for Al toxicity to plants and Al mobility is to keep the soil pH between 6.5 and 8.

Iron

Iron is a major constituent in the lithosphere and can vary between 0.5 and 5% total Fe in normal soils. The general rule governing the mobilisation and fixation of Fe are oxidising and alkaline conditions which promote Fe precipitation, while acid and reducing conditions promote solubility. The content of soluble Fe in soils is extremely low in comparison to the total content. The Fe concentration in soil solution of neutral soil varies between 0.03-0.55 mg/L but can be as high as 2 mg/L in acidic soils (Kabata-Pendias and Mukherjee, 2007).

Uranium

An element that did not receive attention during the characterization process of WTR is uranium. Due to contamination of some surface water resources in SA with U due to gold mining, U in WTR derived from these sources need to be considered. Uranium has radioactive as well as chemically toxic properties and is moderately mobile in oxidizing conditions across the whole pH range and immobile in reducing conditions (Alloway, 1995). Uranium is absorbed by clay minerals and organic matter and typical values in soil range between 0.8 and11 mg/kg (Kabata-Pendias & Pendias, 2001; Alloway, 1995).

Uranium is a common naturally occurring and radioactive substance. It is a normal part of rocks, soil, air, and water, and it occurs in nature in the form of minerals – but never as a metal. Large amounts of U can react with the tissues in the human body and damage the kidneys. The radiation damage from exposure to high levels of natural or depleted U is not known to cause cancer (ATSDR, 1999).

Especially the Wonderfonteinspruit catchment area, located in Gauteng, is at risk. Several studies have been conducted in this area by a number of authors. It is estimated that tailings dams within the Wonderfonteinspruit Catchment contain 100 000t of U of which 50t is discharged annually into the receiving water courses within the Wonderfonteinspruit Catchment. A total of 24 tons of dissolved U was calculated to be released into the environment from unlined tailings deposits alone. At present the U and other heavy metals in the Wonderfonteinspruit (Cd, Cu, Zn, As and Co) are adsorbed in the sediment. Environmental conditions such as acid mine drainage, acid rain, drying out of the sediment and influx of water, dredging operations, tailings spillages and turbulence caused by cattle drinking the water or children playing in the water can cause the mobilization of U into the water column of the Wonderfonteinspruit (Coetzee *et.al.*, 2006).

Other sources of diffuse release of possibly polluted water include run-off from contaminated surfaces such as slimes dams, rock dumps, high-grade ore piles, metallurgical plants, etc. seepage from unlined return-water dams and evaporation facilities containing highly contaminated process water, leakages from broken canals, pipelines, etc., as well as spillages from recovery plants. Storm water drainage systems, into which windblown dust from adjacent slimes dams is flushed by run-off from sealed surfaces are also likely to constitute a major source of potential water pollution. Based on (conservative) assumptions regarding the affected surface area and average deposition rates of dust from adjacent slimes dams, it was estimated that approximately 10t of (particle-bound) U per year are flushed by storm water into receiving watercourses (Coetzee *et.al.*, 2006).

Relatively little of the U in the Wonderfonteinspruit currently reports downstream at the inlet to the Potchefstroom WTP, although the guideline values for chemical toxicity are sometimes exceeded, indicating that a number of environmental processes are concentrating U within fluvial sediments and within the local groundwater systems. Analytical data on the fluvial sediments and some soils influenced by groundwater confirmed these concentration processes (Coetzee *et.al,* 2006).

The US EPA remediation goals for U in contaminated soils are 16 mg/kg for residential soil and 200 mg/kg for industrial soils. With all these information in mind, it is recommended that U be monitored in WTR where U is known to be present in elevated concentrations in the source water. Dr Philip Kempster of DWAF (personal communication February 2009) indicated that a limit of <200 mg/kg U in WTR destined for land application will be acceptable.

Comparison between WTR and wastewater sludge

The WTR data was compared to wastewater sludge data (Table 10), indicating the following:

- The TCLP extractable element concentrations in WTR are significantly lower than that of wastewater sludge. No data is available for the TCLP extractable Mn concentration in wastewater sludge.
- The total (bomb digestion) concentrations of the elements of concern (except Mn) in the WTR are significantly lower than the total (*aqua regia* extraction) concentration of these elements in wastewater sludge, although the bomb digestion is a stronger extraction than the *aqua regia* extraction.
- The elevated Mn, Pb and Zn TCLP concentrations of WTR would hamper disposal, because it is governed by the Minimum Requirements (1998), but would not prevent it.
- The total element content of the WTR is significantly lower than the limits set for sludge destined for unrestricted agricultural use, except for Mn.

Table 10: Comparison between South African WTR and wastewater sludge

	TCLP extractable		**Total concentrations**		**Sludge guideline values**	
	WTR mg/L	**Sludge mg/L**	**WTR # mg/kg**	**Sludge ## mg/kg**	**TCLP* mg/L**	**Aqua regia** mg/kg**
Cd	bd	1.05-295	bd – 4	0.2-110.5	<0.03	<40
Co	bd	1.4-784.5	3.5-39	1.9-499.5	<0.97	<5
Cr	bd	138.8-274.4	39-77	24.9-3587	<4.7	<1200
Cu	bd	23.3-1147	5.4-95.4	34-4339	<0.1	<1500
Mn	44.8-849	-	282-15266	92.3-3432	<0.3	<260
Ni	bd	bd – 243.5	14-58	18.1-1570	<1.14	<420
Pb	0.79-1.64	1.3-1200	5.8-58.9	19-3758	<0.1	<300
Zn	2.51-23.7	142.2-4683	33.1-2737	155-9540	<0.7	<2800

Bomb digestion ## Aqua regia digestion
* For waste disposal (DWAF, 2005) ** For unrestricted agricultural use (WRC, 2006)

A comparison between the metal concentrations in WTR, wastewater sludge and agricultural soils (USEPA, 1996) is shown in Table 11.

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Table 11: Comparison between trace element and metal concentrations (mg/kg) in WTR, wastewater sludge and agricultural soils [a]

Constituent	WTR [b]	Sewage Sludge [c]	Agronomic Soil
Aluminium	60 111.0 (52 095)		72 000[d]
Arsenic	14.7 (14.7)	9.93 (18.84)	7.2[d]
Barium	122.5 (127.52)		580[d]
Boron	40.7 (61.3)		33[d]
Cadmium	5.15 (11.67)	6.94 (11.76)	0.265 (0.253)[e]
Calcium	20 815.0 (33 108)		24 000[d]
Chromium	49.5 (56.5)	118.6 (339.2)	54[d]
Copper	270.2 (326.1)	741.2 (961.8)	29.6 (40.6)[e]
Iron	52 751.0 (63 642)		26 000[d]
Lead	79.9 (100.2)	134.4 (197.8)	12.3 (7.5)[e]
Manganese	385.4 (398.5)		9 000[d]
Mercury	1.5 (2.5)	5.2 (15.5)	0.09[d]
Molybdenum	9.1 (12.9)	9.2 (16.6)	0.97[d]
Nickel	37.8 (53.8)	42.7 (94.8)	23.9 (28.1)[e]
Selenium	2.8 (1.5)	5.2 (7.3)	0.39[d]
Strontium	84.3 (60.6)		240[d]
Vanadium	35.4 (17.4)		80[d]
Zinc	1 047.4 (3 036.1)	1 201.9 (1 554.4)	56.5 (37.2)[e]

a Data are arithmetic mean and standard deviation ( ) presented as mg/kg dry weight.
b Survey of 12 land-applied WTR, including 10 alum and 2 ferric (Brobst, 1994).
c U.S. EPA, 1990a.
d Shacklette and Boerngen, 1984.
e Holmgren et al., 1993.

4.3 Organic pollutants

There were no data available in South Africa on the organic pollutants in WTR. The literature review also indicated that these constituents in WTR are not monitored internationally. The WTR consists primarily of residues from the first stages of water treatment i.e. coagulation/flocculation/granular media filtration. During these processes none of the volatile or semi-volatile organic compounds, synthetic organics and pesticides would be removed from the raw water. These are removed during the granulated active carbon stage of the water treatment process where the little residue produced is not added to the rest of the WTR. Analytical results of a pesticide screening of selected WTR are presented in Table 12. These results show that no pesticides were detected in any of the samples.

4.4 Infectious substances

There were no data available in South Africa on the infectious substances in WTR. The literature review also indicated that these constituents in WTR are not monitored internationally. The concentration of infectious substances in WTR would be dependent on the quality of the raw water.

Chemical coagulation is critical to the effective removal of microbial pathogens. Considered in terms of equivalent particle sizes, the bacteria, protozoa and parasites are microscopic particles, while viruses are similar to colloidal particle sizes. Coagulation destabilizes microbial pathogens by modifying (neutralizing or reducing) surface charges, promoting inter-particle contact, creating bridges between pathogens and other particles and enmeshing into flocculated particles.

Flocculation promotes formation of larger aggregates that incorporate microbial pathogens to allow effective separation in downstream processes. Without proper coagulation/flocculation many microbial pathogens will pass through sedimentation and filtration treatment processes. Properly operated coagulation/flocculation/filtration can reliably remove 90-99% of bacteria, viruses and protozoa.

The water treatment process removes the infectious substances from the water and they would then be present in the residues. It is possible that the initial chlorination of the raw water would kill such organisms but since these are potentially constituents of concern. The results of a pesticide screening and infectious substances (pathogen) analyses on six SA WTRs are presented in Table 12 (Hughes *et al*., 2006). The results indicated that the WTRs contain no pesticides or nematodes and low total aerobic plate counts. These data appear to justify the decision given earlier not to consider these substances as a cause for concern.

Table 12: Pesticide screening and infectious substances in six WTR sampled in 2006

Property	Blackheath	Ixopo*	Faure	Rand#	Midmar*
Nematodes	nd	nd	nd	nd	nd
Total Helminth ova/g dry mass	0	0	0	0	0
Total aerobic plate count (cfu/g)	970	187	1 830	1 320/1 800	>300
Faecal coliforms (cfu/g)	0	0	0	0	0
Pesticide screening (mg/kg)	nd	nd	nd	nd	nd

nd = none detected
* slurry samples
# two separate sub-samples submitted for analysis hence two results for plate counts

5 CHARACTERISATION OF WTR

Initial characterization of WTR is essential to enable selection of applicable management options and to determine the feasibility of these options. However, the initial characterization is based on the total metal content (aqua regia digestion) of the WTR and further investigation and analyses will be required once a management option is selected.

It is recommended that the **Pollutant Class A** classification for wastewater sludge, detailed in the Sludge Guidelines (Snyman & Herselman, 2006), be used for this characterization (Table 13). Only 8 metals of concern are included in this classification. However, other elements might also be of concern to the receiving environment and will be addressed in detail in the relevant sections applicable to the selected management options. The total concentration of uranium (U) in WTR from water sources with elevated U concentrations need to be determined before a management option is selected. The recommended limit for U in WTR is <200 mg/kg.

Table 13: Recommended limits for total metal concentration in WTR

Constituent	Total concentration (mg/kg)
Arsenic (As)	<40
Cadmium (Cd)	<40
Chromium (Cr)	<1 200
Copper (Cu)	<1 500
Lead (Pb)	<300
Mercury (Hg)	<15
Nickel (Ni)	<420
Zinc (Zn)	<2 800

The decision making process for selection of appropriate management options for WTR is based on the initial determination of the total metal content.

Table 14 shows different management options which can be considered based on the total metal content of the WTR, as well as potential restrictions and additional analyses and investigations that might be needed. Once the management option is selected, additional analyses and investigation might be necessary which will be discussed in the sections that follow.

Table 14: Appropriate management options based on metal content

Management option		Total metals < Metal limit		Total metals > Metal limit
Land application	✓	Additional NH_4NO_3 analyses	X	Not permissible
On-site disposal	✓	Additional TCLP analyses	!	Maximum load restrictions
Off-site disposal	✓	Additional TCLP analyses	!	Maximum load restrictions
Discharge to WWTP	✓	Additional COD and/or BOD analyses	!	Additional COD and/or BOD analyses, rate and volume restrictions
Discharge to source	!	Additional analyses and restrictions on discharge rate and volume	X	Not permissible
Re-use options	✓	Additional investigations needed	!	Options might be restricted due to metal content

Legend:
✓ = Permissible; ! = Permissible with restriction; X = Not permissible

5.1 Characterisation of WTR intended for land application

WTR intended for land application, especially for agricultural use, have to be of exceptional quality in order to protect the general public as well as the receiving environment. In order to protect the food chain as well as the soil, surface- and groundwater resources, the available fraction of metals and other elements in the WTR need to be determined. It is recommended that the NH_4NO_3 extraction be used for this assessment and that all potential constituents of concern be determined, including Al, Fe and Mn.

- NH_4NO_3 extractable trace element and metal concentrations (Appendix A);
- Kjeldahl digestion to determine N (Appendix A);
- Bray 1 extraction to determine available P (Appendix A); and
- Dominant cations and anions (NO_3, SO_4, Cl. etc.).

Since certain crops are more tolerant than others for some of these constituents, these analytical results can be used to assess whether agricultural use will be feasible and which crops could be cultivated. The application rate will also depend on these results as well as the results of the soil investigation.

The concentrations of organic constituents (pesticides) and infectious substances (pathogens and parasites) are perceived to be low in SA WTR. However, in cases where the WTP are aware that these substances are present in the raw water, the WTR need to be tested for these substances before land application, especially agricultural use.

5.2 Characterisation of WTR for disposal

The characterization of WTR intended for disposal is based on the leachable fraction of elements present in the WTR and the hazard rating of the waste. This is discussed in detail in the chapter on disposal in this document (Chapter 10: On-site and off-site disposal).

6 RESULTS AND FINDINGS OF RISK ASSESSMENT

The risk ranking matrix was populated for each of the receptors and the pathways, concentrating on the information that is available on the source (WTR). A separate matrix was developed for physical properties, nutrients and macro-elements, micro-elements and metals (Appendix A). Since organic pollutants and pathogens are not perceived as contaminants that may have a negative impact on receptors, these were omitted from the risk assessment. Mitigating factors for high risk areas have been recommended where applicable. The sections that follow summarize the findings of the relative risks associated with the application of WTR to land for (a) crop production and beneficial use and (b) dedicated land disposal.

6.1 Workers

There are three pathways through which workers at water treatment plants could be adversely affected by land disposal of WTR on the premises of the water treatment plant i.e. direct contact and inhalation of dust and/or volatile pollutants. However, it is assumed that workers comply with OHSA, 1993 and are equipped with the proper PPE. It was decided to exclude the workers from the risk ranking matrix.

6.2 General public

Ten pathways were considered through which the general public could be impacted. These pathways generally have several barriers with the human receptor being the third or fourth receptor (Table 1). The exposure from the consumption of crops grown on WTR amended soil represents the most critical pathway for the general population followed by the ingestion of contaminated drinking water.

The main constituents that could be of concern for the general public are the metals and micro-elements in WTR. However, the metal content of the WTR is generally low and the probability of the general public being adversely affected by land application or disposal of WTR is low.

The high Mn content may pose a health problem to the general public. Manganese is an essential element for plants but is phytotoxic in high concentrations. Plants will therefore die before the Mn concentration in the plant will be high enough to adversely impact the consumer.

According to Adriano (2004) the toxic effects associated with ingestion of Mn are relatively low. The main routes of absorption of Mn and its salts are via the respiratory and gastrointestinal tracts. The extent of absorption is dependent, in part, on the solubility of the Mn compound involved. Manganese oxides are less soluble than manganese salts. However, they can form chelates with organic compounds, which make them more soluble. Uptake of dietary Mn is controlled by dose-dependent intestinal absorption, biliary excretion and intestinal elimination. Adult humans normally maintain stable tissue levels of Mn regardless of intake. No information on dermal absorption of Mn could be found. Little is known about absorption of Mn through the respiratory tract in humans. As for all particles, absorption is expected to be largely dependent on the size of the inhaled particles. Many small particles that penetrate into the alveoli are eventually absorbed into the blood. Larger particles deposited in the upper airways can be transported out of the airways by mucociliary clearance and swallowed. Therefore, when intake from inhalation exposure is assessed, absorption from the gastrointestinal tract should also be considered. There appears to be some data to support the view that adverse respiratory effects may follow occupational Mn exposure, under certain circumstances (Institute for Environment and Health/Institute of Occupational Medicine, 2004).

Although the risk assessment indicated limited risk for the general public, the following mitigating factors could be implemented to protect the general public are:

- access restrictions to land application and disposal sites where WTR with high metal and micro element concentrations are applied;
- buffer zones between land application sites and dwellings;
- application restrictions (soil limits, maximum application rates and crop restrictions) to protect vegetation and indirectly protect the general public; and
- buffer zones or trenches between land application sites and surface water bodies.

6.3 Soil

Soil is the most vulnerable receptor for land application and disposal of WTR since it is the first line of defence. The application of WTR to land can have positive effects on soil properties such as an increase in water holding capacity and a decrease in extractable acidity. However, negative effects are also possible due to constituents that may be present in high concentrations in WTR such as Mn. Even though the metal and nutrient contents of the South African WTRs analysed are low, high application rates at disposal sites may cause soil degradation after several years of application.

The main constituent of concern for the soil receptor is Mn and the cumulative effect of other trace elements and metals. The soil attenuation capacity may be exceeded and the trace elements and metals may become mobile and pollute the groundwater and nearby surface water. By protecting the receiving soil (setting maximum permissible levels), the vegetation, surface water and groundwater could be indirectly protected and the risk to the end-user (humans and/or animals) could be decreased significantly.

Negative effects are manageable and mitigating factors could include:

- application restrictions for agricultural use;
- setting maximum loads for disposal sites;
- setting maximum permissible metal levels for the receiving soil for both land application and disposal sites; and
- setting management controls to ensure that application of WTR cannot cause crusting or impaired soil structure (e.g. Hughes *et al*., 2000).

6.4 Vegetation

Vegetation is vulnerable to several of the constituents present in WTR (e.g. nutrients, trace elements, metals). Plants are in direct contact with the WTR and the WTR/soil mixture from which available elements are absorbed by the plant roots.

The high concentration of Mn in South African WTRs may have a negative impact on vegetation. Manganese is a phytotoxic element which may decrease yield and food quality when present in high concentrations in WTR applied to agricultural land. Natural vegetation at disposal sites may also be impacted negatively by application of WTR with elevated Mn concentrations. However, the pH of most WTRs immobilizes the Mn and renders it generally unavailable for plant uptake (risk rating 6 (low risk)).

The following mitigating factors could be introduced to protect the vegetation:

- application restrictions for agricultural use;
- crop restrictions;
- setting maximum load restrictions at disposal sites;
- setting maximum permissible metal and micro-nutrient levels for soil; and
- setting management controls to ensure that application of WTR cannot cause crusting or impaired soil structure (e.g. Hughes *et al*., 2000).

6.5 Air

Aspects of concern for air quality include air-borne dust and odours. Dust may be a problem, due to the fine particles in the WTR, during land application (when ploughed into the soil). Sporadic dust problems can also occur during the windy season.

Odour problems could be a problem in areas where the raw water is eutrophic and where there are algal blooms. The odour of the WTR could have a negative impact on public acceptance of land application of WTR.

Sporadic dust and/or odour nuisance may adversely affect air quality. The probability is low for dust problems (may occur once every 100 days), but the odour problem at disposal sites may be higher (1 in 10-100 days). The risk rating is medium to low (<10).

Possible mitigating factors include:

- dust suppression measures may need to be implemented during the windy season or in areas where regular dust problems occur; and
- buffer zones between disposal sites and dwellings to alleviate odour problems.

6.6 Surface water

Surface water quality could be impacted via runoff from soil amended with WTR (land application) or via direct runoff from WTR (disposal sites). The WTR may cause turbidity of surface water due to fine particles transported to the surface water during rainstorms or pollution due to constituents that may dissolve during rainfall events and runoff into nearby surface water. The actual impact of WTR on surface water is mostly unknown. However, data from the Umgeni Water disposal site at Brookdale Farm (Hughes *et al*., 2005) shows that no such contamination is affecting a small dam immediately down slope from a section of the disposal area. Monitoring of this dam since September 2002 has revealed that amounts of, for example, Mn have always been <0.02 mg L^{-1}, Zn < 0.03 mg L^{-1}, and NO_3 almost always below 0.05 mg N L^{-1} (N. McNab, Umgeni Water, pers. comm.).

The major aspects of concern that may impact on surface water are the fine particles (clay and silt) and soluble constituents in the WTR (especially Mn). According to the South African Water Quality Guidelines the allowable Mn concentration for human consumption is 0.05 mg L^{-1} and to sustain aquatic life it is 0.18 mg L^{-1}. The Minimum Requirements suggest an AE of 0.30 mg kg^{-1} (DWAF, 1998). The concentration of Mn in South African WTR is thus a real reason for concern.

Possible mitigating factors to protect surface water from potential pollution could include:

- buffer zones between land application and disposal sites and surface water bodies;
- safe storage at land application sites before application;
- trenches around disposal sites; and
- slope restrictions to minimise runoff at land application sites.

6.7 Groundwater

In general, groundwater is a vulnerable receptor for pollution in South Africa. Groundwater can be impacted by the movement of nutrients and other elements through the soil profile. Although the concentrations of N and P in the WTR are not excessively high, the possibility for leaching, especially of N, still exists, especially at disposal sites. Phosphorus is generally not considered to be a leachable element, except from very sandy soils, as it is usually strongly held in soils. The high Mn content in WTR is also a concern. The relatively high pH of the WTR will immobilise Mn but movement may still be possible if the pH of the soil decreases (pH <5.5 will mobilise Mn). Particularly at disposal sites the attenuation capacity of soils may be exceeded after several years of high application rates and the Mn may become mobile. Data from a borehole at Brookdale Farm monitored since September 2002 reveal no contamination with Mn (all <0.02 mg/L) or NO_3 (almost always below 0.05 mg N/L) (N. McNab, Umgeni Water, pers. comm.).

Aspects of concern in WTR for groundwater contamination are nutrients (N, and to a much lesser extent P) and soluble constituents (trace elements and metals). The elevated concentration of leachable (TCLP extractable) Mn in South African WTR is especially a reason for concern.

Possible mitigating factors (should the risk to groundwater be high) could include:

- application restrictions based on the elements of concern for land application;
- depth restrictions to groundwater; and
- maximum load restrictions for disposal sites.

6.8 Grazing animals

Grazing animals may be impacted by ingesting WTR amended soil, by ingesting plants with high concentrations of potentially toxic elements (e.g. Mn) or by drinking surface water impacted by WTR application. The pathways through which grazing animals are impacted have several barriers that have to be overcome before the constituent of concern reaches the animal (the animal in most cases is the third receptor). The consequences for grazing animals will probably be moderate (some intervention needed) and the probability is 1:1 000 animals. Risk rating <8 (low risk).

Possible contamination of surface water and groundwater with Mn is the aspect of concern. Currently the impacts through these pathways are purely speculative since limited research has been conducted on the issue.

The impact is assumed to be manageable and mitigation factors can include:

- application restrictions for land application;
- maximum load restrictions for disposal;
- access restrictions for grazing animals on disposal sites where potentially toxic elements are known to be high; and
- buffer zones between WTR and surface water and groundwater.

6.9 Other fauna

Fauna may be impacted by ingesting WTR amended soil, by ingesting plants with high concentrations of potentially toxic elements (e.g. Mn) or by drinking surface water and groundwater impacted by WTR application. The consequences will probably be low (some intervention needed to maintain biodiversity) and the probability is 1:100 or 1:10 animals. Risk rating 10 (medium risk).

The vulnerability of natural fauna would have to receive case-specific attention. According to the Minimum requirements (DWAF, 1998, 2005), endangered species would have to be protected and therefore an environmental impact assessment would be needed where disposal is practiced.

Possible contamination of surface water and groundwater with Mn is the aspect of concern. Currently the impacts through these pathways are purely speculative since limited research has been conducted on the issue.

The impact is manageable and mitigation factors can include:

- application restrictions for land application;
- maximum load restrictions for disposal; and
- buffer zones between WTR and surface water and groundwater.

7 INTERNATIONAL GUIDELINES AND LEGAL FRAMEWORK

The views and guidelines of the international community were studied to determine how they developed their guidelines and what constituents they focused on. Internationally the term ‘water treatment sludge’ is commonly used, but in South Africa the term ‘water treatment residue’ is used to distinguish it from wastewater sludge. In the following sections both these terms are used.

The United Kingdom and the European Union (EU) list WTRs as “controlled wastes” and all such wastes are “directive wastes” and licenses are required to receive, treat, store, or dispose of “directive waste”. The EU approach to waste management policy, established in the Waste Framework Directive 75/442/EEC (amended by Directive 91/156/EEC, by Directive 91/692/EEC and by Commission Decision 96/530/EC) as well as on the Sixth Environment Action Programme “Environment 2010: our future, our choice”, is based on the guiding principle of the waste hierarchy which gives preference to waste prevention, then to waste recycling and reuse, and lastly to waste disposal. Because WTR prevention is difficult to achieve, preference must be given to WTR recycling and reuse, provided these are technical and economical feasible. Disposal of WTR to landfill must be done only when there is no other solution available (Carvalho and Antas, 2005). However, despite this intention almost all WTR produced in the EU is sent to landfill.

Few countries have guidelines for land application of WTR. Among those that do are the United States of America, Australia and New Zealand.

7.1 United States of America

At the federal level, the U.S. Environmental Protection Agency (EPA) has not established any regulations that are specifically directed at water treatment plant (WTP) residuals. Applicable regulations are those associated with the Clean Water Act (CWA); Criteria for Classification of Solid Waste Disposal Facilities and Practices (40 CFR, Part 257); the Resource Conservation and Recovery Act (RCRA); the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Superfund; and the Clean Air Act (CAA). The CWA limits direct discharges into a watercourse while the other legislation governs other methods of use and/or disposal of wastes. Most states are responsible for establishing and administering regulations that will meet the requirements of these acts. The regulation of wastes, therefore, is the responsibility of individual states (National Drinking Water Clearinghouse, 1998).

The USEPA published a document entitled: ‘Technology Transfer Handbook: Management of water treatment plant residuals’ (USEPA, 1996) which is a complete management programme for water treatment facilities. The following steps are included in the management plan:

- characterisation of the WTR (quality and quantity);
- appropriate regulatory requirements;
- feasible disposal options;
- selection of appropriate residuals processing/treatment technologies; and

- residuals management strategy.

The Water Pollution Control Act of 1972 defined WTR as industrial waste and it is listed as a solid waste under 40 CFR Part 257. If land application is to be considered a viable option, the WTR should be proven non-hazardous. The toxicity characteristic leaching procedure (TCLP) test was developed to assess the leachability of substances from potentially hazardous wastes. Recommended tests on the TCLP extract include 31 organic chemicals and 8 inorganic parameters (As, Ba, Cd, Cr, Pb, Hg, Se and Ag). Generators must analyse the wastes and if the results exceed the regulatory TCLP levels (Table 15), the waste is considered hazardous and so cannot be disposed of on land. The quality of WTR considered suitable for land disposal in the USA varies from state to state. Many states do not apply the procedure to water treatment residues after early testing showed that the substances released were well below the regulatory levels. Sensible raw water source selection and sensible chemical purchasing avoids producing residues containing levels of hazardous chemicals that may cause adverse environmental effects.

Table 15: Constituents and regulatory limits for land application of WTR in the USA (USEPA, 1996)

Constituents	Limit (mg/L)	Constituents	Limit (mg/L)
Arsenic	5	Hexachlorobenzene	0.13
Barium	100	Hexachloro-1,3-butadiene	0.5
Benzene	0.5	Hexachloroethane	3
Cadmium	1	Lead	5
Carbon tetrachloride	0.5	Lindane	0.4
Chlordane	0.03	Mercury	0.2
Chlorobenzene	100	Methoxychlor	10
Chloroform	6	Methyl ethyl ketone	200
Chlorium	5	Nitrobenzene	2
o-Cresol	200	Pantachlorophenol	100
m-Cresol	200	Pyridine	5
p-Cresol	200	Selenium	1
Cresol *	200	Silver	5
2,4-D	10	Tetrachloroethydene	0.7
1,4-Dichlorobenzene	7.5	Toxaphene	0.5
1,2-Dichloroethylene	0.5	Trichlorethylene	0.5
1,1-Dichloroethylene	0.7	2,4,5-Trichlorophenol	400
2,4-Dinitrotoluene	0.13	2,4,6-Trichlorophenol	2
Endrin	0.02	2,4,5-TP (Silvex)	1
Heptachlor (and its hydroxide)	0.008	Vinyl chloride	0.2

* If 0-, m-, p-cresol concentrations cannot be differentiated, the total cresol concentration is used.

The USEPA's view on land application of WTR can be summarized as follows: "*Care must be taken to ensure that the site is suitable for use of WTR and that controls (best management practices) are in place to protect public health and the environment*" (USEPA, 1996).

General restrictions for agricultural use include:

- the application rate should be determined by using agricultural methods, as with fertilizer;

- the lifetime application amount of WTR on agricultural soils is determined by the trace element concentrations of the WTR; and
- the same buffer zones that apply to land application of wastewater sludge also apply to land application of WTR which include minimum distances from surface water, property lines, residences, schools, etc. (USEPA, 1996).

The disposal of WTR is generally the alternative chosen by water treatment plants that either generate residues continually or have a quantity or quality problem. These disposal sites are designed to treat and dispose of large quantities of residues through soil microorganisms, sunlight and oxidation. The soils are used to bind the metals and render them immobile and unavailable. Application rates vary from 20 to 200 t ha^{-1} yr^{-1}. Generally stricter requirements apply to disposal than other land application practices. Sites need to be carefully designed, managed and monitored (USEPA, 1996).

7.2 Australia

Investigations initiated by the Federation for Water Research in association with the Water Services Association of Australia, were conducted in Australia between 1993 and 1996. The objective was to identify the potential for WTR (mainly alum residues), which is subject to stringent EPA guidelines with respect to handling and disposal, to be used as a soil ameliorant in preference to dumping it in municipal landfill sites. It was necessary to establish whether it had any physical or chemical properties that might pose an environmental health hazard when released. In all laboratory, glasshouse and field experiments, the residue was found to possess no serious detrimental properties, in particular no soluble aluminium, by comparison with natural soils in Australia. On the contrary, a number of beneficial properties were identified, including low bulk density, high infiltration rate, some available nitrogen, a neutral to alkaline pH, and modest calcium carbonate equivalence (Water Services Association of Australia, 1997).

The principal legislation addressing the use of WTR in South Australia is the Environment Protection Act, 1993. In particular, Section 25 imposes a general environmental duty on all persons using WTR, requiring them to take all reasonable and practicable measures to prevent or minimise any resulting environmental harm.

The Australian guideline provides general requirements and guidelines for the use of WTR for land application and applies to a specific site or area of land given its current use and does not relate to future land use. The overall objective of the guidelines is that WTR should be used in a manner that does not cause any harm to groundwater or surface waters, or create any dust, noise or odour problems. Water treatment residue should not be applied to land in a manner or in amounts that diminish the conservation value of a site, or in amounts that adversely impact on its agricultural use.

Maximum permissible contaminant levels are suggested (equivalent to Grade B Biosolids; Table 16) and WTR that is applied to agricultural land, other than horse tracks, should not exceed these levels. It should be applied onto land in a manner that ensures an even distribution of the material, causes no ponding on the surface of the land, and produces no runoff from the site. Vegetation used as forage by any livestock should not be coated or contaminated with WTR, and it should not be applied to land currently under cultivation for crops intended for direct human consumption. Interference with the natural habitat of Australian native animal species should be minimized.

Table 16: Maximum permissible contaminant levels in Australian WTR (Water Services Association of Australia, 1997)

Contaminant	Concentration (mg kg^{-1})
Arsenic	20
Cadmium	11
Copper	750
Mercury	9
Nickel	145
Zinc	1400
Lead	300

General restrictions which apply to land application of WTR in Australia include:

- Buffer zones:
  - occupied dwelling or school – 50 m;
  - property boundary – 20 m; and
  - open watercourse or borehole – 100 m.
- Application restrictions to minimize:
  - over-application of nitrogen;
  - phosphorus deficiencies;
  - overly alkaline conditions; and
  - overloading the soil with heavy metals.
- No livestock grazing allowed if the copper levels in the WTR exceed 200 mg kg^{-1}.
- No application allowed to land that has waterlogged soil or a slope greater than 5% unless engineering works are installed to eliminate the risk of contaminated surface runoff.
- The WTR should be ploughed into the soil profile (approximately 100-300 mm depth) unless this is counter to the intended use of the area e.g. a horse track, or if ploughed may increase the risk of runoff or soil transport down slope.
- Should not be applied to land with a pH ($CaCl_2$) below 5.5, unless the addition of WTR (in accordance with the site management rate specified), or any other soil conditioner, will raise the pH of the soil to this level after equilibration with the soil. Furthermore, the soil pH ($CaCl_2$)

should be maintained above 5.5 during the land application period and for two years after the application of WTR at the site has ceased (Government of South Australia, 2003).

No guidelines could be found for disposal other than landfill. Landfills are a mechanism for effectively treating and disposing of those wastes that, at the present time, it is neither technically feasible nor economically viable to avoid, re-use, recycle or reprocess. The Australian EPA is committed to ensuring that this unavoidable waste disposal is conducted in an environmentally responsible way. This includes ensuring that existing and potential landfill occupiers are aware of the risks landfilling poses to the quality of air, water, land and community amenity. It also involves ensuring that these occupiers take responsibility for managing these risks in the most effective way possible, e.g. by encouraging stabilisation of landfilled waste within one generation.

These Guidelines assume that there are five principal environmental management techniques for landfills that a landfill occupier must consider in order to achieve the best environmental outcome:

- site selection – an appropriate location will have natural barriers and buffer distances to help reduce environmental risk;
- design and construction – including all aspects of the design and construction of the landfill and associated infrastructure;
- monitoring – including all monitoring and reporting of air, water, noise and waste;
- site operations management – including all operational measures required to manage a landfill in an environmentally acceptable manner; and
- remediation and post-closure management – including the measures needed to minimise the impact of closed landfills and ensure the beneficial use of landfill sites after closure (Environmental Protection Authority, 1996).

7.3 New Zealand

Until very recently (before 1997) no guidelines for land application/disposal of WTR existed in New Zealand. Some water suppliers pumped groundwater or even surface water in a few cases, directly into their distribution system. Some of these supplies may have been disinfected (usually by chlorine or sometimes with ultraviolet light), or the pH corrected, or fluoride added, or aerated to remove gases. Apart from residues resulting from the addition of a chemical solution or powder, these water suppliers produced no wastes.

Other water supplies include a treatment process to remove some or all of colour and turbidity, iron and manganese, tastes and odours, and microorganisms. These treatment processes generate WTR that must be discharged. Many water suppliers still discharge their WTR to natural water without any further processing.

Guidelines for the management of WTR have been developed (New Zealand Water and Waste Association, 1997) to assist water suppliers, regional councils, and their consultants to discharge WTR in an environmentally friendly way. The guidelines aim to:

- ensure that water treatment plant wastes are handled within the legislative framework;
- discuss the adverse environmental effects that may result from their discharge;
- offer a consistent, national approach to mitigating these effects; and
- describe the options available for handling water treatment plant wastes.

The guidelines discuss the types of water treatment process used in New Zealand that produces a waste, and all the disposal scenarios. Potential land applications used for the final disposal of WTR include:

- permanent lagooning;
- landfilling (on-site monofills and regional sanitary landfills) or land reclamation;
- application to pasture or forest; and
- discharging to a wetland.

The most appropriate disposal method varies from plant to plant, and depends on land availability, distance to a suitable disposal site or sewer, the amount of WTR, landfill acceptance criteria, and environmental requirements. Land application is one of the most common methods of disposal of water treatment plant residues. Land application allows sunlight and soil microorganisms to biodegrade the organic matter contained in the WTR while the soil binds the metals, thereby utilising the land itself as a treatment system (New Zealand Water and Waste Association, 1997).

The guidelines highlight the concern related to the tendency for aluminium to fix phosphorus in the soil, making it unavailable to plant roots for growth. Other factors such as general physical instability and the potential high trace element content of WTR generate cause for concern. It is relevant to note here that the study by Hughes *et al*. (2005) [notably that of Buyeye (2005)] showed that the South African WTRs examined also showed extremely high P adsorption capacity when this investigation was carried out in the laboratory. However, the field experiments using a polyacrylamide WTR reported in those documents that ran for over 5 years revealed no P deficiency in either of the grasses used as test species. Similar findings, from field experiments using alum and other types of WTR, have been reported by workers in Australia (e.g. Ahmed *et al*., 1997) and the USA (e.g. Grabarek and Krug, 1987; Geertsema *et al*., 1994). Buyeye (2005) suggests that any adsorption of P encouraged by the WTR could be beneficial on soils prone to leaching of P such as those of coarse texture. Indeed the potential of alum WTR to adsorb P is being tested in the USA on irrigated soils where leaching of P has the potential to lead to eutrophication of surface and groundwater (E. Dayton, Ohio State University, pers. comm.).

Few land disposal schemes operate in New Zealand at present, and monitoring results are limited. Any water supplier considering land disposal should conduct simple leaching tests (not TCLP) if their WTR contains any substances that could affect the soil or plants. Landfill operators in New Zealand are going through the process of developing "*waste acceptance criteria*". At present each application to dispose of WTR at a landfill is considered afresh. Most landfill operators at this stage are only interested in whether the WTR is "*spadeable*". With respect to WTR, it is highly likely that this assessment will become more technical in the sense that "*spadeable*" will probably be defined in engineering terms in due course. There does not appear to be any chemical reason to constrain disposal of WTR at New Zealand landfills (New Zealand Water and Waste Association, 1997).

Large earthen basins, termed lagoons, have been used as a method of WTR thickening as well as a means of ultimate disposal. WTR solids settle in lagoons and the supernatant is normally discharged to natural water or recycled to the head of the plant for treatment. Often it is intended that the lagoon is to be used for storage and thickening, but the costs of emptying it, and the difficulty in knowing where to transfer the WTR, means that the lagoon is allowed to dry out and perhaps be filled in. These are becoming less economically attractive with the implementation of national regulations governing their construction and operation. Groundwater monitoring is often required to detect any degradation of ambient groundwater quality.

A lagoon that is left to "*revert to nature*" will take a long time to dry out. After the supernatant has been drained away or allowed to dry off, the WTR at the surface forms a crust, giving the appearance that the lagoon is now filled with dry WTR. This is not so. The crust-covered lagoon can be compared to a frozen pond – the surface may or may not support the weight of a human or stock. Therefore it is important to fence off the lagoon and to ensure that it remains fenced off. It may take several years before the WTR dries out to the base of the lagoon. There will be a large amount of shrinkage during the drying out process (New Zealand Water and Waste Association, 1997).

8 SOUTH AFRICAN LEGAL CONTEXT

During the development of the new Sludge Guidelines, an extensive legal review has been conducted on the utilisation and disposal of wastewater sludge (Hughes, Snyman, Herselman & Ndoro, 2008). Since WTR and wastewater sludge are both classified as waste in terms of the National Water Act (NWA, Act 36 of 1998), which states that: '*"waste" includes any solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted'*, the legal context will be similar.

A number of environmental management related policies and law reform programmes have been introduced in South Africa over the last few years. This renewal process was spearheaded by the South African Constitution of the Republic of South Africa which laid the foundation for a democratic and open society in which government is based on the will of the people. The Constitution promotes equity, protects the rights of access to resources and also stipulates fundamental environmental rights in the "Bill of Rights" which aims to improve the quality of life for all citizens. These Constitutional environmental rights were enacted through a framework statute, the National Environmental Management Act , 1998 (Act No. 107 of 1998) (NEMA), which can be described as South Africa's "primary" or "parent" environmental statute as it gives guidance to all environmental management related legislation.

Collectively a hierarchy of policies and legislation, which includes South Africa's international commitments, the Constitution, applicable Acts of Parliament, Provincial Legislation and Local Government Bylaws, govern environmental management in South Africa. Amongst these the NEMA, NWA and ECA serve as the primary legislation that guide waste management and pollution control. These statutes together with other media specific environmental legislation all reflect and pursue the common goal of sustainable development. The 'sustainable development hierarchy' in terms of South African legislative context is depicted in Figure 3 (Samson, 2001 *adapted*).

The legislative framework of governance consists of several levels (DWAF, 2004), including:

- Principles;
- Policy;
- Legislation;
- Regulations; and
- Best Practice Guidelines.

The South African Water Treatment Residue Guideline can be categorised together with the Sludge Guidelines as a Best Practice Guideline. However the guidelines can be considered regulatory if contained within a water use authorisation.

The existing legislative framework within South Africa now promotes more environmental responsibility and duty, while at the same time supporting much needed social and economic growth.

Due to the diverse and fragmented nature of environmental law, pollution laws in South Africa arise from various sources, from the pure environmental to safety and health, planning, nature and conservation and natural resources, to name but a few.

In terms of the National Water Act (NWA, Act 36 of 1998) the following apply to water service providers (WSP) and water service authorities (WSA) regarding water abstraction and treatment:

- If a WSP abstracts, treats and then supplies to reservoirs under control of the WSA:

    - The WSP must have the relevant authorisations, i.e. for abstraction and storage i.e. Section 21(a) and (b) respectively;

    - The WSA would also then need an authorisation for storage, i.e. Section 21(b).

If a WSA abstracts, treats and then store in reservoirs the WSA must have the relevant authorisations, i.e. for abstraction and storage, i.e. 21(a) and (b) respectively.

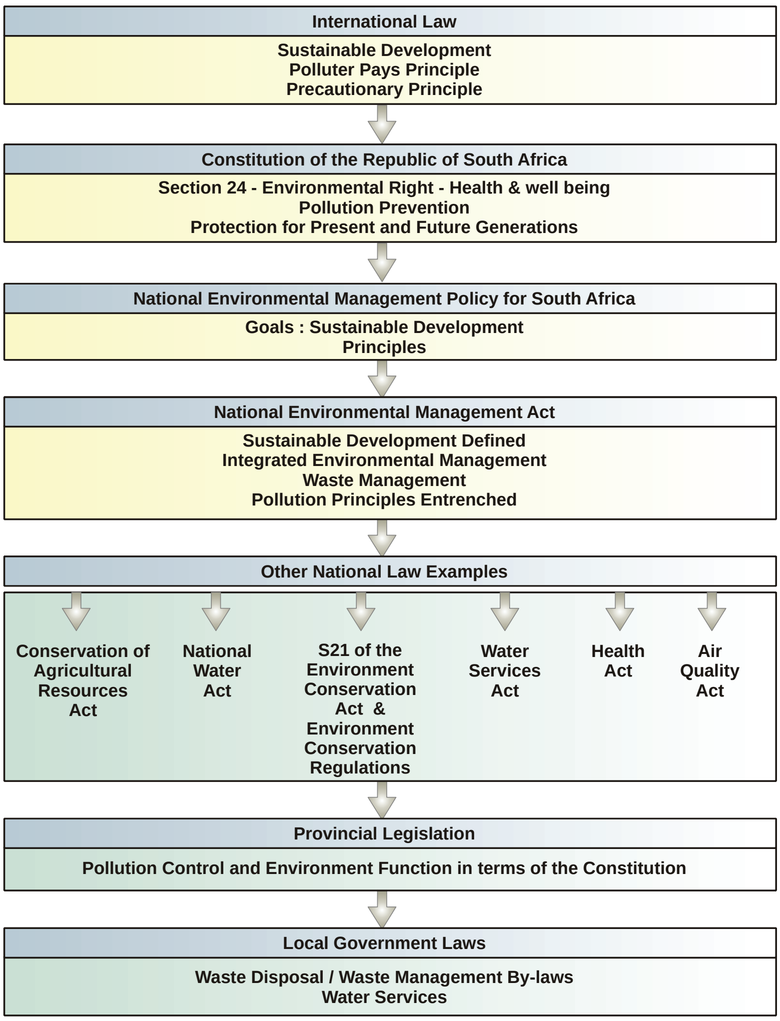

Figure 3: Sustainable development hierarchy (Samson, *2001 adapted*)

8.1 The National Water Act (Act No. 36 of 1998)

The National Water Act (Act No. 36 of 1998) (NWA) manages the water resources in South Africa and has as its fundamental principles sustainability and equity which serve central guiding principles in the protection, use, development, conservation, control and management of water resources. The NWA identifies as its purpose the need for promoting efficient, sustainable and beneficial use of water in the public interest, facilitating social and economic development while concurrently reducing and preventing pollution and degradation of water resources.

To give effect to the interrelated objectives of sustainability and equity, a management approach has been adopted that introduces measures to protect water resources by setting objectives for the desired conditions of resources, and simultaneously putting measures in place to control water use and limit impacts to acceptable levels (DWAF, 2004). The NWA also introduces several new important concepts, the following which are relevant to the WTR management in terms of the water use and the water use authorisation process (DWAF, 2000):

- The scientific indivisibility of water as part of the hydrological cycle is recognised and the *water resource* is defined to be all water found in various phases of the hydrological cycle, including the water found *underground*;
- To achieve effective resource protection, two distinct but integrated sets of measures are introduced, namely *resource directed* and *source directed* measures. Resource directed measures set clear *objectives* for the desired level of *protection* for resource quality based *inter alia* on the resource classification system, user requirements, etc.; and source directed measures aim to control the *source of potential impacts* on the water resource (e.g. water use authorisations, best management practices – such as the WTR Guideline, etc.);
- In terms of the NWA, use of water is no longer limited to consumptive uses such as abstraction of water, but also includes non-consumptive use, such as wastewater discharge and recreation. The NWA identifies *11 water uses* in terms of section 21 (Table 17), which is regulated by a range of regulatory instruments (licences, Schedule 1, is an existing lawful use, or is permissible under a general authorisation). With regard to wastewater management, *sections 21(e), (f)* and *21(g)* of NWA are of specific relevance, as most producers and/or users would require a water use authorisation in terms of these sections of the NWA;
- The NWA furthermore recognises water as a valuable commodity (an "economic good"), since all authorised use of water will be charged for through a pricing strategy for water use charges in terms of Section 56 of the NWA. In this regard waste discharge charges, are being developed under section 56 (5) of the NWA for uses that may impact on the water resource, in the fulfilment of the principles of *pollution prevention* and the *polluter pays*. In terms of this waste discharge charge system that is currently under development, a section 21 (e), (f) or (g) water use is subject to the system of waste discharge charges;
- The concept of the "Reserve" which comprises that quantity and quality of water required to satisfy basic human needs and to protect aquatic ecosystems, in order to ensure *ecologically*

sustainable development and is introduced. This concept is based on sections 24 and 27 of the Constitution; and

- The NWA also defines, in Chapter 16 of the Act, acts and omissions which are considered *offences*, and are bound by associated penalties. Of specific relevance to the management of wastewater the following offences should be noted:

  - Failing to comply with any condition attached to a permitted water use under the NWA;

  - Failing or refusing to give data or information, or give false or misleading data or information when required to do so in terms of the NWA;

  - Unlawfully and intentionally or negligently committing any act or omission which pollutes or is likely to pollute a water resource; and

  - Unlawfully and intentionally or negligently committing any act or omission which detrimentally affects or is likely to affect a water resource.

Table 17: Water uses as defined in Section 21 of the NWA

Section	Water Uses
21 (a)	taking water from a water resource
21 (b)	storing water
21 (c)	impeding or diverting the flow of water in a watercourse
21 (d)	engaging in a streamflow reduction activity (currently only commercial afforestation)
21 (e)	Engaging in a **controlled activity** – activities which impact detrimentally on a water resource (identified in section 37 (1) or declared as such under section 38 (1) *viz*.: • **Irrigation of any land with waste** or water containing waste which is generated through an industrial activity or a waterwork; • An activity aimed at the modification of atmospheric pollution; • A power generation activity which alters the flow regime of a water resource; and • Intentional recharging of an aquifer with any waste or water containing waste.
21 (f)	**discharging waste** or water containing waste into a water resource through a pipe canal, sewer, **sea outfall** or other conduit
21 (g)	**disposing of waste in a manner** which may detrimentally **impact on a water resource**
21 (h)	disposing in any manner water which contains waste from, or which has been heated in, any industrial or power generation process
21 (i)	altering the bed, banks, course or characteristics of a watercourse
21 (j)	removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people
21 (k)	using water for recreational purposes

8.1.1 Regulation of water use

In terms of section 4 of the NWA, a person is entitled to a water use if it is a Schedule 1 water use, a continuation of an existing lawful water use, or authorised in terms of a general authorisation or licence. These regulatory instruments involve different levels of regulatory control, and the specific circumstances determine the type of water use authorisation that is applicable. A water use is not permitted unless it is authorised by one of these authorisations. The NWA's provisions in respect of Schedule 1 use and general authorisations are primarily intended to reduce the administrative load of authorising every use in the country.

Section 41 of the NWA also specifies that in application for a licence a responsible authority (e.g. DWAF Regional Office) may require an impact assessment that must comply with the EIA regulations promulgated under section 26 of the Environment Conservation Act (Act No. 73 of 1989). This is of specific relevance to disposal of WTR, as the selected disposal option may require such an assessment if it is required to be authorised in terms of section 21 (g) of the NWA.

Types of Water use Authorisations and situations that determine the required type of authorisation are:

- **Schedule 1 uses**: Includes water uses that involve small quantities of water, mainly for domestic use (including non-commercial livestock and stock watering, and water for use in emergency situations and certain recreational use) and where the responsibility for waste and wastewater management lies with another person authorised to do so. Water use is also subject to any other relevant laws, ordinances, bylaws and regulations. There is no formal requirement for users to register a Schedule 1 use.
- **Existing lawful use**: A transitional measure that the Act permits for those water uses that were lawfully exercised under any law preceding the promulgation of the NWA, which had taken place between 1 October 1996 and 31 September 1998.
- **General Authorisations**: Water use is permissible without a licence provided that it is compliant to the conditions of the General Authorisation. General authorisations allow a limited, but conditional water use without a licence. Limits are placed on water use under the general authorisation depending on the nature of the use and the capacity of the resource to accommodate the use without significant degradation.
- **Water Use Licence**: Water uses that exceed Schedule 1 use, are not covered by or exceed the limits imposed under a general authorisation and are not regarded or declared as an existing lawful use; require an authorisation by a water use licence.

Regulation/Notices in terms of the NWA relevant to WTR Guideline:

- Regulations requiring that a water use be registered (Government Notice Regulation 1352, Government Gazette No. 20606 of 12 November 1999);

- Establishment of a Pricing Strategy for Water Use Charges in terms of section 56 (1) of the National Water Act (Government Notice Regulation 1353, Government Gazette No. 20615 of 12 November 1999);
- Revision of General Authorisations in terms of Section 39 of the National Water Act, 1998 (Act No. 36 of 1998) (Government Notice Regulation 399, Government Gazette No. 26187 of 26 March 2004); and
- General Notice – Preface to the proposed Pricing Strategy for Raw Water (Notice 1045, Government Gazette No. 27732 of 1 July 2005).

8.2 National Environmental Management Act (Act No. 107 of 1998)

The National Environmental Management Act (Act No. 107 of 1998) (NEMA) serves as the guiding framework legislation for environmental management in South Africa. It can be described as South Africa's "parent" environmental statute and guides decision-making in all legislation concerned with the environment.

The NEMA reiterates the provisions of Section 24 of the Constitution and entrenches the internationally accepted principle of sustainable development. The NEMA includes in Chapter 2, a set of fundamental guiding principles which governs the actions of organs of state that may significantly affect the environment. These principles include amongst others, the "polluter pays", "cradle to grave", "precaution" and "waste avoidance and minimisation". It is a legal requirement that these principles must be taken into consideration in all decisions that may affect the environment. NEMA also emphasises the need for integration and harmonisation of policies, legislation and actions relating to the environment.

While the Sludge Guidelines should be guided by all the principles of Chapter 2 of NEMA, of specific relevance to the development of the management options are the following:

- Sustainable development requires that a risk averse and cautious approach is applied, which takes into account the limits of current knowledge about the consequences of decisions and actions.
- Environmental management must be integrated, acknowledging that all elements of the environment are interlinked and interrelated, and it must take into account the effects of decisions on all aspects of the environment and all people in the environment by pursuing the selection of the best practicable environmental option (BPEO). (NEMA defines best practicable environmental option as 'the option that provides the most benefit or causes the least damage to the environment as a whole, at a cost acceptable to society, in the long term as well as short term).
- NEMA also imposes a duty on everyone who causes, has caused or may cause significant pollution or degradation of the environment to take reasonable measures to prevent it occurring, continuing or recurring. Where harm to the environment is authorised by law or cannot reasonably be avoided or stopped, a duty exists to minimise and rectify the harm. Although everyone has this duty, the Act singles out the owner of the land or premises, a person in control or a person who has the right to use land or premises on which the activity or process is or was

performed or undertaken, or any other situation exists, which causes, has caused, or is likely to cause significant pollution or degradation of the environment, to take reasonable measures.

8.2.1 Waste Bill

The National Environmental Management: Waste Bill was developed as subsidiary legislation to NEMA. The Waste Bill is framework legislation that provides the basis for the regulation of waste management, detailing regulation of different types of wastes requiring specific regulatory approaches to ensure that they are optimally managed from an environmental perspective. The Bill includes:

- National waste management strategy, norms and standards;
- Institutional and planning matters;
- Waste Management Measures;
- Licensing of Waste Management Activities;
- Waste Information; and
- Compliance and Enforcement, General matters and miscellaneous matters.

The definition of waste in the Waste Bill states the following: '***''waste''*** *means any substance, whether or not that substance can be reduced, re-used, recycled and recovered—*

a) that is surplus, unwanted, rejected, discarded, abandoned or disposed of;

b) which the generator has no further use of for the purposes of production;

c) that must be treated or disposed of; or

d) that is identified as a waste by the Minister by notice in the Gazette, and includes waste generated by the mining, medical or other sector, but—

i. a by-product is not considered waste; and

ii. any portion of waste, once re-used, recycled and recovered, ceases to be waste;'

Regarding the reduction, re-use, recycling and recovery of waste, Section 17(1) of the Waste Bill states: "*Unless otherwise provided for in this Act, any person who undertakes an activity involving the reduction, re-use, recycling or recovery of waste must, before undertaking that activity, ensure that the reduction, re-use, recycling or recovery of the waste—*

a) *uses less natural resources than disposal of such waste; and*

b) *to the extent that it is possible, is less harmful to the environment than the disposal of such waste."*

A new section in waste legislation is that of "Contaminated land". The purpose of the section is to provide for the remediation of contaminated land. It includes sections on identification of investigation areas, consequences of identification, consideration of assessment reports, remediation, transfer and registration of contaminated land.

The Waste Bill provides the licensing of waste management activities with DEAT as the leading authority but still considering co-operative governance. The process includes application procedures for licence application, appointment of persons to manage the process, factors to consider for the authorities, contents of waste management licences, transfer of waste management licences, renewal of licences and revocation and suspension of licences.

The **Waste information** chapter provide for the gathering of waste information by government to be able to monitor the effectiveness of initiatives of policies and strategies on waste management. It includes the requirements for establishment of waste information system, specific objectives for the national waste information system, and requirements for provision of information and conditions for access to this information.

Since the Waste Bill has only been accepted in October 2007, the roll-out is still underway and it is still uncertain how it will impact on the utilization and disposal of WTR.

8.3 Environment Conservation Act (Act No. 73 of 1989)

Although NEMA has repealed many of the provisions of the Environment Conservation Act (Act No. 73 of 1989) (ECA), the Environmental Impact Assessment (EIA) regulations in terms of ECA still remain in force until they are replaced with new regulations under the NEMA (currently in draft format – Government Regulation Number 764 of 25 June 2004). The regulations, (Government Regulation Number 1182 of 5 September 1997), are made in terms of section 26 of ECA, and relate to EIAs provided for in sections 21 and 22 of the ECA, and the provisions dealing with waste management under section 20. Policies published in terms of the ECA also promote the principle of sustainable development and the polluter pays.

8.3.1 Environmental Impact Assessment Regulations

The regulations promulgated in terms of Section 26 of the ECA, aim to control activities, as listed in Sections 21 and 22 that have a detrimental effect on the environment. The objectives of these sections are to:

- Ensure that the environmental effects of activities are taken into consideration before decisions in this regard are taken;

- Promote sustainable development, thereby supporting Section 24 of the Constitution;
- Ensure activities undertaken do not have a substantial detrimental effect on the environment, and to prohibit those activities that will;
- Ensure public participation in the undertaking of activities, and
- Regulate the process and reports required to enable the Minister or the designated competent authority to make informed decisions on activities.

The regulations describe the list of activities which are considered to pose a potential detrimental effect on the environment in terms of Section 21 of the ECA, and stipulate the requirements of the EIA required in terms of Section 22 of the ECA, for these identified activities. The EIA process must be conducted and an EIA report must be submitted in order to obtain an authorisation for a particular activity. In terms of WTR management and its beneficial use, the activities listed in Schedule 1 of these regulations that are of relevance are contained in Table 18.

Table 18: Activities identified in terms of Section 21 of the ECA that are of relevance to the management of WTR

SCHEDULE 1
1. The construction or upgrading of: (c) transportation routes and structures, and manufacturing, storage and handling or processing facilities for any substance which is dangerous or hazardous and is controlled by national legislation.
2. The change of land use from: (c) agricultural or undetermined use to any other land use.
8. The disposal of waste in terms of section 20 of the ECA, 1989.
9. Scheduled processes listed in the Second Schedule to the Atmospheric Pollution Prevention Act, 1965 (Act No. 45 of 1965) (This schedule is still applicable in terms of section 62 of the National Environmental Management: Air Quality Act, Act 39 of 2004).

These activities must undertake an EIA before an authorisation is issued, which will take the form of a record of decision (ROD). This process maybe required for any of the WTR management options selected. The delegated authority responsible for the issuing of these authorisations is the Provincial Departments of Environmental Affairs and Tourism. However, the depending on the specific situation the detail and extent of the EIA will vary. This can vary from a full EIA to a scoping level assessment. If the situation permits it, for example the construction and upgrading of sewage treatment plant infrastructure, an exemption to the EIA can be applied for.

It must be noted that an authorisation granted by Minister of Environmental Affairs and Tourism or his delegated authority, does not necessarily exempt that activity from water use authorisation issued by DWAF in terms of the NWA. However, since the authorisations required by both authorities, require similar investigations and processes, they are usually conducted concurrently in the spirit of co-operative governance and harmonised decision-making (Section 22 (4) of the NWA, 1998).

8.3.2 Waste Management

In terms of section 20(1) of the ECA, no person may, establish, provide or operate a disposal site without a permit issued by the Minister of Water Affairs and Forestry. This was considered the appropriate regulatory authority as the longer term impact resulting from the disposal of waste on land is on the water environment, particularly the groundwater environment, which could pose as a severe threat on groundwater quality, with irreversible impacts. However, since 1989, there have been significant policy changes, legislative and technological developments in the area of environmental management as a whole and waste management in particular. These developments have included amongst others:

- The adoption of a Integrated Waste Management Approach and Waste Management Hierarchy; and
- Disposal technologies now pose threats to all environmental media, not just water.

In this regard the DEAT, together with the provincial environmental departments, are seen as the most appropriate integrated waste management authority to assume responsibility for the entire pollution and waste management cycle. This will provide the required waste management co-ordination, coherence and consistency. To this end, the authority for the administration of waste disposal sites has now been transferred to the Minister of Environmental Affairs and Tourism in terms of Section 1 of the Environmental Conservation Amendment Act, (Act No. 50 of 2003). Section 1 of the Environment Conservation Amendment Act however was commenced through a Presidential Proclamation on 3 January 2006. On this date, the Section 20 ECA disposal site permit function and competency was transferred from DWAF to DEAT.

<u>Section 20 Requirements</u>

In terms of section 20 (6) of the ECA, "*No person shall discard waste or dispose of waste in any other manner, except (a) at a disposal site for which a permit has been issued in terms of section 20 (1); or (b) in a manner or by a means of a facility or method and subject to such conditions as the Minister may prescribe*". In this context it is therefore important to understand the legal definitions of **disposal site** and **waste** in terms of the ECA, 1989.

Disposal site: *"means a site used for the accumulation of waste with the purpose of disposing or treatment of such waste"*. This implies that a person treating waste for re-use or any other purpose may only do so after approval has been obtained from the Minister of Environmental Affairs and Tourism. It is also important to note that in obtaining a permit in terms of Section 20 (1) of the ECA, 1989, the EIA regulations promulgated for implementation of Sections 21, 22 and 26, must be complied with.

Waste: *"means any matter, whether gaseous, liquid or solid or by any combination thereof, which is from time to time designated by the Minister of Environmental Affairs and Tourism by Notice in the*

Gazette, as an undesirable or superfluous by-product, emission, residue or remainder of any process or activity". In this regard, Government Notice 1986 in Government Gazette 12703 of 24 August 1990 describes what is meant by 'waste" in the context of the ECA definition. In relation to WTR, it is considered a waste in terms of this notice (see below), and thus its management has to satisfy the requirements of Section 20 of the ECA, 1989.

However a number of waste products, including potentially hazardous wastes escaped this regulation due to this definition, and this has resulted in a potential threat to the environment. This definition in terms of the ECA, 1989, also does not apply in all instances and situations for waste disposal on land in a manner that may detrimentally impact on a water resource. In these situations, these activities may be regulated in terms of the NWA, 1998, through a licence, general authorisation or a directive in terms of section 19, as they identified as a waste in terms of the NWA.

This scenario may hold true for many WTR disposal sites for example, (1) instances where the disposal sites ceased to operate prior to 1990, and are still causing deterioration of water resource quality; (2) instances where the activity cannot be regulated by the ECA, such as the irrigation of land with waste; and (3) instances where the water resource is under threat, and holder of permits under the ECA, and also required to apply for water use licences.

Minimum Requirements

The Minimum Requirements (1998) are a series of documents developed as part of the waste management series by the DWAF. As DWAF has until recently been mandated through Section 20 of the ECA to ensure the correct management of waste in South Africa, it developed a regulatory system to protect the environment and the public from the harmful effects of bad waste disposal practices. This 'regulatory system' took the form of the Minimum Requirements, which were published in 1998 (second edition), and included the minimum procedures, actions and information that was required from a permit applicant who required a waste disposal site permit. The Minimum Requirements provide the applicable waste management standards or specifications that must be met in the absence of any valid motivation to the contrary. These documents also provide a point of departure against which environmentally acceptable waste disposal practices can be distinguished from those that are environmentally unacceptable. The definition of waste in terms of the Minimum Requirements is as per the ECA, 1989 specified in Government Notice 1986 in Government Gazette 12703 of 24 August 1990. In terms of this definition WTR **is defined as a waste**.

The Minimum Requirements is enforceable through the Section 20(6) of ECA, 1989 and Section 22 of NWA, 1998. Conformance to the Minimum Requirements means conformance to its objectives which include prevention of water pollution, and the protection of human health and the environment. These objectives support the Constitution in terms of Section 24 in the Bill of Rights.

The Minimum Requirements (Second Edition, 1998) produced as part of the Waste Management Series, by the DWAF, comprises the following:

- **Document 1**: Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste
- **Document 2:** Minimum Requirements for Waste Disposal by Landfill
- **Document 3:** Minimum Requirements for the Monitoring of Water Quality at Waste Management Facilities

8.4 WTR management options and related authorisations and/or licenses

Different utilization and disposal for WTR will require different authorisations and/or licenses and can be summarized as follows:

- Discharge of residue from WTP into a water course falls under Section 21 of the NWA and should be authorised accordingly (Section 21(g));
- On-site disposal of WTR on land requires:
  - A disposal site permit i.e. Section 20 of Environment Conservation Act (ECA); and
  - A Water Use Authorisation i.e. Section 40 of NWA;
- Off-site disposal of WTR on land and landfill requires a Section 20 ECA permit;
- Off-site beneficial use – user must comply with Directions in terms of Section 20 (5)(b) of ECA (Act No. 73 of 1989);
- Agricultural use – producer/user must comply with Sections 3 and 6 of the Conservation of Agricultural Resources Act (CARA) (Act No. 43 of 1983).

In terms of Section 20 of the ECA (Act 73 of 1989) (ECA), no person may dispose of waste unless under the authority of a permit issued in terms of the ECA (DWAF, 2003). A disposal site permit, guided by the Minimum Requirement Series for Waste Disposal that informs users in terms of waste disposal standards, waste classification and monitoring (DWAF, 1998) would be needed for disposal of WTR.

The NWA is not only concerned with land disposal of WTR but allows for a 'general authorization' that does not require a license, but is subject to the relevant regulations under Section 26 and conditions imposed under Section 29. These Sections require *inter alia* that waste standards be prescribed, and that adequate monitoring and analysis be undertaken based on 'permissible levels for some or all of its (the waste) chemical and physical components'. With the signing of the Memorandum of Agreement between DWAF & DEAT, the agreement is that all disposal on land will require a disposal site permit in terms of ECA and DWAF can dispense with the license requirement on condition that all the water aspects are adequately covered.

9 LAND APPLICATION / AGRICULTURAL USE

Land application of WTR is an increasingly popular management option in the water supply industry due to the escalating regulatory and environmental constraints associated with disposal. This application process may beneficially modify soil properties while recycling residual components. Potential disadvantages of land application of WTR include an increase in the concentration of metals in the soil and possibly in ground water; adsorption of soil phosphorus by WTR, decreasing the productivity of the soil; and possible effects caused by the application of poorly crystallized solids of aluminium and iron.

The most common land application techniques for WTR are:

- Land application on agricultural land;
- Land application on forest land;
- Land reclamation.

Whether adding WTR to soil has adverse environmental effects or is beneficial depends on a multitude of factors, some interrelated. Some of the factors that will affect the suitability of this disposal system include:

- pH and chemical content of the WTR and receiving soil;
- plant available and leaching characteristics of the WTR;
- WTR application rate and frequency;
- the soil type;
- cation exchange capacity of the soil;
- rainfall/irrigation rates;
- the intended use of the land; and
- the nutrient requirements of plants.

The agronomic application of WTR to land presents an attractive and potentially sustainable management option for many water treatment plants. Successful implementation of this management option requires an understanding of the effects of WTR on soil fertility and physical properties. The physical characteristics of soil that determine whether it can support vegetative growth include cohesion, aggregation, strength and texture. These parameters directly affect the hydraulic properties of a soil, such as moisture-holding capacity, infiltration, permeability, and drainage. Any adverse impact on these hydraulic soil characteristics from land-applied WTR can effect crop growth and ultimately degrade ground water quality. Management strategies need to be implemented and parameters such as pH control, crop selection and availability, application rates, and fertilizer requirements must be included in the management planning.

9.1 Effect of WTR on soil properties

Published research results on the effect of WTR on soils are minimal when compared to research done on wastewater sludge and its effect on soil properties. The main reasons for this are:

- WTR is perceived to be relatively innocuous and therefore posed limited risk for adverse environmental effects compared to wastewater treatment sludge (Elliott and Singer, 1988); and
- until recently there was limited legal restriction to WTR being returned to water courses. Consequently alternative forms of waste disposal were not seen as pressing issues deserving of additional research.

A summary of the effect of WTR on the physical and chemical properties of soils will be presented in the sections that follow.

9.2 Soil physical properties

Most of the published data focus on chemical aspects of WTR and not the physical properties. However, research conducted by Rengasamy *et al*. in 1980 on the effect of alum WTR on three soil types showed that WTR could be used as a soil conditioner due to improvement of soil physical properties and its high tendency to adsorb phosphorus.

9.2.1 Water retention

Rengasamy *et al*. (1980) found that WTR increased the water holding capacity of clay soils by 18% and that of sand by 85%, after the addition of 20 Mg/ha of WTR as a suspension. The effect of alum WTR on soil water retention has been further addressed by Geertsema *et al*. (1994) and Ahmed *et al*. (1997) who found that alum WTR had a non-significant influence on the soil's water retention.

Dayton and Basta (2001) examined 17 WTRs from Oklahoma for plant available water (PAW). They found that the median value of 0.139 kg/kg was within the typical range for soils (0.063 to 0.300 kg/kg). They concluded that while some WTRs may have high water holding capacities, PAW may be low. Ahmed *et al*. (1997) also found that pure air dried WTR has relatively high mass water content at matrix potentials of -30 kPa and -1500 kPa but low PAW. They attributed this low PAW content to a predominance of fine pores that characterised the WTR. For this reason they recommended against using pure WTR as a root growth medium. Nevertheless, they concluded that during land disposal, PAW may be controlled more by the aggregate-size distribution of the soil-WTR mixture than by the WTR alone.

Hughes *et al*. (2005) conducted field trials with WTR in South Africa. They found that WTR influenced several soil physical properties. Soil bulk density decreased following the addition of WTR to soil. This caused an increase in porosity (particularly macro porosity) and therefore water retained at saturation. This effect was reduced at Brookdale after about 4 years, while it was still very evident at Ukulinga Farm after the same period of time. An increase in water retention at wilting point (-500 kPa matrix potential) also occurred, owing to the high micro porosity of WTR aggregates. Despite these effects, very little change was measured in either plant available or readily available water content. Neither gypsum nor lime caused any significant change in water retention. A slight improvement was noted on the PAM treatment at Brookdale Farm but this effect did not persist for very long after the trial was established

9.2.2 Permeability and hydraulic conductivity

The infiltration process is therefore important in effective soil, water and crop management. Rainfall received at the soil surface can infiltrate the soil, contribute directly towards surface runoff or be stored temporarily in soil surface depressions. With WTR-amended soils, the rate of infiltration is of particular concern. If infiltration is reduced after waste addition, the amount of surface runoff will probably be increased and with that an increase in the risk of accelerated soil erosion. On the other hand, if water-soluble pollutants are added with the waste, an increase in the infiltration rate may be detrimental in terms of especially groundwater pollution. One of the few studies that addressed this issue is that of Ahmed *et al.* (1997) in a field trial in Adelaide, Australia. Alum WTR was applied to clayey soil and they found that the infiltration rate of theses soils increased significantly with WTR application.

Hughes *et al*. (2005) found that *in situ* field measurements were strongly influenced by natural spatial variability, WTR caused a marked increase in the saturated hydraulic conductivity. The reasons for this relate to the higher porosity and the inherently stable nature of the WTR aggregates, which imparts a more open structure to the soil and reduces the extent of pore blockage.

9.2.3 Soil aeration

The capacity of the soil to maintain gas exchange with the atmosphere is an integral factor in determining the feasibility of land treatment as a waste disposal practice. Adequate aeration is important for the respiration of plant roots and microorganisms (Glinski and Stepniewski, 1985) and for the assimilation of the waste product. Information regarding the effect of WTR on soil aeration is rare. Ahmed *et al.* (1997) found that bulk density was reduced significantly and total porosity increased significantly with increasing application rate of an alum WTR.

9.2.4 Soil structure

Deterioration in soil structure or a decrease in its stability may hinder the capacity of the WTR amended soil to support plant growth and maintain adequate levels of soil workability. The influence of WTR on soil stability is therefore important to evaluate the potential of land treatment as a disposal option but there have been limited studies on specifically the influence of WTR on this subject.

Rengasamy *et al*. (1980) showed that alum WTR had a beneficial effect by decreasing clay dispersion and slaking, so improving the stability of soil aggregates against the disruptive forces of water.

Skene *et al*. (1995) and Ahmed *et al*. (1997) refer to the aggregation properties of WTR, but not to their influence when incorporated with soils. Skene *et al.* (1995) examined a polymer WTR and an alum WTR as plant growth media. They reported that when the WTRs were subjected to a few wetting and drying cycles they broke down to a loose granular structure resembling gravel. These aggregates were, however, not prone to slaking during rapid wetting. The gravel texture means that the WTRs were generally very porous and drained well.

9.2.5 Soil strength

Soil mechanical strength provides anchorage for plants and therefore can have both a direct and indirect influence on crop growth (Young and Mullins, 1991, De Freitas *et al*., 1996). Direct influences relate to root growth and production while indirect effects refer to the timing of land management practices such as tillage or cultivation (Jayawardene and Blackwell, 1990). Since WTRs comprise essentially silt- and clay-sized material, release of this fine fraction due to structural breakdown of the WTR may alter soil strength. Excessive mechanical strength, in particular, is extremely undesirable as it often leads to reduced seedling emergence, poor aeration properties, reduced hydraulic transport and increased risk of sediment scour and entrainment (Mullins *et al.*, 1987, 1990; Proffitt *et al.*, 1995). This factor is of special importance in the successful operation of the land treatment system, since excessive soil strength development could potentially hamper the successful establishment of crops and therefore compromise the viability of the disposal scheme.

The only published study to have directly investigated the influence of WTR on soil strength is that of Rengasamy *et al.* (1980) who reported a decrease in soil strength in response to a maximum WTR application of 20 Mg/ha. Indirectly, Bugbee and Frink (1985) also alluded to the reduction in soil strength with increased WTR application.

9.2.6 Summary of SA studies

By concentrating the disposal of WTR onto a relatively small area of land there may be detrimental effects on soil physical properties due to the blockage of pores with associated problems in terms of changes to hydraulic properties. Hughes *et al.* (2005) monitored the effects of the Midmar WTR on the Hutton and Westleigh soils for 5 and 4 years, respectively. In addition, by laboratory experiments the project was extended to include two other soils with very different properties (a Valsrivier and a Cartref). A wide range of soil physical measurements was taken in the field from all the main applied treatments.

The overwhelming conclusion from all these measurements was that the Midmar WTR actually improved the soil physical properties of both soils shortly after application. With time the soils on the treated plots have gradually reverted to the situation that pertains on the control plots. There is no evidence that even the very high application rate (1280 Mg/ha) has resulted in any adverse effects on the physical condition of either the structurally stable apedal Hutton or the hard-setting Westleigh soils. Similar conclusions were reached for the Valsrivier and Cartref soils.

9.3 Soil chemical properties and soil fertility

Most studies give a basic overview of the chemical properties of the WTR used in any particular study. Dayton and Basta (2001), Basta (2000) as well as Schmitt and Hall (1974) studied the chemical properties of WTR to determine their potential as a soil substitute. They found that the WTRs showed potential to act as soil substitutes as generally nutrients were within typical soil ranges. Where deficiencies existed, it was suggested that moderate amounts of fertiliser could alleviate the problem.

9.3.1 Heavy metals in WTR

Some studies have examined specific aspects of the chemical make-up of WTRs, in particular metal content and fractionation. Elliott *et al*. (1990b) examined the composition and distribution of Cd, Cu, Cr, Ni, Pb and Zn in eight alum and Fe WTRs. Total metal concentrations in these WTRs varied widely and this variability was partly explained by the composition of the added flocculant that exerts an important role in metal contamination of the resulting residue, and to the background concentrations of metals in the coagulated sediments. Elliott *et al.* (1990b) concluded that provided the pH of the soil was maintained above 6.0 there existed little risk of leaching and potential groundwater contamination, since the concentrations of all elements, including Cd, were below the permissible maximum levels for land application.

9.3.2 Phosphorus studies

Some studies have examined the transformation and mechanisms of P uptake in WTR-amended media. Jonasson (1996) conducted a P fractionation study of WTR treated with additional P. It appeared from this study that a large proportion of the added P was chemisorbed by amorphous and crystalline Al and Fe or bound as Ca-P complexes. Cox *et al.* (1997) conducted a fractionation experiment on alum WTR treated soil (and fertilised with P) to determine the forms and availability of P in the mixtures. They found that ‘loosely bound’ or plant available fractions decreased in the mixtures as WTR application rates increased. They also found that Fe, Al and Ca bound fractions increased with increasing WTR application rates. This indicated that P was adsorbed and complexed by these components, making it unavailable for plant uptake. Butkus *et al.* (1998) examined P uptake by metal hydroxides and oxides typically associated with WTRs. They modelled P uptake by hydrous ferric oxide using a diffuse double layer model. From this they found that the amount adsorbed by the hydrous oxide could not account for all P sorbed by WTRs and concluded that a large proportion of the P may also be bound by cationic polymers added during WTR thickening.

9.3.3 Effect on plant growth

In contrast to the literature on soil physical properties, a large proportion of the studies have examined the effects of WTRs on plant growth when incorporated into growing media and soil. Rengasamy *et al*. (1980) found increased maize yield with respect to the zero application in a field trial with three soils, irrespective of the form in which the WTR was applied, and whether fertiliser was added or not. This increase in DM yield was most noticeable when the three soils used were fertilized with the optimum application rate of 2 Mg/ha application rate.

Bugbee and Frink (1985) concluded that the WTR was not toxic to plants, but may lead to P deficiencies at high application rates under glasshouse conditions. Elliott and Singer (1988) also showed reduced P availability on the WTR-amended treatments. Their results also showed a substantial reduction in metal (Cd, Zn, Cu, and Ni) uptake with increased $FeCl_3$ residue application. Explanations offered for this trend were that the WTR had an inherently low concentration of heavy metals, the increase in pH caused by the WTR reduced the availability of these metals to plants, and the precipitation of these metals in the solid phase further decreased uptake by the plant.

Heil and Barbarick (1989) measured the ability of alum, $FeCl_3$ and organic polymer WTRs to 'fix' phosphorus. Each WTR was mixed with each of two soil types at rates of 0, 5, 10, 15, 20 and 25 g/kg. The test crop (sorghum) showed a significant improvement in dry matter yield but above a WTR application rate of 15 g/kg, a decline in yield relative to the control was recorded. They explained the reduced yield on the high P adsorption capacity of the WTRs and further showed that this P fixation capacity is similar for the $FeCl_3$ and alum WTR but significantly lower for the organic polymer WTR.

Skene *et al.* (1995) compared the growth and elemental composition of the foliage of broad beans grown in a soil treated with either an alum or a polymer WTR applied at rates of 20, 40 and 100 g/kg. They concluded that these WTRs may have potential as growth media, but would require fertilisation for optimal plant growth. They found that the polymer WTR supplied some macronutrients and did not immobilise P as much as the alum WTR.

Ahmed *et al.* (1997) also found in the pot experiment that P concentrations in plant tissue decreased with increasing application rate of WTR, but that this was not evident in the field. They concluded that while in the short-term WTR additions could lead to P deficiencies, it does not appear to present any long-term problems in the field. They also report on concerns about Al toxicity, but found that background soil concentrations were above those of the WTR examined. Elliott and Dempsey (1991) suggest that, as soil Al concentrations are typically high, the factors controlling Al solubility (such as pH) will determine potential toxicity. As many WTRs are reported to increase pH in the soil, the potential for Al toxicity is low, and has not been reported in any WTR studies in the literature examined.

Based on the results of some of the studies in the literature it is possible that the strong binding effect of WTRs for P might be temporary. Thirty months after the residue was applied to soil, Geertsema *et al.* (1994) observed no significant differences in bioavailable and total P between the control and WTR-treated soils in field experiments. These results are partially supported by those of Ahmed *et al.* (1997) who, in some subsequent cuts of lawn grass grown in pot experiments, observed an increase in P uptake per pot at a WTR application rate of 400 Mg/ha. From this they concluded that with ageing and exposure to wetting and drying this material released more P. They thus proposed that WTR could serve a dual purpose i.e. it could be used to sorb P from polluted waters and then act as a slow release P fertiliser. Essentially the same suggestion was made by Butkus *et al.* (1998), namely that WTR could supply P to soil if amended with it prior to land disposal.

9.3.4 Summary of SA studies

The grassed contours at Brookdale and Ukulinga were used to follow the effects of the Midmar WTR on a test crop (perennial ryegrass/tall fescue) and on the soil chemical properties (Hughes *et al.*, 2005). The installation of soil water samplers at Ukulinga and monitoring of a dam and borehole at Brookdale Farm by Umgeni Water (since 1997) enabled soil water and groundwater data to be collected. In addition, laboratory experiments were conducted using the Midmar WTR and a range of soils.

The results have shown that the Midmar WTR does indeed increase soil pH and that this effect is quite long lasting. In addition, the application of WTR increased extractable Ca and Mg, soluble salt content, cation exchange capacity, chloride and nitrate. Agronomically such effects can be considered to be mainly positive although the increase in nitrate may be a cause for some concern. However, the increase was measured in incubated soils in the laboratory experiment. There was some support for these data from the soil water samplers and the saturated paste soil measurements from the field experiments.

Elevated nitrate concentrations were measured on the fallow plots of both experimental sites but the grassed plots showed lower concentrations probably because the vegetation extracted the nitrate before it leached through the soil. Groundwater nitrate concentrations were generally all <0.05 mg N/L in both dam and borehole samples.

In terms of P sorption Hughes *et al*. (2005) has shown that, as found by other authors, WTRs have a high P sorption capacity. This was shown dramatically both in the laboratory and pot experiments. The results have confirmed that laboratory estimates of P sorption greatly overestimate the effect when one considers the effect on plants in the field. In addition, the results show that the WTR-treated soils released less P and so this characteristic of the WTR could be used to positive effect in areas where leaching or loss of P into groundwater or surface water bodies is a problem.

The heavy metal content of the SA WTR has also been shown not to present any real threat to the environment either by direct leaching (as evidenced by minimal concentrations in the dam and borehole water at Brookdale, and in the soil water collected at Ukulinga) or by uptake by the grass (Hughes *et al*., 2005). The study included a range of soils and included an incubation period to estimate the long-term dissolution of the WTR under different soil conditions. Eight metals were analysed and only Mn was measurable in any appreciable quantities. Although the results varied between the soils, overall it seems that application of the Midmar WTR can reduce the amount of soluble metals in soils through sorption and thus lessen the prospect of any pollution danger where this material is land treated.

9.4 Agricultural Land

Agricultural use of WTR is the beneficial application or disposal of residuals on agronomic lands. Successful implementation of this disposal option requires an understanding of the effects of WTR on soil fertility and physical properties. The physical characteristics of soil that determine whether it can support vegetative growth include cohesion, aggregation, strength, and texture. These parameters directly affect the hydraulic properties of a soil, such as moisture-holding capacity, infiltration, permeability, and drainage. Any adverse impact on these hydraulic soil characteristics from land-applied WTR can effect crop growth and ultimately degrade ground water quality (Elliott *et al*., 1990).

Addition of lime to agricultural soil is a common practice in areas where the soil pH is too low for optimal plant growth. Lime modifies the balance between acidity and alkalinity in the soil. Soil pH should be maintained at 6.5 or above to minimize crop uptake of metals (USEPA, 1983). In addition to providing a desirable pH for plant growth, lime residuals can be substituted for agricultural limestone and offer calcium carbonate equivalence (CCE) or neutralization effectiveness. Lime residuals can be dewatered to higher solids content than alum residuals can; therefore, the potential for unique disposal or co-disposal opportunities is greater than for other residuals. Studies show the neutralizing power of lime residuals is equal or superior to that of agricultural limestone (Che *et al*., 1988). Lime residuals increase the porosity of tight soils, rendering the soils more workable for agricultural purposes.

Lime residuals can be applied as a liquid or dewatered and applied as a cake using an agricultural manure spreader. The application rate for lime residuals must be calculated on a dry weight basis, and then converted to the equivalent wet weight for application to the farm field.

Alum residuals have the consistency of very fine soils when dry. Bugbee and Frink (1985) indicate that alum residuals improve the physical characteristics of soil media but inhibit plant growth by adsorbing phosphorus. As stated earlier, this reduction in phosphorus available to plants is different from the toxicity problem that may be associated with land application of WTR. To obtain optimal plant yields, phosphorus fertilizer must be added.

As previously mentioned soil conditioning effects from organic matter in WTR are probably quite small and may not be measurable under field conditions. Management practices such as lowering application rates can control the dusting and rapid drying seen in fields amended with alum residuals. Application of alum residuals at rates that are not considered excessive (20t/ha) does not cause environmental degradation. Alum residuals are applied as a liquid unless the WTP has dewatering capabilities. Liquid alum residuals can be applied with a liquid manure spreader, like lime residuals, or with conventional irrigation equipment.

Land application of lagoon WTR allows sunlight and soil micro-organisms to biodegrade the organic matter contained in the WTR while the soil binds up the metals, thereby utilising the land as a treatment system. Recent concern over the mobilisation of aluminium in the environment is linked to suggested health problems associated with human exposure to aluminium. Aluminium mobilisation may also have an adverse effect on plant and aquatic life (Ogilvie, 1997).

Phosphorus that binds to alum residue may be available to plants too slowly for crops which have high rates of growth and a high phosphorus demand. If the amount of phosphate reactive aluminium in the soil is great enough to perturb the phosphorus cycle in the ecosystem, then fertility problems will be observed (Elliott *et al*, 1988; Bugbee & Frink, 1985). Supplementary phosphate fertilisation may be able to correct this phosphate deficiency; this may not be economical.

Elliott and Singer (1988) investigated the impact of iron WTR on the fertility of a silt loam soil by looking at the effect WTR incorporation had on the growth of tomato shoots. They concluded that land application is a feasible option for disposal and, provided that a suitable crop is chosen and the WTR loading is monitored, there should be no detrimental effects to plant growth.

Although alum WTR contains few if any plant nutrients (usually particularly low in nitrogen), it may contribute other beneficial properties such as improving soil structure, increasing water retention, and minimising fertiliser run-off (Rengasamy *et al*, 1980; Bugbee & Frink, 1985; Elliott & Singer, 1988). The incorporation of WTR into soil will improve the soil's cation exchange capacity and enhance the soil's ability to retain fertiliser.

The agronomic application of WTR to land presents an attractive and potentially sustainable method of disposal for many water treatment plants. Management strategies need to be implemented and parameters such as pH control, crop selection and availability, application rates, and fertilizer requirements must be included in the management planning.

Mobilisation of heavy metals has been investigated in many studies (Elliott & Singer, 1988; Elliott *et al*, 1988; Elliott & Dempsey, 1991; and Geertsema *et al*, 1994) and it has been demonstrated that mobilisation of these metals is not an issue. In most WTRs the presence of heavy metals is negligible (Grabarek & Krug, 1987; Heil & Barbarick, 1989; Budhia & Black, 1994).

9.5 Forestry / Silviculture

Silviculture, another agricultural practice, is the establishment, growth, reproduction, and care of forest trees as a crop. Land application of both wastewater and WTR is relatively uncommon in silviculture compared with application to agricultural lands. Bugbee and Frink (1985) indicated the following effects of residuals application to silvicultural use: no significant effects on tree growth, nutrient levels, or the appearance of the forest floor; slightly diminished uptake of phosphorus; and increased soil pH for trees treated with WTR.

Grabarek and Krug (1987) concluded that limited application of WTR to a healthy forested area does not upset the phosphate cycle to the point of affecting forest growth patterns. The effects of long-term (30 months) application of alum residuals were evaluated by Geertsema et al. (1994). The study found no statistically significant differences in soil characteristics, ground-water characteristics, or pine growth analyses between the unamended and the residuals-amended plots. No significant metal migration through the soil profile was reported. At the application rate used in the study, no problems were observed in available phosphorus as evidenced by the similar pine tree growth in the treated and untreated plots. The results of the study did not indicate any environmental problems; therefore, the City of Newport News has implemented a full-scale project.

9.6 Land Reclamation

Sewage sludge is more commonly used than WTR to reclaim surface-mined areas or other disturbed lands and to establish vegetative growth and/or restore or enhance soil productivity. Disturbed lands include highway construction sites, overgrazed rangelands and other construction sites. In combination with other fertilizers, however, WTR may benefit reclamation efforts. WTR can be used to treat a particular or site-specific concern. For example, lime residuals can control soil pH just as they do in agriculture, but in these cases the pH adjustment may be more critical because mine soils can be very low in pH. In addition, alum residuals can control runoff of excess phosphate into surface waters. Care must be taken to ensure that the site is suitable for use of WTR and that controls (best management practices) are in place to protect public health and the environment. On a mine reclamation site, WTR may actually be used as a topsoil replacement.

Whether adding WTR to soil has adverse environmental effects or is beneficial depends on a multitude of factors, some interrelated. It is not possible to draw up a yes/no table or a set of maximum values. Land disposal schemes require site specific investigation.

9.7 Restrictions and requirements for land application

Once land application is selected as the preferred disposal option, the next step is to evaluate the land application site, the costs associated with that site and the potential social and environmental impacts on the site. Initial site investigation will enable the producer/user to collect background/baseline data which could help to assess the impact of land application over time.

9.7.1 Prevention of erosion

The slope of the site and land preparation influence the amount of soil erosion and potential surface run-off and ponding from applied WTR.

9.7.2 Soil quality

The concentration of nutrients, trace elements and metals will give baseline concentrations to determine incremental effects of land application on the soil. The soil pH will indicate whether acidic conditions could cause metals to be available for plant uptake or leach through the soil profile and whether lime softening residues can be used to alleviate acidity.

It is recommended that the total (aqua regia) and/or NH_4NO_3 extractable trace element and metal concentrations be determined before WTR application. Ideally, the total metal concentrations need to be below the total investigative level (TIL) (Table 19). At locations where the total metal content exceeds the total maximum threshold (TMT) indicated in Table 19 or the available metal concentrations exceed the MAT (Table 19), land application of WTR is not permissible.

It is recommended that the NH_4NO_3 extractable trace element and metal concentration be determined before WTR application. If the available metal concentrations exceed the MAT (Table 19), land application of WTR is not permissible.

Table 19: Recommended limits for metals in WTR amended soils (mg/kg)

Metal Elements	Total investigative level (TIL) (aqua regia)	Total maximum threshold (TMT) (aqua regia)	Maximum available threshold (MAT) (NH_4NO_3)
Arsenic (As)	2	2	0.014
Cadmium (Cd)	2	3	0.1
Chromium (Cr)	80	350	0.1
Copper (Cu)	100	120	1.2
Lead (Pb)	56	100	3.5
Mercury (Hg)	0.5	1	0.007
Nickel (Ni)	50	150	1.2
Zinc (Zn)	185	200	5.0

The concentration of Al, Fe and Mn should also be considered because the concentrations of these elements in the WTR might be elevated and additional application might induce toxicity symptoms in crops. These elements are major constituents in soils and therefore no maximum limits can be set. The normal ranges (total concentrations according to Kabata-Pendias and Mukherjee (2007)) of these elements are detailed below and can be used as a baseline:

- Al: 10 000-40 000 mg/kg;
- Fe: 1000-100 000 mg/kg; and
- Mn: 10-9000 mg/kg.

However, for agricultural use the available or soluble concentrations of Al, Fe and Mn are more important than the total concentrations, which are strongly influenced by the pH and redox (especially for Mn) conditions in the soil. The normal ranges of soluble Al, Fe and Mn in soils (Kabata-Pendias and Mukherjee, 2007) are as follows:

- Al: 0.4 mg/L at neutral pH and 5 mg/L in acidic soils (pH <4.5);
- Fe: 0.03-0.55 mg/L at neutral pH and up to 2 mg/L in acidic soils; and
- Mn: 10 mg/L in normal soils.

9.7.3 Application rate

In general, application rates are determined using agricultural methods, as with fertilizer. In the case of WTR, this fertilizer recommendation is at least two fold; the nutrient requirements for the crop are based on the expected yield and the available nutrients in the soil.

The first nutrient to consider is nitrogen. WTR tend to be very low in this nutrient. Basing the application rate on nitrogen alone, however, may cause problems with the crop yield because aluminium and/or iron hydroxide solids present in WTR are strong adsorbents of inorganic phosphorus. The low concentrations of phosphorus in WTR may further diminish total phosphorus in soils, restricting plant growth. It is therefore recommended that both the N and P concentrations be considered when the application rate is calculated. Additional P fertilizer might be necessary.

The N (total Kjeldahl nitrogen – TKN) and P (Bray1 extractable) content of both the soil and WTR need to be determined before WTR application. According to the Fertilizer Handbook (Fertilizer Society of SA, 2003), Bray1 extractable P concentrations in the soil can be divided into 3 classes (Table 20) with different recommendations for fertilization. This information together with the WTR P content can be used to determine the application rate. The P adsorption of the WTR should also be considered. The N requirements for different crops vary and the application rate of WTR should be determined for the specific crop.

The concentrations of Al, Fe and Mn have to be considered to prevent toxicity of these elements. The tolerances of the selected crops need to be considered.

By applying WTR at agronomic rates, the nutrients and essential trace elements will be utilized by the crop and reduce leaching and the potential for surface and groundwater contamination.

Table 20: Recommended treatment associated with soil Bray1 extractable P concentrations (mg/kg) for grain and vegetable crops (Fertilizer Society of SA, 2003)

	Low / deficient	**Intermediate**	**High**
Grain crops	<8	8-30	>35
Vegetable crops	<15	15-50	>60
Treatment recommended	Build-up soil P	Normal P-fertilization	Maintenance or no P fertilization

When excessive amounts of WTR is applied to land it may have negative impacts on the receiving environment due to accumulation of metals, Mn, Al, Fe and, in some cases even U, in the soil which could be taken-up by the crops. It is therefore recommended that users of WTR consider the metal content (and Mn, Al, Fe and U) in the WTR before application and that they comply with the agronomic application rate to protect the soil, crops and, ultimately, human health.

9.8 Monitoring requirements for land application sites

9.8.1 WTR monitoring

The quality of WTR needs to be confirmed before application. At least 3 composite samples of WTR must be collected and the following analyses are recommended:

- *Aqua regia* and/or NH_4NO_3 extractable trace element, macro element (Al, Fe and Mn) and metal concentration (Appendix B);
- Kjeldahl digestion to determine N (Appendix B);
- Bray 1 extraction to determine available P (Appendix B);
- Dominant cations and anions (NO_3, SO_4, Cl, etc.); and

- Organic constituents and infectious substances where the raw water is known to have elevated concentrations of these constituents.

9.8.2 Soil monitoring

A soil monitoring programme is recommended to determine nutrient requirements before application as well as the plant available trace element and metal concentrations in the soils. The following programme is proposed:

- Collect soil samples from all areas where WTR application is considered;
- Determine the nutrient requirement for the particular crop to be cultivated using the following methods:

  - Kjeldahl digestion to determine N (Appendix B);

  - Bray 1 extraction to determine available P (Appendix B);

  - Soil pH(H_2O) – it is recommended that a soil pH >6.5 be maintained to alleviate mobility and toxicity of metals and macro elements.

- Determine the total (aqua regia) and/or NH_4NO_3 extractable concentration of trace elements, macro elements and metals to establish whether the soil can continue to receive WTR (Appendix B).

The soil monitoring data have to be compared to the metal limits detailed in Table to determine whether further WTR application will be permissible and to ensure that the soil quality do not deteriorate to such an extent that the land-use are compromised. Concentrations of Al, Fe and Mn in soil must be considered to prevent plant toxicity for the selected crop.

9.9 Record keeping requirements

Once the applicable permits and licences have been granted, WTR utilisation and disposal essentially become self-regulatory. This implies that certain records must be kept by the producer and user. The following record need to be kept:

- Copy of the applicable licences and permits;

- The original or certified copy of the contract between the producer and user (if applicable);

- Data on the mass of WTR applied to land; and

- Monitoring results of WTR and soils.

10 ON-SITE AND OFF-SITE DISPOSAL

WTR is an industry specific waste with specific characteristics and properties pertaining to it. The nature and characteristics of WTR compared to other wastes warrants the need for sector specific guideline to ensure its responsible management. The reality is that many WTPs use on-site lagoons as management and final disposal options. These facilities are not designed as waste disposal facilities and do not comply with the Minimum Requirements. The water industry is generally not accustomed to the complex waste management requirements in South Africa, but rather to the legislation and requirements of DWAF. This Part of the WTR Guideline attempts to form a "bridge" between the waste management industry and the water industry and aims to consolidate all the requirements of managing WTR as a waste in one document.

10.1 Disposal options

The most common disposal techniques for WTR are:

- On-site disposal in lagoons and dedicated land (DLD); and
- Off-site disposal on landfill:
  - Co-disposal with municipal solid waste on landfill;
  - Use as daily landfill cover;
  - Monofill of WTR only on landfill; and
  - Co-disposal with WWTP biosolids.

10.2 Characterisation / Hazard rating of WTR intended for disposal

According to the Minimum Requirements (latest edition), there are four steps in the classification of a Hazardous Waste:

- Identification of the waste or waste stream as probably Hazardous.
- Testing and analysis to determine the hazardous properties, characteristics and components of a waste. This will confirm whether the waste is Hazardous or not.
- Classification and treatment in accordance with SANS 10228:2003 "The Identification and Classification of Dangerous Goods for Transport".
- Hazard Rating of the waste to determine the Minimum Requirements for disposal.

An additional step would be to re-analyse a waste (after treatment) with the objective of possible delisting and reclassification. This would apply in cases where, because of pre-treatment, low concentration, low mobility or other applicable factors, waste can delist to a lower Hazard Rating.

Hazard Rating for disposal takes into account the toxicity (LD_{50}), ecotoxicity (LC_{50}), carcinogenicity, mutagenicity, teratogenicity, persistence, environmental fate and Estimated Environmental Concentration (EEC) of the waste. In addition to classifying and ranking hazardous waste for the reasons explained, it is also important to determine the amount of the hazardous substance(s) that may leach and migrate from the disposal site, over indefinite time. This concentration of hazardous substances is expressed as EEC and determined by site specific or fixed-scenario risk assessment or both.

10.2.1 Estimated environmental concentration (EEC)

The EEC reflects the concentration of the substance that is available to humans and the environment and hence the potential exposure and risk. To determine the effect or response of the substance on human health or aquatic ecosystems (for which the EEC has been determined), the hazard or inherent toxicity of the substance (LC_{50}, chronic human health toxicity, etc.) must be established and compared to the EEC. this is done through a fixed scenario or a site specific risk based approach.

In the **fixed scenario** risk assessment, it is assumed that the total mass of a hazardous substance disposed of on one hectare of a disposal site will leach into one hectare groundwater with a depth of 15 cm underlying the disposal site. This amount is expressed as the EEC. This approach is derived from techniques used by the USEPA for determining an aquatic EEC. This definitive body of groundwater is an assumption and forms part of the precautionary approach and presents a worst case scenario. Of importance, however, is that the acceptable exposure level may not be exceeded in this body of water.

Alternatively, a **site specific risk based approach** to determine the EEC may be followed to take into account all site specific attenuation factors, such as waste treatment, mode of site operation, climatic conditions and engineering attributes in the form of covers, liners and leachate interception.

The EEC based on the fixed scenario risk assessment is expressed as (ppb) = dose (g/ha/month) x 0.66. In the ‘fixed-scenario’ approach to determine the EEC, the Total Load is calculated by multiplying the allowed monthly volume per hectare by a factor of 100 (the ‘site attenuation factor’). The EEC is used to determine:

- the amount of waste that can safely be disposed of, not exceeding acceptable exposure;
- the maximum amount of a given hazardous substance in the waste that can safely be disposed of at a landfill site (Total Load); and
- whether a waste, initially regarded as Hazardous, can be delisted and disposed of at a General Waste disposal site equipped with leachate management.

10.2.2 Acceptable Risk Level (ARL)

The EEC is always compared to **acceptable risk level (ARL)** calculated for the following three risk based scenarios:

- acceptable exposure to the environment;
- a systemic acceptable exposure for human health;
- an acceptable exposure to human health for carcinogenic substances.

Acceptable risk to the environment, which is 0.1 x LC_{50} of the contaminant, and which will result in a concentration that would cause a mortality incidence of one in three hundred thousand in the aquatic environment. The LC_{50} or acute eco-toxicity is the concentration at which a substance would kill 50 per cent of organisms if it were disposed of directly into a body of water. If the concentration of the hazardous substance does not exceed ten percent of the LC_{50}, it represents an Acceptable Risk Level (ARL) to the environment that would cause a mortality incidence of one in three hundred thousand in the aquatic environment.

LD stands for "Lethal Dose". LD_{50} is the amount of a material, given all at once, which causes the death of 50% (one half) of a group of test animals. The LD_{50} is one way to measure the short-term poisoning potential (acute toxicity) of a material. In nearly all cases, LD_{50} tests are performed using a pure form of the chemical. The chemical may be given to the animals by mouth (oral); by applying on the skin (dermal); by injection at sites such as the blood veins (intravenous), muscles (intramuscular) or into the abdominal cavity (intraperitoneal). The LD_{50} value obtained at the end of the experiment is identified as the LD_{50} (oral) or LD_{50} (skin), etc., as appropriate. Researchers can do the test with any animal species but they use rats or mice most often. In each case, the LD_{50} value is expressed as the weight of chemical administered per kilogram body weight of the animal and it states the test animal used and route of exposure or administration; e.g. LD_{50} (oral, rat) – 5 mg/kg, meaning that 5 milligrams of that chemical for every 1 kilogram body weight of the rat, when administered in one dose by mouth, causes the death of 50% of the test group.

If the lethal effects from drinking a compound are to be tested, the chemical (soluble form) is first mixed in a known concentration in water which the test animals drink. This concentration is usually quoted as parts per million (ppm). In these experiments, the concentration that kills 50% of the animals is called an LC_{50} (Lethal Concentration 50) rather than an LD_{50}. When an LC_{50} value is reported, it should also state the kind of test animal studied and the duration of the exposure, e.g. LC_{50} (rat) – 1000 ppm/ 4 hr or LC_{50} (mouse) – 5 mg/m^3/2 hr.

Dose-response curves (Figure 4) can be used to plot the results of LD_{50} experiments and concentration-response curves can be used to plot the results from LC_{50} experiments. The X-axis plots concentration of the chemical and the Y-axis plots mortality. Figure 4 illustrates a dose-response curve for a toxic substance. The **dose-response curve** normally takes the form of a sigmoid curve. It conforms to a smooth curve as close as possible to the individual data points. For most effects, small doses are not toxic. The point at which toxicity first appears is known as the **threshold** dose level. From that point, the curve increases with higher dose levels.

The evaluation of risk often includes consideration of what is believed to be an acceptable level of risk to decide what exposure can be tolerated for risk management purposes. One fatality in a million people at risk (1 in 10^6) is considered in some countries to be an acceptable level of risk but there may be circumstances where a greater risk, for example – one in a hundred thousand (1 in 10^5), may be considered tolerable if the risk is balanced by a considerable benefit. The USEPA determined that for acute toxicity of a constituent with a typical toxicity profile (slope of the dose-response curve of 4.5) the estimated probability of mortality resulting from exposure to one tenth the value of the median lethal dose (LC_{50}) is approximately 1:300 000. In South Africa the ARL to the environment is the concentration that would cause a mortality incidence of one in three hundred thousand (1 in 300 000) in the aquatic environment and is equal to 10% of the LC_{50}.

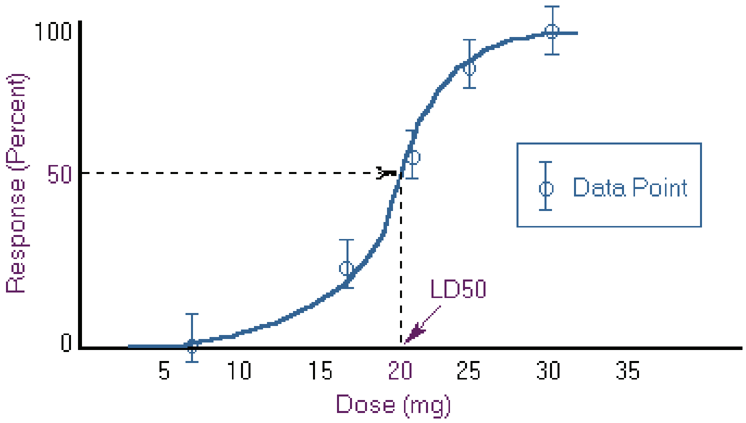

Figure 4: Example of a dose-response curve for a toxic substance

A systemic acceptable exposure for human health is the concentration of a contaminant in water, calculated from a reference dose or Tolerance Daily Intake as derived from chronic toxicity studies and a person of 70 kg mass drinking two litres of water per day.

An acceptable exposure to human health for carcinogenic substances refers to a concentration that would result in an estimated excess probability in human health to develop cancer. It is calculated from a slope factor derived from chronic toxicity studies, a 70 kg person and the consumption of 2 litres of water per day, and is expressed in terms of an excess lifetime cancer risk of 1 in 10 000.

When the EEC is higher than any one of the three exposure levels, the waste stream remains in the hazard rating. When it is lower, the waste stream can delist to be disposed of on an authorized General Waste landfill.

The objectives of Hazard Rating are to indicate:

- the risk posed by a Hazardous Waste and hence the degree of care required for its disposal;
- the class of Hazardous Waste landfill at which the waste may be disposed of;
- the amount of a hazardous substance or compound that can be disposed of at a particular Hazardous Waste landfill site before it begins to pose a risk.

The Hazard Rating is used to classify Hazardous Waste into any of the four Hazard Rating levels. The four Hazard Ratings are ranked according to a logarithmic progression, whereby Extreme Hazard is 10 times more toxic than High Hazard and *1000* times more toxic than Low Hazard.

- Hazard Rating 1 (Extreme Hazard): Is waste of first priority concern, containing significant concentrations of extremely toxic substances, including certain carcinogens, teratogens and infectious wastes.
- Hazard Rating 2 (High Hazard): Is waste of second priority concern with highly toxic characteristics or extremely toxic substances, which are not persistent, including certain carcinogens.
- Hazard Rating 3 (Moderate Hazard): Is waste of third priority concern, which is moderately toxic or which contains substances that are potentially highly harmful to human health or to the environment but are not persistent.
- Hazard Rating 4 (Low Hazard): Is waste that which often occurs in large quantities and which contains potentially harmful substances in concentrations that in most instances would represent only a limited threat to human health or to the environment.
- Hazard Rating lower than Hazard Rating 4: Where the classification falls below Hazard Rating 4. The hazard posed by a waste can be considered to be low enough to allow the waste, with the consent of the Competent Authority, to be disposed of at a General Waste landfill with a leachate collection system.

The Hazard Rating determines the class of landfill at which a waste is disposed of:

- Hazard Rating 1 and 2 = **H:H landfill**
- Hazard Rating 3 and 4 = **H:H or H:h landfill**

More detailed information and procedures on waste classification are detailed in *Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste Section 8 (latest edition)*.

10.3 Delisting

A waste may delist if the estimated environmental concentration (EEC) is equal to or less than one tenth of the LC_{50} for that specific substance (Minimum Requirements, latest edition). The EEC is the concentration of a hazardous substance that may migrate from the disposal site based on the assumption that the total mass of the hazardous substance disposed of on one hectare of a disposal site will leach into one hectare of groundwater with a depth of 15 cm underlying the disposal site. The determination of EEC establishes potential exposure to target populations or organisms, and which could either be determined based on a hypothetical exposure scenario (fixed scenario) or on site specific data. The EEC of the substance in the waste is calculated in grams disposed of per hectare per month multiplied by a factor of 0.66. Therefore, **EEC (ppb) = g/ha/month x 0.66**

The LC_{50} or acute eco-toxicity is the concentration at which a substance would kill 50 per cent of organisms if it were disposed of directly into a body of water. If the concentration of the hazardous substance does not exceed 10% of the LC_{50}, it represents an Acceptable Risk Level (ARL) to the environment that would cause a mortality incidence of 1 in 300 000 in the aquatic environment.

Delisting is when a hazardous compound in a waste moves from a specific risk group to a lower risk or 'non-risk' group. It does not become a non-hazardous compound, but the associated risk declines to a risk, which is smaller or even acceptable. Delisting is regulated by the most hazardous contaminant in a waste stream. The EEC of the contaminant must be compared to the ARL to determine whether such a waste stream will delist or not. Treatment of a contaminant may change its properties, for example mobility, which will affect leachability into the environment. Tests used to prove this would include the "Toxicity Characteristic Leaching Procedure" or the "Acid Rain" test.

Delisting from a specific hazardous rating to a lower hazardous rating or “non-risk” group is when the EEC of a contaminant, is less or below the acceptable exposure of the same contaminant (Table 21). With regard to acute toxicity values, in terms of the LD_{50}, a Reference Dose (RfD) or Tolerance Daily Intake (TDI) of a non-carcinogenic substance is a daily exposure normally derived from tests involving surrogates such as rodents, and extrapolated to the human species, and which is considered not likely to be of appreciable adverse consequence during a lifetime exposure. It is therefore termed the **Acceptable Exposure to human health**, and is expressed in mg/kg body weight/day. The **Acceptable Exposure** for human health of a substance which displays **carcinogenic properties**, is the exposure derived from the Slope Factor (SF) of a dose-response curve in which excess risk is linearly related to dose, and which could result in an additional cancer incidence in a population of 10 000. The EEC is always compared to ARL, to indicate whether either the aquatic environment or human health will be at risk.

Table 21: Acceptable exposure levels, LD_{50} and LC_{50} values (DWAF, 1998)

Hazard Rating	HR4	HR3	HR2	HR1
LC_{50} (mg/L):	100-1 000	10-100	1-10	<1
Acceptable Exposure to Environment (mg/L)	10-100	1-10	0.1-10	<0.1
LD_{50} (mg/kg):	500-5 000	50-500	5-50	<5
Acceptable Exposure (mg/L) to Human Health (systemic):	TDI or RfD x (70 kg/2 L)			
Acceptable Exposure (mg/L) to Human Health (carcinogenic):	$((10^{-4} \times 70\ \text{kg})\ /\text{SF}(\text{mg/kg/d})^{-1}) \div 2\ \text{l}$			
If EEC >0.1 x LC50 **or** >AE (systemic) **or** >AE (carcinogenic)	= RISK and remain in Hazard Rating			
If EEC <0.1 x LC50 **or** <AE (systemic) **or** <AE (carcinogenic)	= NO RISK and Hazard Rating can DELIST to GB+ landfill site			

More detailed information on delisting procedures is detailed in *Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste, Section 8 (latest edition).*

10.4 On-site disposal

On-site disposal of WTR on dedicated land (DLD) or lagoons is generally the alternative chosen by those WTP that either generate residuals continuously or have quantity or quality concerns. Due to high application rates of WTR, the disposal site needs to be carefully designed to contain any of the residual constituents that might threaten public health or the environment. Surface runoff controls including physical structures such as dikes, ditches and lagoons have to be implemented and control must be taken of leachate that is generated which may require collection and treatment prior to discharge or disposal.

The following restrictions and requirements are recommended for on-site disposal of WTR:

10.4.1 Initial site investigation

The aim of initial site investigation is to collect background/baseline data which could be used to assess the impact of the disposal practices over time. In cases where a new site is selected as part of a new WTP or major extension, the initial site investigation will form part of the EIA that will be required to obtain a RoD from DEAT. It is recognized that most existing on-site disposal sites are confined to the boundaries of the WTP which were delineated some time ago. However, it must also be remembered that WTPs were not developed in the most suitable areas for waste disposal (near rivers, dwellings, etc.). According to Section 24 of the Constitution: '**Everyone has the right to an environment that is not harmful to their health or well-being**'. The establishment and operation of a disposal site must therefore not violate the constitutional right of the communities living in the vicinity of the site (Minimum Requirements, latest edition).

The objectives of disposal site selection are as follows:

- To ensure that the site to be developed is environmentally acceptable and that it provides for simple, cost-effective design, which in turn provides for good operation;
- To ensure that, because it is environmentally acceptable, it is also socially acceptable.

The EIA process might require a more detailed investigation. The site investigation for existing and new sites should include (as a minimum):

- Topography – The slope of the disposal site should be considered to minimise run-off, erosion and ponding. The selection of a disposal site needs to include an evaluation of landscape topography along with the soil and underlying geologic layers. The landscape can be looked upon as a surface transport system for the applied WTR, while the soil can be looked upon as an internal transport system for WTR constituents. An important component of topography for site selection is the slope since it is an important factor in determining the run-off that is likely to occur. Most soils on a 0-6% slope will have a slow to very slow run-off rate; soils on a 6-12% slope have medium run-off rate and soils on steeper slopes generally have a rapid run-off rate. The length and shape of slopes also influence the rate of runoff from a site. Rapid surface runoff can readily erode WTR-soil mixtures and transport them to surface waters. Specific guidance on maximum slopes allowable for WTR disposal sites under various conditions, such as WTR physical characteristics, application techniques, and application rates, should be obtained from the designated regulatory agency (Metcalf & Eddy, 1989; Lue-Hing *et al.*, 1992).
- Soil properties – Disposal sites are often located on lands that are largely composed of disturbed or naturally unproductive soils. This lessens the public perception that productive lands will be spoiled or polluted. In selecting a disposal site, soil surveys are an important source of information in making preliminary judgement on the suitability of potential sites for WTR disposal. An important component of the soil survey is the land capability or suitability

classification where land is classified according to the most suitable sustained use that can be made of it while providing adequate protection from erosion or other means of deterioration (Lue-Hing *et al*., 1992).

The soil structure, permeability and cation exchange capacity (CEC) will indicate whether the soil will act as a natural liner to minimise leaching of elements. **Texture**, defined as the relative proportions of various sized particles (sand, silt, clay) in a soil, can have a significant impact on the suitability of a soil for WTR application. Texture influences the tillage, soil water retention, permeability, infiltration, and drainage of soils. Coarse-textured soils are easier to till and manage than are fine-textured soils. Soil texture influences the soil **water retention** curve. Clay soil holds far more water at a given soil water potential than does loam or sand. The addition of WTR will shift the water retention curves in soils of various textures. Increases in soil **water holding capacity** occur in both fine-textured and coarse-textured soils. Water transmission properties of soils are important in selecting a dedicated site for WTR application. These properties (hydraulic conductivity, infiltration, and permeability) affect the amount of water in runoff and the amount leached through the soil profile. For land application of WTR, a moderate to moderately rapid, but not excessive, soil hydraulic conductivity is usually desirable. Soils with very low or excessive hydraulic conductivity should be avoided because of the impact on permeability, drainage, and runoff (Lue-Hing *et al*., 1992). It is recommended that soils with clay content <15% should not be considered for land disposal.

Infiltration, the downward entry of water into soil, is the principal means by which dissolved salts and organics are transported into and through soils. Infiltration of water into soils depends on the initial water content, soil water potential, texture, structure, and the uniformity or homogeneity of the profile. Generally, coarse-textured soils have higher infiltration rates than fine-textured soils.

Soil chemical properties need to be evaluated in assessing the suitability of a site for the application of WTR. These properties help to determine the rate at which WTR can be applied because of their effect on the chemical reactions that may occur with WTR-applied components in the soil. The **soil pH** at a selected site is important because it affects the chemical and microbial reactions in WTR-amended soils and the uptake of ions by plants. With time WTR-applied inorganic constituents become soluble and part of the soil solution. Soil pH affects the solubility of the inorganic constituents and their availability for exchange reactions, sorption and precipitation, plant uptake, leaching, reactions with soil organic matter, and utilization by soil micro-organisms. Soil pH is the parameter most consistently identified as controlling the solubility of WTR-applied metals. Almost all metals, except for molybdenum and selenium, are more soluble at a low pH and their solubility decreases as the soil pH increases (Lue-Hing *et al*., 1992). It is recommended that soil pH >6.5 be maintained at all times to limit the mobility and availability of metals and macro elements.

The concentration of nutrients, macro elements, trace elements and metals will give baseline concentrations to determine future impacts of disposal on the soil.

- Surface water – Where surface water resource contamination is a possibility, background water quality sampling is required to determine the baseline values which can be used for comparative purposes in future.

- Groundwater – Groundwater quality (up gradient and down gradient) will give baseline information to assess future impact of disposal on groundwater quality. The depth to **groundwater**, the yield and the importance of the groundwater as a resource are important. The vulnerability of the aquifer and the risk of its possible pollution should be assessed to determine whether the site is suitable for WTR disposal. Generally, the greater the depth to the water table, the more desirable the site is for WTR disposal. WTR should not be placed where there is potential for direct contact with groundwater (Metcalf & Eddy, 1989). A minimum depth of 5 m to the aquifer is recommended for WTR disposal sites. DEAT, in consultation with DWAF will not issue permits in terms of Section 20 of the Environment Conservation Act unless land has been zoned for waste disposal. For the purposes of permitting of waste disposal sites the Department will base its regulatory response upon the importance and vulnerability of the aquifer which may be threatened by waste disposal activities. The hydraulic gradient should be determined to assess the direction of groundwater flow and the position of the monitoring boreholes. Groundwater quality (up gradient and down gradient) will give baseline information to assess future impact of disposal on groundwater. Initial groundwater sampling should be done at a frequency high enough to obtain statistically valid background information. For any long-term facility, three initial sampling exercises, all within 90 days and not less than 14 days apart, are suggested (Minimum Requirements, latest edition).

According to the Minimum Requirements (latest edition) the following areas are classified as areas with fatal flaws with regard to landfill. The land disposal of WTR should also not be permitted at these sites:

- Areas within the 1 in 100 year flood line (wetlands, vleis, pans and flood plains) to minimize water pollution.

- Unstable areas (fault zones, seismic zones and dolomitic or karst areas where sinkholes and subsidence are likely).

- Areas characterised by steep gradients where slope stability could be a problem and soil erosion would be prevalent.

- Areas of groundwater recharges on account of topography and/or highly permeable soils to minimise groundwater pollution.

Buffer zones are areas of land separating the registered surveyed boundaries of disposal sites from the registered surveyed boundaries of identified sensitive land use categories. The establishment and maintenance of buffer zones are enforceable in terms of the National Health Act (Act No 61 of 2003), which makes provision for measures to prevent any nuisance, unhygienic or offensive condition that may be harmful to health.

Buffer zones will vary in size, depending on the disposal site classification, and the nature and extent of the anticipated environmental impacts. Factors that may influence the size of a defined buffer zone include topography, micro climatic conditions, waste types, the operating plan and the results of consultation with interested and affected parties. Scientific investigations, which may include any dispersion modelling and health risk assessments, will be used to define the various areas of influence associated with the disposal site. The extent to which these areas of influence could result in a health impact defines the size of the buffer zone. The shape of the outer perimeter may not be regular (i.e. a straight line or circle), resulting in an amorphous buffer zone form.

A buffer zone should preferably comprise unpopulated land. No land use that is deemed to be incompatible with the proposed disposal operation may be allowed within the buffer zone. The local authority and the relevant government departments may permit certain land uses within the buffer zone, subject to such conditions as they may impose. Limited industrial developments may typically be found to be compatible with disposal operations. To guard against undesirable land use encroachment and to prevent conflict of interests in the future, measures to control development within the buffer zone should be implemented as soon as a candidate site is found to be feasible (Minimum Requirements, latest edition).

Recommended buffer zones include (Volume 3 of Sludge Guidelines, 2008):

- Depth to aquifer >5 m.
- Distance from surface water/borehole must be >400 m.

These buffer zones may be relaxed on condition that proof is provided that the groundwater and surface water is adequately protected. An increase in buffer zones may also be required depending on site conditions.

10.4.2 Management requirements for on-site disposal

The on-site disposal site needs to be managed in such a way that the receiving environment will be protected. Management requirements include:

- Run-off collection – Run-off includes rainwater and other liquid that drains over the land and runs off the land surface. Run-off may be contaminated by WTR and must be collected and disposed of according to the licence requirements. According to the USEPA Part 503 Rule on Surface Disposal of Sludge (1994), the run-off collection system must have the capacity to handle run-off from a 25 year, 24-hour storm event. In SA the 1:100 year rule applies. This requirement ensures that run-off which may contain pollutants is not released into the environment, especially into nearby surface water bodies. In some disposal practices like existing, unlined lagoons, this is not possible. In these cases, a stringent monitoring program should be adopted.
- Surface water resources near the disposal sites need to be protected against contamination by constituents from the waste disposed of at the site. This could be achieved by:
  - Constructing cut-off trenches or bund walls down-gradient of the disposal site to intercept run-off;
  - Increasing the distance between the waste disposal site and the water body to ensure no run-off will reach the water body;

- Planting non-edible crops/plants/trees with a high water demand that will intercept run-off.

- Groundwater protection – Groundwater is a key component of the water resources of South Africa. As such it will provide much of the water required for basic needs, especially since the country's surface water resources are unevenly distributed and cannot cope with the growing demand for water. Groundwater is especially important because almost 66% of South Africa's population depends on groundwater for their domestic water needs and essential domestic needs can be met cost-effectively from groundwater sources.

  Groundwater, in many parts of the country, provides the only means of satisfying basic human needs. Present coverage of water supply is estimated at around 68%. The target is full coverage to satisfy basic needs by 2007. As the country's people start depending more and more on groundwater, so the need grows to provide for the security of its supply. Protection of groundwater has, therefore, now become a national priority. It is common for groundwater to be poorly managed. This is because of its invisible nature – it takes a long time to notice when it has become polluted and, unlike surface water, it has limited ability to purify itself. It is difficult, and often impossible, to restore polluted groundwater, and certainly very expensive (DWAF, 2000). Therefore, WTR placed on land should not contaminate the aquifer. Aquifer contamination means introducing a substance that can cause the concentrations of constituents of concern in groundwater to increase above regulated limits. For this reason there are certain areas such as the subterranean government water control areas as set out in Table 4 of Schedule 4 of Government Notice 399 of 26 March 2004 where waste disposal may not be allowed.

  Water applied to the soil surface through rainfall and irrigation events subsequently enters the soil through the process of infiltration. If the supply rate of water to the soil surface is greater than the soil's ability to allow the water to enter, excess water will either accumulate on the soil's surface or become runoff. Soil water infiltration is controlled by the rate and duration of water application, soil physical properties, slope, vegetation, and surface roughness.

  The following are recommended:

  - the buffer zone between the soil surface and the aquifer be increased to >10 m in the case of liquid WTR disposal
  - soils with clay content <20% should not be considered for WTR disposal
  - WTR irrigation should be scheduled to prevent the soil profile from getting saturated

  Groundwater is a valuable resource in the South African context and WTR placed on land should not contaminate the aquifer. The owner/operator should provide proof that groundwater is not contaminated by means of:

  - Implementing a groundwater monitoring programme;
  - Monitoring of the transmission zone at regular intervals (every 3 years);

- Proof that groundwater monitoring is not required based on a detailed study by a qualified person, either because of the depth of the water table, the amount of waste disposed or other site specific factors.

It is recommended that the groundwater quality should not deteriorate more than 1 class (acceptable to tolerable) due to WTR disposal for any elements that might leach from the WTR (as indicated by the TCLP test). A groundwater monitoring programme will serve as an early warning system to indicate potential contamination of the aquifer/s at the disposal site. The number of monitoring wells and their proper placement will depend on the location of the water table and direction of groundwater flow. The depth of the monitoring wells will depend on the depth of the water table. The monitoring network should include the integration of unsaturated and saturated zone sampling. The chemical quality of the groundwater should be compared to the baseline groundwater quality prior to WTR disposal to determine if any contamination has occurred.

- Liner requirements – A liner is a low permeability layer placed beneath a land disposal site, designed to direct leachate to a collection drain or sump, or to contain leachate. It may comprise natural materials, synthetic materials, or a combination thereof. Appropriate liners might be required when:

  - WTR with HR that cannot be delisted are disposed of; and

  - The disposal site is situated on sandy soil (<20% clay).

  For more information on liner design requirements, consult the latest edition of the Minimum Requirements for Waste Disposal by Landfill.

- Soil quality – During development of the Sludge Guidelines total trigger values (TTV) and maximum permissible levels (MPL) for 8 metals in the receiving soil have been set to ensure that the soil quality in unlined facilities does not degrade to such an extent that major intervention is required to restore soil functionality. The same limits are proposed for soils receiving WTR. Other elements that might be of concern at disposal sites will be indicated during the hazard rating of the WTR. These elements might include Al, Fe and Mn, depending on the treatment process of the raw water and should also be monitored.

- Restrictions on crop production – No edible crops (grain, fruit and vegetables) may be grown on disposal sites (during operation and after closure) unless the owner/operator at the disposal site can demonstrate to the permitting authority that public health and the environment are protected from reasonably anticipated adverse effects of certain pollutants present in the waste.

- Public access restrictions – Public access must be restricted at all disposal sites while the site is in operation and 3 years after closure.

- Restrictions on grazing animals – No grazing animals are allowed on disposal sites unless the owner/operator at the disposal site can demonstrate to the permitting authority that public health,

health of the animals and the environment are protected from reasonably anticipated adverse effects of certain pollutants present in the waste.

10.4.3 Monitoring requirements for on-site disposal

Monitoring requirements have to be implemented to continuously monitor the effect of WTR on the receiving environment. The analytical data collected during monitoring must be interpreted by the WTR producer. If any problems are identified it must be communicated to the relevant Authority. The following is recommended:

- WTR monitoring to determine whether WTR quality increased or decreased with time. Management options may be re-evaluated if the quality of the WTR increases. It is recommended that quarterly TCLP analyses be conducted on WTR samples.
- Groundwater monitoring – According to the Minimum Requirements (latest edition), groundwater should be monitored at disposal sites to ensure that no aquifer contamination occurs due to disposal. Groundwater is a slow-moving medium and drastic changes in the groundwater composition are not normally encountered within days. The frequency with which water samples are to be taken from groundwater access points is therefore a function of the sampling objectives. Monitoring boreholes should be located to intersect groundwater moving away from a disposal site. Consult the *Minimum Requirements for Water monitoring at waste management facilities* (latest edition) for descriptions on borehole design, type, diameter, depth and protection.
  - Monitoring boreholes should be located to intersect groundwater moving away from a disposal site. The number and location of boreholes have to be determined by a responsible person.
  - Boreholes should be located on either side of the disposal site in the direction of the groundwater flow (up-stream and down-stream). For disposal sites a geotechnical investigation is required in order to identify sub-surface geological structures, etc. The boreholes are then sited according to the results – otherwise the water migration pathways and hence the pollution might be missed. If very little is known about the groundwater gradient, then at least one monitoring borehole should be placed at the lowest topographical point.
  - Monitoring boreholes must be such that the section of the groundwater most likely to be polluted first is suitably penetrated to ensure realistic monitoring results. This implies that monitoring boreholes will at least extend through the weathered zone, the aquifer below and 5 m into the non-water-yielding formation deeper down. The latter is intended to act as a sump, where material that falls down the borehole will accumulate, without affecting the performance of the monitoring system.
  - Groundwater levels must be recorded on a regular basis to detect any changes or trends. Regional groundwater levels are indicative of the direction of groundwater movement. A change in the natural water-table gradient indicates that external forces are acting upon the aquifer. Such forces may be due to groundwater abstraction through nearby boreholes, or recharge from impoundments.

- Quarterly sampling and analyses (pH, EC, PO_4, NH_4, NO_3, COD and elements with elevated concentrations in TCLP extract) of groundwater is recommended.

- Water sampling, preservation and analyses should be done according to prescribed procedures described in *Minimum Requirements for Water monitoring at waste management facilities* (latest edition) (Appendix B).

If the restrictions and requirements in this guideline are adhered to, groundwater should be adequately protected. However, it is recognised that in some unforeseen circumstances groundwater contamination may be observed for which a closure and remediation plan is required.

- Surface water should be monitored to ensure that surface water bodies are not contaminated by WTR disposal. Surface water chemistry may change within minutes, depending on controlled or uncontrolled discharges. Flow from fountains and streams should be estimated. If pollution occurs as a result of WTR disposal, continuous recording of flow and water quality should be done (Minimum Requirements, latest edition). Surface water should be monitored monthly to ensure that surface water bodies are not contaminated by WTR disposal practices. Water sampling, preservation and analyses should be done according to prescribed procedures (Appendix B). Analyses should, as a minimum, include pH, EC, PO_4, NH_4, NO_3, COD and elements with elevated concentrations in TCLP extract.

- Soil monitoring is only required at unlined disposal sites. Soil monitoring will serve as an early warning system on the mobility of constituents of concern in the soil profile and the potential for groundwater contamination.

  - Soil sampling and analyses should be conducted biannually;

  - Increase the sample frequency when the soil pH<6.5 and/or soil clay content <20%.

  - Soil analyses should include, as a minimum:

    - *aqua regia* digestions with an ICP scan to determine the concentration of metals;

    - water soluble extraction to determine the soluble concentrations of Al, Fe and Mn (Appendix A);

    - determination of the pH, EC, PO_4, NH_4, NO_3 and other major cations and anions present in the WTR

  - Soil sampling and analyses should be done according to described procedures (Appendix B). Soils should be sampled at 100 mm intervals to a depth of at least 500 mm.

10.4.4 Closure, remediation and record keeping requirements

Remediation and closure design should account for site-specific considerations. DWAF is in a process of formulating a remediation strategy, which will provide further guidance on site- specific remediation. Closure is the final step in the operation of a disposal site. In order to close a disposal site properly, however, closure must be preceded by remediation, to ensure that the site is environmentally acceptable. The site must also be rendered suitable for its proposed end-use (Minimum Requirements, latest edition). A remediation and closure plan for all disposal sites is required and should be developed by a responsible person.

Aspects that should be addressed include:

- Remedial design to address identified problem areas (or future problems);
- Size of the disposal site (localised waste pile or large area irrigated with WTR);
- Extent of pollution – sites where metals have not migrated down the soil profile will require a less complicated rehabilitation plan than sites where groundwater contamination has already occurred;
- Future land-use;
- Final landscaping and re-vegetation;
- Permanent storm water diversion measures, run-off control and anti-erosion measures; and
- Post-closure monitoring plan and implementation.

Once the applicable permits and authorisations have been granted, WTR disposal areas essentially become self-regulatory. This implies that certain records must be kept by the WTR producer and disposal site owner/operator.

The following records need to be kept:

- Copy of the applicable licences and permits;
- Initial site investigation/baseline data of soils, surface- and groundwater; and
- Monitoring results of WTR, groundwater, surface water and soils.

These data could be used to obtain insight into the environmental degradation due to WTR disposal and to determine whether the mitigating factors implemented in this Guideline were sufficient to protect all receptors

10.5 Off-site disposal on landfill

The disposal of waste on landfills in South Africa is dealt with in the Minimum Requirements for the Handling, Classification and Disposal of Hazardous waste and Minimum Requirements for Waste Disposal by Landfill. All actions required in the design, operation, monitoring and closure of landfill sites in South Africa are described in these publications. This part of the WTR Guideline presents procedural guideline for disposal of WTR on landfill.

10.5.1 Landfill classification

The Minimum Requirements detail landfill designs based on the specific landfill classification. Waste type, waste volumes and the water balance determine the landfill classification.

- General waste can be disposed of at general landfill sites denoted G;
- Hazardous waste site are denoted H.

Based on waste volumes, landfills are classed as:

- Communal (C) – sites designed to receive <25t/day;
- Small (S) – sites designed to receive 25-150t/day;
- Medium (M) – sites designed to receive 150-500t/day;
- Large (L) – sites designed to receive >500t/day.

Climatic and/or site specific water balances are used to determine whether a site has a positive ($\mathbf{B^+}$; precipitation exceeds potential evaporation) or negative water balance ($\mathbf{B^-}$; evaporation exceeds potential precipitation). Sites accepting general waste (municipal and delisted hazardous waste) have a classification describing these three aspects. Example: GLB+ landfill – receives more than 500 tons per day of general waste and is expected to generate leachate more than one year out of five.

10.5.2 Basic procedure for disposal on landfill

The basic procedure followed for landfill disposal is as follows:

- Determine the hazard rating (HR) of the waste using analytical results (TCLP test) as follows:
  - Compare the EEC with the ARL;
  - The constituents of concern (COCs) exceeding the AE or ARL determine the HR (HR1 most toxic – HR4 least toxic);
  - Determine the maximum acceptable load that may be disposed of per hectare per month;
- Determine the potential to delist the WTR to a lower HR (treatment or total load principle);
- HR2-HR4 waste may be delisted and disposed of on a GLB+ or GMB+ site;
- HR1 waste should be disposed of on H:H or H:h sites.

Examples of hazard rating and delisting of waste are presented in the latest edition of the Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste.

10.5.3 Management requirements for disposal on landfill

- Solids content / consistency – General landfill sites will not accept WTR with a liquid or viscous consistency. Table 3 show the physical consistency of coagulant and lime softening residues at different solids content. Since the different WTR show different characteristics at different solids content, no blanket minimum solids content can be recommended, but will depend on the WTR and the landfill operator. This requirement should be based on site specific investigation and specific landfill site requirements.

- WTR analyses/monitoring information – Since the waste quality is fundamental in the management of the landfill site, the landfill operator should be certain of the WTR quality/toxicity. This is especially important in cases where the WTR needs to be treated (limed) before it delists. Although quarterly TCLP analyses on WTR samples is recommended, the landfill operator may require additional monitoring, especially in the case of WTR that needs to be treated before it can be delisted for disposal.

- It is a Minimum Requirement that no more than 200 mm/year of leachate be generated at a given landfill site. A landfill which receives liquids in a **B-** climate will (all things being equal) produce less leachate than an identically operated landfill in a **B+** climate. It is therefore possible to co-dispose of more liquid per ton of dry waste in a **B-** area without necessarily producing any more leachate than is produced under identical conditions in a **B+** area. In general, a landfill in a **B-** area may produce leachate sporadically, but will not necessarily produce leachate in an average year. However, in wetter **B+** areas of the country, significant leachate will be produced even in a drier than average year, even if no liquids are co-disposed. In either case, the approach is to limit leachate generation to 200 mm/year over the area of the waste body, or to a figure for which the leachate treatment capacity may be designed. Because there may be existing or future need to dispose of liquid wastes in wet areas, a nominal limit to leachate produced, under typical wet season weather conditions at any co-disposal site, is set at 200 mm per year. This allows for limited co-disposal of liquid wastes in wet areas but very much more effective liquid waste co-disposal in drier areas such as Gauteng. The limit of 200 mm per year is a figure which will ensure socially and environmentally acceptable conditions. It may only be exceeded if it can be shown that the overall design of the landfill, the leachate management system and the leachate treatment system can easily accommodate this flow. Regardless of the co-disposal ratio used or the amount of leachate generated, **it is a Minimum Requirement that there are no free liquid surfaces on the landfill and that the fill is trafficable.**

- The co-disposal ratio of 1:10 is the maximum permitted under the Minimum Requirements (latest edition), but depending on the metal levels in the WTR this ratio might need to be reduced (the other reason for a reduction in the amount of WTR allowed would be the limit on the amount of leachate permitted from co-disposal sites. It is accepted that only a fraction of these metals are available for leaching and therefore the results from a TCLP test may be used. Once the leachable concentrations of these metals (and any others of concern) have been determined, then the Acceptable Exposure (AE) and EEC must be calculated. The co-disposal ratio is limited to EEC $\leq$ AE. Once the co-disposal ratio has been determined, the Total Load, described in Minimum Requirements (latest edition) must also be considered. This limits the total load of any compound to be disposed of on a landfill over its design life.

- Run-off collection and management must include (Minimum Requirements):
    - Run-off and storm water must always be diverted around one or both sides of the waste body, by a system of berms and/or cut-off drains.

- Water contaminated by contact with waste, as well as leachate, must be contained within the site. If it is to be permitted to enter the environment, it must conform or be treated so as to conform to the water quality limits specified in terms of the Permit.

- The basis of trenches and cells must be so designed that water drains away from the deposited waste.

- The contaminated run-off from the landfill must be stored in a sump or retention dam. It may be pumped from the dam and disposed of if it conforms to the water quality limits specified and stipulated in the Permit.

- A 0,5 m freeboard, designed for the 1 in 100 year flood event, must always be maintained in the case of contaminated water impoundments and drainage trenches.

- All temporarily and finally covered areas must be graded and maintained to promote run-off without excessive erosion and to eliminate ponding or standing water.

- Clean, uncontaminated water, which has not been in contact with the waste, must be allowed to flow off the site into the natural drainage system, under controlled conditions.

- All drains must be maintained. This involves ensuring that they are not blocked by silt or vegetation.

10.5.4 Site selection and investigations

The initial site selection and investigation for the landfill site should be conducted according to the Minimum Requirements for Waste Disposal by Landfill. The following components should receive particular attention when co-disposal of liquid wastes is proposed:

- Specific water balance studies should be undertaken for landfill sites where WTR disposal is proposed. Operators of landfill sites with a negative water balance must prove that no leachate will be generated due to WTR co-disposal. Co-disposal of liquid wastes affects the classification of proposed landfills, and may only be practiced at B^+ sites provided that the site is equipped with an appropriate leachate management system. It is a requirement (Minimum Requirements, latest edition) that a site specific water balance be undertaken for sites for which co-disposal is proposed although it may only take place on M and L sites that are denoted B^+. Even sites that may have a negative water balance based on the climatic or site specific water balance would have to be designed as B^+ sites if co-disposal is proposed. A site specific water balance is required for both co-disposal and no co-disposal cases to show the difference.
- Site stability assessments are essential to the landfill design. Stability assessments must be done by a professional engineer at sites where WTR co-disposal is practised. The construction of landfills usually involves excavating into natural soils. This can be unsafe, particularly with trench systems. It is therefore necessary to analyse the stability of these cut slopes to ensure that they are safe against shear failure. The stability of a slope depends on its slope angle or

inclination, on its overall height and on the properties of the material of which it is composed. In the case of slopes cut into natural soils, the geotechnical properties of the soils should be determined by means of *in situ* or laboratory shear tests. The stability of the slope must be analysed by a suitably qualified professional geotechnical engineer.

The stability of the outer slopes of landfills should also be checked, especially when the slopes are steep and/or high, the moisture content of the waste is high, or co-disposal is practiced. It is imperative that where assumptions have been made in slope stability calculations, for example on the moisture content of incoming wastes, or on the co-disposal ratio employed, that these are clearly stated in reporting, so that these can be monitored and audited during the landfill operation.

Data on the slope design properties of solid waste is not readily available and may have to be determined for the particular waste stream. Leachate pore pressures may arise and may affect the stability of a landfill. Experience in South Africa and elsewhere during the past decade have shown that leachate pore pressures are particularly likely to occur in landfills where liquids are co-disposed of or where leachate is recycled. It has also become evident that landfilled waste that is close to or above the field capacity may liquefy, if it fails in shear, resulting in a flow failure. This type of shear failure is particularly dangerous to life and the environment (Minimum Requirements, latest edition).

- The spacing and orientation of trenches must be considered in 6-monthly stability assessments. As a precautionary principle the shear strength of WTR should be assumed to be zero.
- As a general rule, trench orientation should be perpendicular to the crest of a landfill and no trenching should occur within 30 m of the crest.
- The effective degree of mixing that is achieved with trenching should be taken into account when calculating an acceptable co-disposal ratio in terms of leachate generation.

10.5.5 Monitoring requirements for landfill

Monitoring serves to quantify any effect of the operation on the environment, especially the water regime, and act as an early warning system, so that any problems that arise can be identified and rectified. Such problems would include malfunctioning drainage systems, cracks in the cover, leaking liners and surface or groundwater pollution. The monitoring requirements in “Landfill Operation Monitoring” and “Water Quality Monitoring” (Minimum Requirements for Waste Disposal by Landfill (Latest edition)) should be complied with.

10.6 Dedicated Land Disposal

Dedicated land disposal (DLD) of WTR is generally the alternative chosen by those operations that either generate residuals continuously or have quantity or quality concerns. DLDs are designed to treat and dispose of large quantities of residuals through soil microorganisms, sunlight, and/or oxidation. In addition, the soils are used to bind or fix the metals, thus making them unavailable.

A distinct advantage to using a DLD is that, for the most part, the WTP controls the application times, rather than other factors (e.g. crop growth cycles). DLD application rates are generally much higher than those of other land application operations, ranging from 20t/ha to greater than 200t/ha. This increased application rate can greatly decrease the amount of land required for the WTP. The trade-off between DLDs and other land application options is that stricter requirements generally apply to the DLDs. Increased application rates require that the site be carefully designed, managed, and monitored.

The site must be designed to contain any of the residual constituents that might threaten public health or the environment. The site must take more care with surface runoff controls and the generation of contaminated leachate or infiltration. Generally, surface water controls include physical structures such as dikes, ditches, and lagoons. Control of leachate that is generated may require collection and treatment prior to discharge or disposal (USEPA, 1996).

10.7 Other land application options for WTR

Other applications for WTR include use at turf farms, parks and recreational areas, highway rights of way, airports, and construction sites. Most of these projects utilize WTR as a soil replacement or soil amendment. For example, in turf farming, each time a crop is harvested, a significant amount of soil is removed.

WTR can be used as a partial replacement. The other options also typically require imported soil, and in areas where topsoil is scarce residuals may be used as a partial or total replacement. As with all land application projects, however, the quality of the residuals must be matched with the needs of the user (USEPA, 1996).

10.8 Application Procedures

Once land application is selected as the preferred disposal option, the next step is to evaluate the land application site, the costs associated with that site, and the potential social and environmental impacts on the site. In addition, the costs of dewatering and hauling must be reviewed because the higher the percentage of solids, the less volume of residual must be hauled. The land area requirement depends on the application rate. In general, application rates are determined using agricultural methods, as with fertilizer. In the case of WTR, this fertilizer recommendation is at least two fold; the nutrient requirements for the crop are based on the expected yield and the available nutrients in the soil. The first nutrient to consider is nitrogen. WTR tend to be very low in this nutrient. A WTP should always check the nitrogen content of the residuals to be land applied. Basing the application rate on nitrogen alone, however, may cause problems with the crop yield because aluminium and/or iron hydroxide solids present in WTR are strong adsorbents of inorganic phosphorus. The low concentrations of phosphorus in WTR may further diminish total phosphorus in soils, restricting plant growth (USEPA, 1996).

As previously noted, concentrations of trace metals will likely determine the lifetime application amount of WTR on agricultural soils. Most metals in WTR are bound in forms not readily released into solution due to their strong adsorption and co-precipitation by aluminium and iron hydroxides freshly formed in the coagulation treatment step.

Buffer zones between residuals applications, such as surface water, drinking water wells, drainage ditches, property lines, residences, schools, playgrounds, airports, and public roadways, play an important role in a successful WTR management program. Identification of site specific buffer zones may be critical to the land application program. In addition, many states have buffer zone regulations that must be followed (USEPA, 1996).

11 DISCHARGE TO THE WASTEWATER TREATMENT PLANT (WWTP)

Discharge of WTR to a wastewater treatment plant (WWTP) is another disposal option for water utilities. These options are often economically attractive and transfer disposal liability to the WWTP. The American Water Works Association (AWWA) Water Industry Database (AWWA/AWWARF, 1992), a survey of WTPs currently discharging to a WWTP, reveals that such plants are variable in size, and typically treat surface water supplies as opposed to ground waters. Conventional WTPs (coagulation, sedimentation, and filtration) commonly discharge filter backwash solids and/or clarification basin residuals to a sanitary sewer system for eventual treatment at a WWTP. The information related in this section was primarily taken from the USEPA (1996) document on the management of water treatment residuals.

Several factors must be considered when evaluating the feasibility of discharging residuals to a WWTP. The interests and concerns of WWTP managers and operators are different from those of similar personnel in water utilities. Factors for a WWTP to consider are available capacity (conveyance system and treatment plant), treatment process compatibility, and final disposal requirements. Introducing water treatment residuals to a WWTP may offer some benefits in terms of process performance. On the water treatment facility side, pre-treatment requirements, storage facilities, and conveyance systems must be considered. Costs and service agreement terms must also be evaluated.

Regulatory requirements, especially those related to ultimate disposal, must also be addressed. Regulatory requirements imposed on WWTPs will be directly or indirectly imposed on the WTP discharging to the WWTP. Quality issues, especially levels of metals and other inorganic constituents, are likely to be a concern.

Discharging of WTR to WWTP may result in:

- An increase in the sludge volume of the WWTP;
- Improved phosphorus removal from the wastewater; and
- Lime softening residuals settle very well and should not affect the wastewater treatment primary settled sludge volume as much as coagulation residuals do.

When evaluating the option of discharging WTR to a WWTP, sedimentation tank capacities must be checked to ensure that they will not be overloaded by the additional solids. This precaution is especially critical for primary sedimentation, since the majority of the residuals solids will be removed here. The capacity of sludge pumps, pipes, and subsequent conveyance systems must also be examined; the removal of a larger volume of sludge at a lower solids concentration would require a larger pumping capacity and/or a higher pumping frequency (USEPA, 1996).

Discharge to a sewer is possible only when water treatment and wastewater treatment facilities work together cooperatively. Information sharing is imperative to establish such a relationship. A water utility should provide information concerning residuals quality and quantity, dry solids content, pH, nutrients, heavy metals, and other relevant parameters. In addition, a wastewater utility and water utility must cooperate to determine whether positive or negative effects can be expected at the wastewater facility with respect to hydraulic conditions in the sewer lines, hydraulic and process capacity at the WWTP, sludge treatment, and ultimate disposal of WWTP biosolids.

11.1 Advantages

The advantages for the receiving WWTP include:

- increased removal of suspended solids and/or biochemical/chemical oxygen demand (BOD/COD),
- increased removal of additional phosphorus, and
- The discharge of WTP ferric residuals can counteract the problems of H_2S formation in sewers and at the WWTP.

11.2 Disadvantages

Potential limiting concerns for a WWTP when it accepts WTR include:

- increased final suspended solids,
- decreased effective digester capacity,
- overloading of primary clarifier and sludge removal systems, and
- overloading of dewatering operations.

11.3 Considerations / requirements for discharge to WWTP

The local discharge requirements imposed by a wastewater utility may be governed by:

- Impact of residuals on the waste conveyance system (sewer, pump station, force mains, abrasion, and corrosion).
- Impact of residuals on either the liquid or solids process treatment system at the wastewater treatment facility (e.g. rate of discharge, solids concentrations, need for flow equalization).
- Concerns about biotoxicity (within the WWTP or in the plant’s effluent).

The following limitations may be prescribed by the WWTP before they will accept WTR:

- Limitations on maximum discharge rates, often during stated periods of the day;
- Maximum BOD concentration limits;
- Maximum total suspended solids (TSS) concentration limits;
- Total dry solids limits—tons/day maximum;
- Cessation of discharge upon notification during high storm flow periods; and

- Pre-notification of discharge occurrences (USEPA, 1996).

11.3.1 Equalization of discharge flow

WWTP often impose requirements on a WTP that govern the release of WTR to a sanitary sewer. The most common of these requirements is equalization of discharge flow. Equalization restrictions may include limitations on the time of day of discharge, the maximum flow over a certain period, or the maximum solids discharge that is allowed. Sometimes, discharges of peak flows during otherwise low flow periods in the sanitary sewer may be desirable (USEPA, 1996).

11.3.2 Quality Discharge Limitations

Limitations may be imposed on TSS or total dissolved solids (TDS), pH range, heavy metal constituents (either from a receiving water quality or residuals standpoint, or from a biotoxicity standpoint), and on corrosion causing constituents. According to the USEPA (1996), these limitations may be in a permit that regulates discharge directly to the WWTP through a force main or truck discharge, or in a permit for discharge to a sanitary sewer. Most municipal permit limitations imposed on industrial discharge to sanitary sewer systems contain a provision that the water discharged must be in a pH range of 6 to 9. This could cause problems for lime softening WTPs that have continuous discharge of softening residuals. Neutralization facilities for pH adjustment before discharge at the water treatment facility may be required.

<u>Trace elements and metals</u>

Heavy metals in the water environment are increasingly regulated to ensure against toxicity to humans, plants and aquatic organisms. Heavy metals are generally concentrated in the residual solids of water treatment and wastewater treatment wastes, and limitations on the ultimate disposal of those residuals, as well as on the dissolved fraction of heavy metals in the effluent, are becoming more stringent. A final quality concern is the amount of heavy metal impurities in the water treatment chemicals used at the WTP. The effect of contaminants on the chemical character of treated residuals can be significant (USEPA, 1996).

Another cause of increased metals concentrations in a WWTP effluent can be the mobilisation of metals that occurs when WTR are processed in a WWTP's solids handling processes, and recycled flows from solids handling are returned to the liquid process train.

Iron residuals can also benefit the wastewater treatment process through partial promotion of pre-sedimentation and partial phosphorus removal. They can also minimize problems with sulphide or H_2S formation by keeping the H_2S content in anaerobic digester gas at an acceptable level.

Passing the TCLP test allows a WTR to be classified as nonhazardous; however, it does not preclude the possibility of toxic effects on a WWTP if the WTR is discharged to the facility. Although organics and inorganics can be the cause of toxic effects from WTR, heavy metals are most often responsible for toxicity problems at WWTPs.

Nearly all heavy metals can exert toxic effects at elevated concentrations. Heavy metals can be grouped into “essential” and “nonessential” metals, according to their importance in biological systems. The vast majority of heavy metals fall into the “essential” category. Cadmium, mercury, and lead are the most commonly found nonessential heavy metals. In assessing the potential toxicity of individual heavy metals, two important issues should be considered:

- For metals essential to biological processes, an increase in concentration can often improve biological conditions if a deficiency of metals existed initially; and
- When they are present in excess, the essential metals can sometimes exert greater toxicity than the nonessential heavy metals.

Metal speciation plays a major role in the potential toxicity of a particular heavy metal. The dissolved portion, available as the free metal ion, is generally the most toxic to biological systems. This simple differentiation between the dissolved and particulate forms, however, is generally not adequate to determine toxicity effects. Heavy metals in the dissolved phase can be free metal ions, or can be tied up with inorganic or organic compounds to form complexes. Heavy metals in the particulate phase are capable of being bound to the surface of other solids, or tied up in the bulk phase of a precipitate (USEPA, 1996).

Organic Loading

The organic content of WTR varies widely, depending heavily on the quality of the raw water processed at the WTP. The concentration of organic matter in WTR, as measured by BOD or COD, is not typically in the range of that found in wastewater.

Although organics loading is typically the controlling parameter for the biological unit treatment processes in both the liquid and solids handling process trains at a WWTP, the additional organics loading encountered by introducing WTR generally does not have a significant impact (USEPA, 1996).

Solids Loading

The introduction of additional solids from WTR generally does not significantly affect the WWTP (USEPA, 1996). In several cases, alum and iron residuals from WTPs have actually improved the efficiency of primary clarification in WWTPs. A common factor related to the discharge of WTR to a WWTP is an increase in sludge from the WWTP, with a corresponding decrease in the volatility of the sludge. If a significant portion of the precipitates in the WTR is in colloidal form, the solids pass through primary and/or secondary clarification at the WWTP.

A key impact of WTR on WWTP unit processes is that additional residuals handling will be necessary. The effects of the additional residuals on clarification, digestion, dewatering and final disposal must be considered. Generally, final sludge volume increases as the amount of influent WTR. An increase in the primary clarifier sludge volume is to be expected with the addition of WTR to raw wastewater.

Liquid/Solids Separation

Liquid/solid separation is an important unit operation in water and wastewater treatment. The success of the overall treatment process depends greatly on a facility's ability to separate solids from the liquid stream. Liquid/solid separation can be accomplished by several unit operations. When WTR are discharged into a sanitary sewer system, one of the first unit processes that they encounter is primary sedimentation at a WWTP. Several studies conducted on the impact of WTR on the sedimentation process have reported fairly consistent results.

Data (USEPA, 1996) show that at a WTR dosage of up to 50 mg/L, removal of suspended solids from the primary sedimentation tanks improved. At dosages above50 mg/L, the percentage removals may be expected to drop. When WTR were accepted on a regular basis at the WWTP, the primary sludge solids content dropped from 5.8 to 4.7 percent. The addition of high concentrations of alum residuals tended to produce a primary sludge that was difficult to handle. Dosages of fresh alum less than 100 mg/L or WTR of 40 mg/L were reported to produce a more manageable product.

During a full-scale evaluation of alum residuals discharged via sanitary sewer to an activated sludge WWTP (USEPA, 1996), it was found that the efficiency of primary settling decreased by approximately 10 percent. Phosphorus removal improved by approximately 12 percent, and scum removal and settling improved in secondary clarification.

Dewatering

In its unthickened condition (e.g. underflow withdrawal from a clarifier), a WTR/sludge blend normally has a solids concentration in the range of 2 to 6% total solids. Thickening can reduce the water content to the range of 9 to 15% total solids. Dewatering of thickened residuals will result in a cake with a solids content of 18 to 40 percent.

Although available information has generally shown that sludge dewaterability is not negatively impacted by alum residuals, gravity settling of the sludge may be affected. The ability to reduce the water content of sludge depends on many factors, including the physical, chemical, and biological characteristics of the sludge, and the unit operations employed to thicken or dewater it. To date, the science of dewatering has not advanced to the point when sludge dewaterability can be predicted precisely without actual testing.

11.4 Summary

When coagulation sludge is discharged to a WWTP:

- the WWTP sludge volume will generally increase,
- phosphorus removal from the wastewater will be improved, and
- sludge concentration in the underflow may decrease.

Lime softening residuals settle very well and should not affect the wastewater treatment primary settled sludge volume as much as coagulation residuals do.

11.4.1 Aspects for WWTP to consider

Capacity

When evaluating the option of discharging WTR to a WWTP via a sanitary sewer system, sedimentation tank capacities must be checked to ensure that they will not be overloaded by the additional solids. This precaution is especially critical for primary sedimentation, since the majority of the residuals solids will be removed here. The capacity of sludge pumps, pipes, and subsequent conveyance systems must also be examined; the removal of a larger volume of sludge at a lower solids concentration would require a larger pumping capacity and/or a higher pumping frequency (USEPA, 1996).

Aerobic digestion and activated sludge processes

To accommodate WTR, an aerobic digestion system must have the physical capacity to accept the additional solids loading that residuals bring. Although the volatile solids contribution from the residuals is expected to be low and should not significantly affect the overall volatile solids loading to the digester, the impact of the residuals on hydraulic and solids retention time, as well as the overall reduction in volatile solids concentration, must be considered.

Toxic compounds present in WTR can adversely affect the biological processes of wastewater treatment facilities. Dissolved solids present in a liquid phase waste may thwart the biological process, depending on their form and/or concentration. Pre-discharge equalization techniques may alleviate toxicity problems, as a continuous discharge of suitable dilution will enhance the ability of the microorganisms present in the biological process to adapt and adjust to the presence of any inorganic ion. If the dosing of WTR is equalized so that surges do not occur, and the dose is kept below 150 to 200 mg/L, no direct effect on the activated sludge process is likely to take place, although downstream process effects or solids handling process effects are possible (USEPA, 1996).

Several investigations have found no evidence that alum hinders the substrate removal properties of the activated sludge process (USEPA, 1996). No change in the efficiencies of COD and BOD removals when alum sludge was discharged into a wastewater treatment plant is evident. In a series of laboratory-scale studies, the effects of alum sludge on the activated sludge process was studied and it was reported that no significant effects on either COD or TOC removal were observed at alum dosage of up to 100 mg/L. When a shock load of alum sludge was introduced to the system, the COD and TOC removals were decreased. The system was able, however, to recover to the same COD and TOC removal efficiencies before the shock load.

Despite several findings reporting the apparent lack of impact of WTR on biological treatment processes, the metal contents of these residuals do pose some concerns. Metallic ions such as hexavalent chromium, cadmium, copper, nickel, aluminium, and silver can hinder biological processes.

The level of salt concentration in WTR is extremely important to the proper performance of the biological processes at a WWTP. Introducing WTR with high sodium chloride concentrations, such as may occur from the undiluted discharge of waste, could cause considerable stress to biological organisms. As a result, COD of the biological reactor effluent could increase after the salt addition. Threshold concentrations of toxic ions in the biological process are the level above which a decrease in the COD removal efficiency of the biological process occurs. If precautions for equalization and dilution of WTR prior to discharge are adhered to, then brine discharges are unlikely to affect the receiving wastewater plant detrimentally (USEPA, 1996).

Anaerobic digestion

Because softening residuals can cause lime deposition, discharging softening residuals to a WWTP may adversely affect the performance of the anaerobic digester. If softening residuals are added directly into the anaerobic digester, the temperature can fall because of the additional volume of inert material. Additional heating may be required in this event.

Unless alum residuals are introduced at a very high rate, anaerobic digesters are unlikely to be significantly affected, provided the digester has adequate capacity to accommodate the increased solids loading. In assessing digester capacity, the reduced volatile solids concentration of the residuals stream must be taken into account (USEPA, 1996).

11.5 Monitoring requirements

Due to the characteristics of WTR which may have an influence on the downstream WWTP, the quality and properties of the WTR need to be monitored on a regular base. The frequency of monitoring will depend on the variability of results and need to be negotiated between the WTP and the WWTP and have to be included as a condition in the legal contract. The monitoring should include, as a minimum, the following:

- pH and Organic load (COD and/or BOD);
- Mobile metals (water or TCLP extract); and
- Solids content.

11.6 Record keeping requirements

It is recommended that the following records be kept by the WTP:

- Copy of the applicable licences and permits;
- Legal contract between WTP and WWTP;

- Discharge volumes and frequency; and
- Monitoring results of WTR.

12 DIRECT DISCHARGE TO SOURCE STREAM

Historically, direct discharge of water treatment effluent to surface waters has been the most commonly practiced disposal method. Recently, this disposal method has been questioned because of concerns about possible risk to public health and aquatic life (USEPA,1996).

The chemistry of aluminium and iron in water are similar to one another; however, iron species are less soluble than aluminium species are over a wider pH range. Because of the potentially adverse effects of aluminium in the environment, more information is available on the discharge of alum residuals to surface waters than is information on residuals produced from the addition of iron salts (USEPA, 1996).

Aluminium is soluble in acidic and basic solutions, but quite insoluble at neutrality. The aqueous chemistry of Al is extremely complex; the molecular form, or species and concentration of each species depend upon pH, complexes with ligands and, to a lesser extent, on temperature and reaction time (Campbell et al., 1983). Aluminium sulphate, used as the primary coagulant in most water treatment systems, dissociates in aqueous solutions and Al^{+3} bonds with water molecules, hydroxide ions, other inorganic ions and organic ions or molecules. When mixed thoroughly with turbid waters at pH levels from 4.0 to 8.5, new compounds form, especially with phosphates and organics, which are very insoluble and which, therefore, precipitate

A key concern regarding the direct discharge of aluminium residuals to waterways is aluminium toxicity in the aquatic environment. When aluminium is mobilized in streams, it may be toxic to aquatic life. It is difficult to generalize about the environmental impacts of WTR discharges on receiving water sources, because such impacts are inherently dependent on an array of physical, chemical and biological stream parameters. The characteristics of each case must be individually assessed to evaluate the potential threat of WTR on the water and sediment qualities of receiving streams. The aluminium species concentration causing toxicity depends on water chemistry, the organism being affected and the effect monitored (USEPA, 1996).

Based on the findings of research on aluminium toxicity (USEPA, 1996), the following recommendations should be followed when disposal to surface waters is being considered for WTR:

- Toxicity tests should be conducted on a variety of representative aquatic organisms from the intended receiving waters to fully determine potential toxic effects to the ecosystem;
- Alum residues should not be discharged to acid streams (pH less than 6); discharge into water with circumneutral pH levels, however, should have minimal effects on primary production, and is acceptable;
- Caution should be taken in discharging alum residues to soft receiving waters (i.e. hardness less than 50 mg $CaCO_3$/l); and
- An environmental assessment should be undertaken for any residue disposal to surface waters. Factors such as receiving water use, sediment structure, water chemistry, system hydrology, and

receiving water biology need to be assessed to ascertain if discharge of alum residues into a specific surface water will have a detrimental effect on the ecosystem.

Limited information exists regarding the impact of direct discharge of WTR on aquatic environments. Research conducted by the USEPA (1996) show that deposition of residuals solids can adversely affect benthic community populations and diversity. These direct consequences on benthic organisms may limit a food source for certain fish species. In addition, solids deposition may affect fish egg survival. Discharge of WTR in slow flowing streams should be avoided while reduced solids mass loading from the WTP during high stream flow will possibly reduce deposition and adverse effects to downstream benthic organisms.

The receiving water chemistry can minimize toxic effects of metals in the discharged waste stream. Hardness, alkalinity, pH, dissolved oxygen, sulphate, and other water quality parameters minimize the inhibitory effects of heavy metals. The chemical characteristics of the waste streams must be determined as well as the contaminant mass loadings to the receiving stream. Using information on stream hydrology and stream and waste quality, a mass balance should be conducted to estimate potential concentrations of contaminants downstream from a prospective point of discharge. Consideration of mixing zone should be included in modelling the system. When considering the future use of the receiving stream, a utility should consider whether direct discharge of its residuals will negatively affect the downstream aquatic life or quality. As part of this consideration, the utility should evaluate upstream and downstream water quality, sediments, and aquatic life to determine if the water has already been negatively affected by some previous use. To fully evaluate the toxicity of the WTPs discharged residuals, a series of toxicity tests should be conducted on a variety of aquatic organisms that are indicative of the organisms inhabiting the aquatic ecosystem (USEPA, 1996).

According to Ogilvie (1997) WTR discharges to surface water can affect natural water as follows:

- A deep pool can almost fill with residue, with the residue surface possibly being mistaken for the streambed. This can be dangerous because small children may think that the water is only knee or waist deep;
- Microbiological activity in a deep pool may cause the residue to become anaerobic, causing evolution of hydrogen sulphide, reducing iron which can stain and coat rocks further downstream, when the iron subsequently oxidizes;
- During the dry season there may be virtually no dilution before the next confluence, or until a significant rain event;
- Bacteria may be concentrated in the WTR during the water treatment process; whether that introduces a health risk to bathers will depend on the source and quality of the raw water and the amount of dilution;
- The general appearance of a stream receiving chemical residues can be quite unpleasant due to coloured floc adhering to tree roots, macrophytes, filamentous algae and the banks; and
- Alum and iron coagulation removes some phosphorus in the treatment process; once discharged to a watercourse, this phosphorus could stimulate undesirable growths.

WTR that are discharged to natural water can render the water quality unsuitable for its intended or regulated use, or affect its natural condition. Ogilvie (1997) recommended that the water quality of the receiving water should not deteriorate to levels above the drinking water standards after discharge and dilution.

12.1 SA context

Following the Stakeholder Consultation workshops, conducted as part of the development process of this Guideline, direct discharge of WTR to the source stream has been removed as a management option. General consensus were reached at all the workshops that this option have negative consequences for the receiving environment due to the potential accumulation and concentration of trace elements, metals and other constituents (organic and infectious substances) in the water source.

13 RESIDUALS REUSE

Although WTR do not have the inherent fertilizer value of wastewater sludge, these reuse alternatives are being practiced:

- Recovery of coagulants;
- Recovery of lime at softening plants (addressed in land application);
- Use in landscape tree nursery (low solids) – discussed in land application;
- Use in making bricks (high solids);
- Use in Portland cement (high solids); and
- Use in turf farming (USEPA, 1996) – land application.

13.1 Recovery and re-use of coagulants

The coagulants added during the water treatment process form a large part of the WTR. An attempt at recovering these coagulants for use in wastewater treatment is an attractive option if the WWTP will not accept the WTR itself. The recovery process normally includes acidification to mobilize the alum and ferric, but alkaline treatment and liquid ion exchange is also possible treatment options (Babatunde & Zhao, 2007).

The effectiveness and purity of the recovered coagulants are varied. The economy of the recovery process is also subject to debate. The following positive effects on WTR after coagulant recovery can be possible:

- Significantly reduce the cost of coagulants used at the WTP and WWTP;
- Can help meet discharge standards at a reduced cost;
- Reduced WTR volume and associated disposal cost;
- Make WTR more suitable for disposal (lower metals contents);
- Improve dewatering characteristics of WTR; and
- Increase the life of the disposal facility (Babatunde & Zhao, 2007).

13.2 Use in making bricks

There have been concerns about the compressive strength and shrinkage characteristics of brick made from WTR. The WTR need to be characterized to determine the components that will affect the process, i.e. organic and water content. A ratio of 80:20 has been found to be optimal. Ferric WTR are more feasible than alum WTR due to their Fe and organic matter content. Ferric WTR also provides some energy savings in brick making because it acts as a fluxing agent. It also provides raw material savings in the use of water and clay. It can also be used together with wastewater sludge in the brick-making process (Babatunde & Zhao, 2007).

13.3 Use in manufacturing of cement

Recycling of WTR to the cement industry is a practical alternative because the chemical composition of the inorganic WTR is similar to the clay used in cement production. WTR can increase the compressive strength of the concrete and benefit the clinker burnability. However, the chlorine level of the WTR has to be low because the chlorine could erode the cement kiln and block its duct (Babatunde & Zhao, 2007).

13.4 Other potential options

A number of studies have specifically examined the potential of WTR to remove excess nutrients from contaminated land, water and other waste products. Water treatment residues were found to be beneficial in removing excess N and P from land that had received excess nutrients from poultry litter, manure or fertiliser (Dayton, 1995; Peters and Basta, 1996; Gallimore, 1999; Gallimore *et al.*, 1999; Haustein *et al*., 2000; Hyde and Morris, 2000; Dayton *et al*., 2001; Callahan *et al*., 2002; Elliott *et al*., 2002). The residue is thus able to prevent or reduce eutrophication. The principle has also been successfully extended to co-application of WTR with wastewater sludge with the aim of reducing the high active P concentrations in the WTR (Ippolito *et al.*, 1999; 2002).

Alum WTR has been tested as a possible replacement for wood shavings in broiler litter (Maurice *et al*., 1998). Having used the WTR from when the chicks were one day-old to market age, these workers reported that there were no discernible negative effects with respect to growth, feed conversions, leg scores and litter characteristics.

The use of industrial by-products to improve the conditions of mine wastes for plant growth and to simultaneously act as a potential disposal option for the by-product have been reported extensively in the literature. The only study known that examines the use of a WTR on mined land is that of van Rensburg and Morgenthal (2003) who investigated the ability of a lime WTR to neutralize acid mine wastes. Chemical analysis indicated that the WTR is suitable as a liming agent because of its alkaline pH (8.08), high bicarbonate concentration (183.03 mg/L) and low salinity (electrical conductivity = 76 mS/m). The high cation exchange capacity of 15.47 $cmol_c$/kg and elevated nitrate concentration (73.16 mg/L) also increase its value as an ameliorative material. The soluble concentrations for manganese, aluminium, lead, and selenium were high at a pH of 5 although only selenium (0.83 mg/L) warranted some concern. According to experimental results, the application of 10 Mg/ha of WTR to acid gold tailings increased the leach water pH from 4.5 to more than 7.5 and also increased the medium pH from 2.4 to 7.5. The addition of WTR further reduced the solubility of iron, manganese, copper, and zinc in the ameliorated gold tailings, but increased the electrical conductivity. The liming tempo was highest in the coal discard profile that had a coarse particle size distribution and took the longest to move through the gold tailings that had a fine particle size distribution. Results from this study indicate that the water treatment sludge investigated is suitable as a liming agent for rehabilitation of acid mine waste.

Dayton and Basta (2001) and Zupancic (1996) considered the use of WTR as a soil substitute, and the potential of WTR to aid in mined land reclamation. However, they did not specifically test the effects of applying WTR to mined land, thus making it difficult to predict how either material would be affected by the other.

Hughes *et al*. (2005) conducted the following studies on alternative uses of WTR in pot experiments:

- Lime WTR and coal mine wastes – grass biomass decreased in mean total yield with increasing WTR application rate, but yield was good up to the 200 g/kg. The pH and EC of the leachates generally increased with increasing WTR addition. The concentration of nutrients in the grasses did not indicate any deficiencies or toxicities. The use of the Rand Water WTR showed that it could be applied to the spoil medium at relatively high concentrations without severely negatively impacting on grass growth, but that more caution should be used when applying this material to the soil medium.
- Lime WTR and combustion ash – while the grass did not grow in the ash treatments, it would seem that with suitable species the Rand Water WTR could be beneficially applied to ash material as a cover layer.

14 STAKEHOLDER CONSULTATION AND FEEDBACK

Comprehensive consultation with the regulating authorities and key stakeholders formed part of the development process of the WTR Guideline. The stakeholder consultation was conducted to test the feasibility of the implementation of the guideline as well as the acceptability of the rationale and the limitations proposed for the guideline. It was considered crucial that stakeholders give their input into the development of the WTR Guideline document to ensure that the final guideline will meet the requirements of WTR producers, users and the regulators. The consultation process included workshops in Gauteng, Western Cape, KwaZulu-Natal and the Eastern Cape, held in September and October 2008.

A wide range of stakeholders from a variety of organisations, institutions, national, provincial and local government, industry and research institutions involved in water and/or waste management sector were invited. This included distribution through the WISA and IWMSA databases, posting of the invitation on the DWAF, Department of Environmental Affairs and Tourism's (DEAT), Department of Agriculture (DoA) and WRC websites and the distribution of invitations through the DWAF Regional Offices to the relevant stakeholders within their responsible catchment areas. These included sectors such as municipalities, provincial health departments, provincial DEAT departments, DWAF officials, and other stakeholders considered necessary.

Each of the workshops consisted of a full day's programme to ensure that participants had ample information and time to interrogate the process and content of the proposed guideline and allowed for time for clarification, written feedback and "informal discussion" time, thereby enabling the capturing of as wide a feedback as possible.

Each work participant was provided with a booklet containing the presentations made at the workshop which included feedback sheets to provide written feedback. An attendance register was also signed by each attendee at each workshop to ensure that the project team recorded all participants and captured all their contact details.

In general stakeholders were very complimentary of the workshops and welcomed the opportunity to participate and give their input. Many found it to be informative and a capacity building session from their perspective, and welcomed such initiatives in the future to keep abreast and informed of such regulatory guidelines.

A wide range of comments was received from stakeholders at the various workshops and training sessions held. The comments received during the workshops were considered and addressed accordingly. Feedback from the workshops on the proposed WTR Guideline was gathered in two ways:

- Participants had the opportunity to verbally raise concerns and matters for clarification during the presentation. In addition, there was discussion time towards the end of each day's workshop programme which also permitted opportunity for comments and raising of issues.

- To cater for people who did not have the opportunity to raise their concerns verbally or were not comfortable to participate verbally, feedback sheets accompanied the workshop material which allowed participants to document their concerns.

These verbal and written comments, issues and concerns were documented by a dedicated scribe. These comments formed part of an issues register for each workshop session. Stakeholders were also encouraged to contact the project team should they wish to discuss any matter further.

Each of the concerns/issues raised were considered in terms of the Guideline and each comment notes how it was addressed/handled. Where necessary the reasons for accepting, rejecting or noting a concern/issue have also been included. This process has ensured transparency should any stakeholder wish to contest an issue.

The issues and concerns raised are detailed in the sections that follow.

14.1 Gauteng workshop: Comments received and issues raised

DEVELOPMENT OF THE WTR GUIDELINE **Saint Georges Hotel, Pretoria** **September 2008**		
Stakeholder details	**Comments from Stakeholder feedback sheets**	**Comments from the Presenter**
Alta Van Dyk, Ivuzi	• Do not agree with the use of the TCLP test. Different metals leach at different pH levels. Rainwater falls at a ph of 7. A1 + Fe leach at ph ranges from 6 to 12. Mn will leach out of anything with a TCLP test. This changes the risk profile completely according to the minimum requirements is a hazardous waste. Some WTR sludges range at a ph of 6-12? The minimum require a revision in this regard. • Could argue the need for a section 21 (f) license as it may be seen on a discharge to the groundwater resource through disposal onto soil. • Refer specifically to A1 and Fe on land application but the TCLP test fail to identify this due to pH limitations. • Site specific criteria should be included comments made such as Department to aquifer 75 m depends on the risk. Waste characterization is critical. • The introduction of a maximum acceptable application limit must also talk to other guidelines such as metal concentration v/s aquatic environment. • Accumulation in soils? • The minimum requirements are based on the total load principle – focus should change to source – pathway-receptor, if there is no pathway, there is no risk? Can deviate on liner requirements • Differentiate between industrial waste and waste that is generated from stream abstraction specific in terms of limitations such as buffer zones. • Pre-disposal values of soils and then a maximum application level? • Maximum permissible level should be a screening level – USEPA + Australia only (Tier 1) and then the risk based on site characterization, waste characterization and the source –	• The TCLP test will ensure that the precautionary approach to disposal is followed, especially when disposal is the management option of choice. • Land application and disposal are managed to protect groundwater. WTR is not discharged to groundwater. • TCLP test not applicable to land application. Rather use NH_4NO_3 extraction. • Included in Guideline. • No restrictions placed on application volumes or rates. Impact to be assessed through monitoring program. • Assessed with soil monitoring program. • WTR remain a waste and the Minimum Requirements must apply. • Quality of industrial WTR will prevent land application. • Initial site investigation will give baseline soil levels to assess impact of WTR on soils. • MPL introduced to ensure

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	pathway-receptor principle. • Liquid-to-solid ratio (spray onto soil? Section 21 (e) license – controlled activity not mentioned) • Define "responsible person" – look at NWA definition • Why is landfill classification criteria as per slide (page34) only applicable to offsite disposal –maybe the definition of off-site and on-site is incorrectly defined based comments made on licensing "portion per property" • "Landfill owner of WTR producer" and monitor requirements maybe not all the same. A farmer may not be taking monitoring seriously– tie to risk?	contamination will not progress to a point where remediation will be needed. • WTR rarely used in liquid form but 21(e) will apply in those instances. • Responsible person defined ito Minimum Requirements. • Off-site disposal is on landfill, therefore the classification. No need for classification of on-site disposal sites. • Responsibility remain with producer to ensure the user comply with the Guideline.
	• With regards to growing edible crops on landfill site: An opinion was raised that people and grazing animals are not found there, thus it of no concern. I disagree. • We have seen incidents of crops grown on Hg –Cd – and Pb – containing & ground • Local populations have cut through fences, and harvested at night. • A possible scenario is that these crops were sold to people who would not have known where it comes from. It could them have been fed children • Due to the widespread possibility of such a scenario, the use of edible crops should be forbidden on landfills.	• Noted, access restrictions and crop restriction for disposal sites are included in Guideline. • Elevated concentrations of these elements will render land application unfeasible. • Access restrictions need to be implemented and the community informed on the risk associated with WTR.
Fidelia Mogamisi	• Since conditions of the soils differ, soil analysis must be performed prior to applying WTR to the soil e.g. soils capable of oxiding P, there might be no need to add P. • Advantages and disadvantages should be clearly defined. • It should be clear that the residue is from water treatment plants and does not include industrial waste.	• Initial soil investigation include in Guideline • Included in Guideline • Noted
Graham Duncan	• Address the requirements for DWAF /GDACE WTR reclamation plans (requirements for these plans) • Recommended groundwater monitoring requirements (Frequency and variables to test for) • WTR to be reclaimed from a disposal site, for agricultural use, must be registered with the Department of agricultural. No land use "Restriction" to be specified by these guidelines.	• Included in Guideline • Included in Guideline • Small WTP will not go through registration process. Restrictions very limited.
Love Shabane	• Application on land should be determined by soil analysis • Source and content of water by the producer of residues must be acknowledged. Also acknowledge the quality of other residues. • Recommendations for agricultural use must be stated (advantage and disadvantage) • Registration with agriculture is very important. • The quality of the residue will enable the farmer to make informed decision. • Detrimental element should be removed.	• Governed by plant nutrient needs. • Noted • Included in Guideline • Noted • Farmer will be informed • Difficult to achieve, will be monitored and managed to reduce risk to receiving environment.

Charlie Crawford	• The guideline should make provision for different sludges
	  • Industrial water treatment.
	  • Industrial water treatment of water used by factories that may harmful substances.
	  • Residual from destination plants.
		• It includes all types of WTR. The quality of industrial WTR may render it unsafe for land application.

<table>
<tr><th colspan="3">DEVELOPMENT OF THE WTR GUIDELINE
Saint Georges Hotel, Pretoria
September 2008</th></tr>
<tr><td></td><td>• The difference between the water components and the solid component must be emphasized and the disposal of each be handled.
• “Residuals” may need to be broadened to include things like endocrine disrupters but will probably only he able to be handled after further research.
• Other aspects are spent activated carbon, waste chemicals not actually used in the plant.
• Good management of sludge/residuals should be discussed for example filter wash water can be recycled but excessive recycling leads to more bacterial in treated water.
• I think it is vital to indicate the maximum quantity of residues that one should not dispose on the land, i.e. the amount that can lead to ground water pollution as well as soil pollution.</td><td>• Noted
• Noted
• Noted
• Noted
• The impact will differ from site to site, no blanket quantity is possible.</td></tr>
<tr><td>Jan Pietersen</td><td>• Incorporate all unit processes:
  • Filter residue.
  • Flotation residue, etc.
• Metals – add uranium (also in now SANS 241)
• P – 7540 mg/kg are possible
• P34 volume/mass kg or tones dry solids/
• 20-30 year flood mark – mass balance.</td><td>• Noted
• Uranium is a site specific problem and those WTP need to include it in their monitoring program</td></tr>
</table>

Issues registered at Workshop	Comments from the Presenter
• Include a description of the characteristics of polyelectrolyte residues	• Included
• Definition to include residues from clarifier, filtration, etc. and have to include residues from all the processes addressed in the guidelines.	• Included
• Guideline cannot be applied retrospective – how will it be applied in areas where contamination has already taken place? What legislative backbone do we have to mitigate / improve the situation?	• Initial site investigation will show contamination and further WTR application and disposal will not be allowed.
• Types of treatment processes to consider: filter backwash, flotation processes, chemical treatment of membranes, mine water treatment, etc.	• Noted
• Re-look the P concentration (Jan Pieterse, John Redelinghuis to assist)	• Site specific investigation and WTR quality analyses will solve problem.
• 21 f licence also needed if groundwater is affected	• Groundwater will not be affected if monitoring program is implemented.
• Does the WUL only apply to wet WTR or dewatered too?	• WUL apply to WTP, not specifically to WTR management option, although it will be a condition of the WUL.
• When is a EIA required?	• EIA will be required for new disposal sites.
Land application	
• Where land application is already practiced, how will this Guideline affect these practices?	• Monitoring will ensure that land-use will not be compromised and that receiving environment will be protected.
• Monitoring is a very important part and need to be elaborated on	• Included in detail in Guideline
• WTR need to be registered as Agricultural lime or soil enhancer	• Noted. This is an option for WTP who want to alienate their WTR
• WTR will not categorically improve soil characteristics, if will differ for different soils	• Noted, included in Guideline
• Maximum application rate to relate to specific soil	• No maximum application rate specified, will be based on plant nutrient requirement, WTR quality and soil quality.

DEVELOPMENT OF THE WTR GUIDELINE **Saint Georges Hotel, Pretoria** **September 2008**	
Disposal	
• Beneficial use for mine reclamation	• It is included as a re-use option
• Big differences between industrial WTR and potable WTR. need to be handled differently	• WTR quality will determine whether industrial WTR can be used beneficially.
• Buffer zones could be relaxed, should be site specific.	• Buffer zones can be relaxed based on site specific investigations.
• Initial site specific data on Al, Fe and Mn need to be determined. Include normal range for soils in Guideline.	• Ranges included in Guideline
• Access to humans and animals should remain, but certain crops might be applicable	• Cultivation of edible crops not permitted.
Discharge to source	
• Very strict monitoring up-and downstream of discharge	• Noted
• It comes out of the river, why is it bad to put it back?	• The chemicals and potential pollutants are concentrated before discharge and the negative impacts are magnified.
Decisions reached by consent of Stakeholders at Workshop	
• WTR not to be discharged to source streams or dams	

14.2 Western Cape workshop: Comments received and issues raised

DEVELOPMENT OF THE WTR GUIDELINE **Lagoon Beach Hotel, Cape Town** **September 2008**		
Stakeholder details	**Comments from Stakeholder feedback sheets**	**Comments from the Presenter**
Aobakwe Galehole : Agrifoods Technology Station.	• The workshop was very insightful; it touched on different aspects of potable water treatment. • It would be most important if small municipalities especially the ones with no or little experience in this regards are called to this kind of workshops. • This can be done by looking into DWAF database, and by checking their last quarterly results and based on performance. • The workshop was focused mainly on chemical toxicity; it would be advantageous to conduct research on the microbiological impact of WTR on the ecosystem. • I suggest that also Department of Agriculture and the farmers from different form be taken into consideration during these workshops.	• Thank you • The invitation was distributed through DWAF • Noted. Microbiological monitoring is recommended where raw water is contaminated and the data will teach us a lot. • DoA was invited.
Unathi Jack	• **Management: Record keeping** – How about extending this to have a record sheet that includes more information such as amount of sludge produced, colour (i.e. are there any unusual observations) season, nature and quality so that when analysing the results there is more information provided. • **Land application** – Think the best way to explain this should include consideration of frequency of disposal or application and the method of application. • **Risk Ranking** – Consideration of extent of impact (i.e. is it expected to be local or cover a wider range) should be made • Nature of WTR together with duration in the environment	• Great idea. The WTP can include as much data as they want to extend their own knowledge as well as that of others. • Application normally before planting season at agronomic rates. • Included in risk assessment. • Characterization and

DEVELOPMENT OF THE WTR GUIDELINE Lagoon Beach Hotel, Cape Town September 2008		
	would also give an indication as to whether the risk would be high or low.	monitoring of WTR quality is essential.
Allen Blanckenberg	• Slides clear and understanding • Good feedback /participation from attendees. • Very informative and gave me some other options of disposing WTR	• Thank you.
Johathan Sudi Trizuluni	• The presentation has been a input to my knowledge as a student in term of sludge disposal and treatment • It is a part of my training that I am not exposed to the fact that the Stellenbosch Municipality does not have many facilities in this part of treatment. • I would like to present my gratitude to be allowed to participate in this workshop and would like attend more for my further knowledge.	• Thank you.
Fred Goliath	• If free chlorine is present in the backwash water that is to be put back into the stream, what must be taken care of not to affect the aquatic life?	• If present, care should be taken to ensure sufficient dilution of its effect.
Mothese Charlie	• Slides clear • Areas with unique and high potential agricultural land should be excluded in disposing and land application restriction. • Mine rehabilitation – beneficial use. • Apply in marginal lands to improve productivity • Give incentives to beneficial users of sludge.	• Thank you. • WTR will not deteriorate land-use if managed correctly. • Noted • They get the WTR for free, should be enough incentive.
Swastika Surujlala	• Before part 4, there should be classification section and based upon classification the other options should be included, like the matrix, e.g. • Classification : ➢ Land Application ➢ On site ➢ Off site ➢ WWTP ➢ Streams	• Included in Guideline.
Nonkululeko Jeyi	• Excellent presentation informative and open for discussion. • Looking forward to the end product. • Thank you	• Thank you.
Kenosi Namame	• Please include guidelines for process controllers and their role in this. The process controller registration and how to effectively maintain this practically (field study) for WWTW accepting WTR. • Private stakeholders should also be invited such as Improchem, Enviroserv and Ecogro. Their input could help clear issues on land use (Insertion/incorporation into compost. How better to dispose and difficulties experienced due to composition and concentration.	• Outside the scope of this Guideline • Discharge to WWTP part of Guideline • If part of WISA or IWMSA, they have been invited.
Carla le Roux	• Beneficial land use should be investigated or rather licensing and laws with regard to land use should be easier and should facilitate this being re-used. • The other option of combining with waste sludge would also be good – maybe it should be done for newer plants to be included in capacity. It would assist in most cases with the waste plant use. • There have been lots of problems with landfill collapse and this should be discouraged at all cost.	• Noted. SA legal context detailed in Guideline. • Noted, included in Guideline • Proper management of landfill will prevent collapse.
Yolanda Nikani	• The presentation was very good and the presenter was very active and presentable. I am a student doing in – service training at Stellenbosch Municipality so I do not have much to add or to correct but what I can say the workshop was very useful to me, I have learn a lot about WTP and WWTP as I have an interest in taking the side of Water when I am finish with my	• Thank you

	Diploma. • Thanks	
Simamkele Fulela	• The presentation was excellent to me and I learned more on it. • Since I have learned more on it I can have some solutions about WTP when there is a problem, and in future the information I've got about WTR I will use it. • Thank you very much	• Thank you
John Charles	• Very good workshop • The workshop gave new perspective on the Legal Frame Work. • The positive inter action of the group.	• Thank you
Johann Kannemeyer	• Good presentation • Similar guidelines to be established as per Waste Water Treatment sludges. • Categories of sludges (WTR) to be identified and rating to determine usage.	• Thank you • Already developed • Included in Guideline
Douglas Kiewiet	• Very well presented, very informative and interactive. • Thank you.	• Thank you
Jan Smut	• Contents were good and with the added comments can give usefully Guideline. • It will be very useful since my plant utilized disposal at sea.	• Thank you
Vericon Marinus	• Well presented and very informative copy of final to be forwarded. • Overall well done.	• Thank you
Merwyn Wright	• I made my comments during the presentation, thanks for listening. • I would have appreciated a key to: ➢ TKN ➢ Bray ➢ TCLP ➢ COC ➢ TTV ➢ MPL ➢ ARL, etc.	• Thank you • List of abbreviations included in Guideline
Daisy Mdluli	• This working was real eye opening. • I will like to see/attend one on waste water sludge as we a currently experiencing a lot of problems in disposing WWS (Coastal waste sludge) • The presenter was brilliant.	• Thank you
Bettina Genthe and Maronel Steyn	• To reiterate the factors to include in consideration of possible hazards please remember parasites as a possible contaminant & pharmaceutical & personal core products, these pass through WW works are in raw water • Removed but maybe not in WT process • Classification it any sludge/residue is the key in managing safe disposal • Lastly the disposal to source should never be permitted.	• Noted. Hopefully the monitoring data will shed more light on the matter in due course. • Noted • Noted, included in Guideline • No longer a management option
Linda Steenkamp, Solar-bee	• Fabulous presentation. • Very useful to have all detail of slides it hard copy format for purpose of making additional notes • I came with the purpose of learning more about handling of water /waste water and have achieved that, look forward to follow up workshops too. • Blue-green algae were mentioned very briefly which is major application for Solar-bee machines – can help that to reduce that problem. • Would it be possible to receive names, address contact details of everyone that was present?	• Thank you

DEVELOPMENT OF THE WTR GUIDELINE Lagoon Beach Hotel, Cape Town September 2008	
Issues registered at Workshop	**Comments from the Presenter**
• Is SO_4 in WTR a problem?	• Not under normal conditions, might be for industrial WTR. SO_4 included in monitoring program.
• Is TKN the best method for N determination?	• For agricultural use it is. Monitoring of NO_3 also included in monitoring program.
• Tracking of hormone cloned materials (Rietvlei)	• Should be included in monitoring program of the specific WTP
• Impact on aquatic plants	• Need to be investigated
• Wetland interactions – root adsorption	• Need to be investigated
• Pathogen removal (enteric viruses, parasites) – some will die-off. Others will persist	• Should be monitored by WTP where raw water contains elevated levels.
• How will the WULA and Permit back-log influence the implementation of the Guideline?	• It will certainly have an effect and will have to be sorted by DWAF and DEAT.
• The impact of discharge to the marine environment should be investigated.	• Noted
• Ferric residues have Cl and SO_4 in them. Will these concentrations pose a problem?	• Elements are included in monitoring program
Land application	
• Include a description of poly residues	• Included
• The maximum application rate should reflect the mobility of metals and protect surface and aquatic environments	• No maximum application rate recommended.
• Maybe include natural ranges of Al, Fe and Mn with MAT?	• Included
• Include fatal flaw areas in land application, as well as initial site investigations	• Initial site investigation included
• Maybe replace land application with "beneficial use on land"?	• Land application defined in Guideline
• Include site investigation results in record keeping	• Included
• Shouldn't monitoring be more frequent initially?	• Quarterly monitoring will be sufficient initially and can be relaxed based on monitoring results
Disposal	
• 1:100 year flood line not realistic	• Not a fatal flaw, should only be considered.
• "Depth to aquifer" restriction might be relaxed based on geology, impermeable layers	• Noted and included.
• Distinguish between wet and dewatered WTR – lagoons get filled up and de-sludged	• Noted
• A characterization / classification of WTR will help	• Included in Guideline
• Include potential ranges of Al, Fe and Mn with TTV and MPL values	• Included
• There are seasonal variation in treatment – higher dosages due to colour, etc.	• Monitoring results will show variability in quality.
• Footprint of lagoon need to be sampled – core thorough pond?	• Difficult to achieve, rather sample from emptied lagoons.
• Maybe maximum loads for disposal sites should also be based on total load principle?	• No maximum load specified, monitoring will indicate when soil can take no more WTR.
• Introduce a decision matrix similar to Sludge Guideline based on characteristics?	• Included
• Include MSDS / chemical certificates of treatment chemicals in Record Keeping file	• Good idea.
• Monitor changes in processes	• Responsibility of WTP
• Co-disposal ratio – based on physical characteristics (compaction), etc.	• Co-disposal ratio based on solid/liquid ratio that a landfill can take.

DEVELOPMENT OF THE WTR GUIDELINE Lagoon Beach Hotel, Cape Town September 2008	
• Lime residuals can be used in landfills?	• The quality will be good enough and it will benefit the landfill.
Discharge to WWTP	
• Algae blooms might be toxic to WWTP	• Noted, COD and BOD need to be monitored before WWTP will accept WTR.
• Monitor quality before discharge	• Included in Guideline
• Notify WWTP regarding any potential problems	• Included in Guideline
• Are there by-laws regarding discharge to sewer?	• Depend and local authority. Need to be considered when agreement between WTP and WWTP are drawn up.
• Size of waste stream and WWTP to be considered	• Noted
• Advantage in use – settling in primary settling tank increased, reduce COD by 60-70% by adding Fe-salt	• Noted and detailed in Guideline
Discharge to source	
• Need to be restricted by volume	• Noted
• Based on catchment levels	• Noted
• Receiving water quality objectives	• Noted
• Need to be licensed by DWAF	• Noted
• Limit on TSS	• Noted
• Limited by concentration of chemicals and pathogens	• Noted
Decisions reached by consent of Stakeholders at Workshop	
• Buffer zones for land application too strict, based on low toxicity of WTR	
• Discharge to source should not be an option	

14.3 Eastern Cape workshop: Comments received and issues raised

DEVELOPMENT OF THE WTR GUIDELINE VENUE :Port Elizabeth (Municipal Board room) DATE :October 2008		
Stakeholder details	**Comments from Stakeholder feedback sheets**	**Comments from the Presenter**
Sinuniso Ndlovu	• The Guideline should stress the importance of effective regulatory processes. As DWAF is in the process of finalizing Regulatory Strategy, reference need to be made on this development. • Guideline need to include financial viability when managing WTR. • Presentation was informative.	• The current regulatory processes applicable to WTR management are included. The Regulatory Strategy developed by DWAF is not yet common knowledge and have not been included in this Guideline. In the enforcement of the Guideline, DWAF need to implement this within the Department. • This is outside of the scope of this document. WTP need to investigate financial implications before choosing a management option. • Thank you

DEVELOPMENT OF THE WTR GUIDELINE VENUE :Port Elizabeth (Municipal Board room) DATE :October 2008	
Issues registered at Workshop	**Comments from the Presenter**
• Have insects been included as a receptor or pathway in the risk assessment?	• No, it has not. The influence of insects was perceived to be negligible since the type of waste is not palatable to insects.
• When reservoirs are cleaned, sludge are removed from it and discharged into storm water channels or flooded unto the surrounding areas. What are the legal implications on this? It happens once in 5 years or so.	• The volume of sludge released should not pose a problem
• The chemical characteristics of poly- and ferric residuals need to be included in the Guideline.	• Included in Guideline
• What about residues from seawater desalinisation plants?	• Not specifically included, but can piggy-back on the Guideline
• What about residues emanating from wastewater being treated to potable standards?	• Not specifically researched, quality will determine whether it can be used
• Is silt and sludge being removed from holding dams also included in the Guideline?	• It is outside of the scope of this guideline.
Land application	
• Buffer zones for land application too stringent based on current research evidence.	• Noted, will be investigated further
• The mobility and availability of Al is strongly dependent on pH. Need to be addressed.	• Restrictions on soil pH included in Guideline.
• Not all labs use NH_4NO_3 extraction method. Can another method be used?	• It is a very easy method to adopt.
Disposal	
• Buffer zones for disposal – does clay content of soil play a role?	• The clay content does play role and reference will be included.
• Will WTR really influence surface water quality since it has been removed from the surface water?	• Chemicals are added and it is concentrated. Will have an impact.
• Restrictions on soil pH for disposal sites?	• Included
• Erecting fences is a problem due to theft. How will we prevent human and animal access?	• Noted, however, you have to act responsibly. Educate the local population on the dangers of the site.
• The frequency of monitoring seems extensive. Is it really necessary?	• You need to monitor since you are potentially contaminating the environment. As indicated, the frequency can be relaxed in due time, based on previous monitoring results.
• Is filter backwash water covered by Guideline?	• It is seen as part of the overall WTR stream.
• Isn't extraction of elements from WTR an option?	• Not really, the concentrations are too low.
Decisions reached by consent of Stakeholders at Workshop	
• No need for maximum application rate for land application, agronomic rate will be sufficient to protect environment	
• Lagoons need more specific restrictions, especially for soil monitoring, etc.	
• WTR disposal into the source stream must not be allowed.	

14.4 KwaZulu-Natal workshop: Comments received and issues raised

DEVELOPMENT OF THE WTR GUIDELINE **VENUE : Ascot Conference Centre, Pietermaritzburg** **DATE : September 2008**	
Issues registered at Workshop	**Comments from the Presenter**
• Desalinisation plants need to be included (mine water treatment)	• Residues from mine water treatment plants are most probably toxic. Same classification can be used to see whether it can be used beneficially.
• The differences between wet and dry application should highlighted.	• Noted
• Discharge to the water course are regulated by Section 21 F	• Will no longer be allowed
Land application	
• Inform reader that P-deficiencies were evident in pot experiment. No proof exists in field trials.	• Included
• Include poly- and ferric residuals descriptions	• Included
• Site specific investigation on land where application is intended (chemical and physical properties).	• Included
• WTR need to be characterised to determine whether land application is applicable	• Included
• Characterization of WTR needs to include organic pollutants – viruses, protozoa, cysts, endocrine disrupters. Raw water is screened regularly for e-coli and annually for crypto.	• Too expensive to include for all WTP. Have to be included into monitoring program of WTP where raw water contains elevated levels of organic and infectious substances.
• Monitor for pH and EC on WTR and soil	• Included
Disposal	
• Consider WTR disposal to ocean	• Have to be investigated
• Buffer zones to disposal too strict based on evidence. Rather >2 m to aquifer and include soil restrictions on clay and pH	• Soil restrictions included, but buffer zones can only be relaxed based on site specific evidence.
• The number of soil samples for monitoring need to be included.	• Included in the Guideline
• Shouldn't the monitoring frequency be based on size WTP? Also based on water quality and change in treatment (SANS)	• Quarterly monitoring recommended taking care of seasonal variation. Difficult to base on size of WTP because the volume of WTR depends on raw water quality, not the size of the WTP.
Discharge to WWTP	
• Legal issues with discharge to WWTP need to be confirmed.	• Need to be investigated
• There need to be a contract between WTP and WWTP	• Recommended in Guideline
• Acceptability of WTR for WWTP determined by COB / BOD	• Included in Guideline
• Solid content restrictions – 2% solids for poly WTR (similar to coagulation WTR)	• Included
• Alum WTR improve settling at WWTP when in liquid form	• Included
• P-removal of WWTP being investigated by Umgeni	• Included
• Continuous discharge is necessary into WWTP (ask Debbie about discharge amount)	• Included

DEVELOPMENT OF THE WTR GUIDELINE **VENUE : Ascot Conference Centre, Pietermaritzburg** **DATE : September 2008**	
Discharge to source	
• When returned to source there need to be a wetland to clean stream	• Noted
• Return to source only in rainy season?	• Noted
• Return to source need extensive monitoring	• Noted
• Small plants do not desludge regularly, might be an option for them	• Noted
• Size of WTP or discharge stream (3 Ml = small)	• Noted
• Flocculent will still be active in the stream and cause sedimentation	• Noted
Decisions reached by consent of Stakeholders at Workshop	
• Maximum loading rate for land application is not applicable.	
• Buffer zones for land application too restrictive. Rather put soil restriction (clay and pH)	
• Discharge of WTR to source not an option	

15 CONCLUSION

Although there are still limited information on the characteristics of WTR and its impact on soil, surface- and groundwater, this Guideline serves as a first step to ensure responsible handling, application and/or disposal of WTR into the environment. Hughes *et. al.* (2007) identified a number of gaps with regard to WTR. One of these is limited information on the characteristics of all types of WTR produced nationally from different raw water sources with different water treatment processes. As part of the development of the Guidelines the characteristics of additional WTRs produced in South Africa have been studied. However, not to such an extent that the characteristics of all types of WTR from all types of treatment options and raw water sources are known. There is also insufficient information on the impact of different types of WTR on soil properties, surface and groundwater and a lack of information on the organic pollutant and infectious substance contents of sufficient representative samples of the variety of WTRs produced nationally.

The following information needs have been identified:

- Comprehensive information on the characteristics of WTR produced in South Africa. Monitoring requirements have been introduced for WTP to gather the necessary information. To optimally utilise this information the treatment process used as well as the raw water quality will be needed. It is recommended that WTP keep all this information on file which will then be valuable data to analyse once the Guideline is updated.

- The impact of WTR application to land and disposal on land on the receiving environment (soil, surface- and groundwater) can be thoroughly assessed based on the monitoring results of WTR users and producers. Since the implementation of this Guideline will take a while to roll-out, a research project might be considered where monitoring is implemented at a selected few WTP to gather the information needed.

- Although the impact of organic pollutants and infectious substances is perceived to be negligible, further monitoring is needed to strengthen this argument. This need to be conducted in areas where the raw water quality is known to be compromised by these elements.

The development of this Guideline lean heavily on the approach and methodology followed during the development of the South African Sludge Guidelines (Snyman & Herselman, 2006). A risk assessment was conducted following the source-pathway-receptor principle. During this assessment situations were identified where utilisation and disposal of WTR would have negative impacts on the receiving environment. Mitigation measures to minimize this impact were identified in the form of restrictions and requirements for each of the management options.

This Guideline document was developed to assist the WTR producer to decide on an appropriate management option for WTR. It informs the reader regarding the legal requirements for each management option as well as restrictions and requirements applicable to the different options. Monitoring programmes are introduced to collect data on the variability of WTR quality as well as to determine the potential impact of the management options on the receiving environment.

The Stakeholder Consultation process conducted to test the acceptability of the rationale and feasibility of implementation of the Guideline resulted in valuable feedback and comments from stakeholders. The comments and suggestions were incorporated into the Guideline, resulting in a better end-product.

It is recognized that new information will be generated through future research and monitoring and it is recommended that these Guideline be updated every 5 to 10 years. This will allow the South African water industry sufficient time to implement the Guideline and highlight shortcomings and constraints. Through the introduced record keeping process, case specific data will be generated that is expected to enrich the local knowledge base.

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APPENDIX A

Outcome of risk assessment

Risk identification matrix
Physical characteristics

Land application (Agriculture & beneficial use)

Particle size, particle density

Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Workers	1.1			0	Assume compliance with OSH Act and Equip worker with PPE	None required
	1.2			0		
	1.3			0		
General population	2.1	1	4	4	No impact expected in terms of the physical characteristics. The general public are not frequently in touch with the waste.	None required
	2.2	3	2	6	Dust is assumed to be a recoverable condition but exposure should be rare events.	None required
	2.3			0	Not applicable to physical properties	None required
	2.4			0		
	2.5			0		
	2.6			0		
	2.7			0		
	2.8			0		
	2.9			0		
	2.10			0		
Soil	3.1	2	3	6	Agriculture: consequence are managable, probability is rare. Increase soil water retention, porosity, plant available water, saturated hydraulic conductivity.	None required
Vegetation	4.1			0	It is assumed that the physical properties of WTR would not impact vegetation	None required
	4.2			0		
	4.3			0		
Air	5.1	2	4	8	Sporadic dust/odour nuisance may occur once every 1000 days while in storage before application or before incorporation into the soil	None required
	5.2	2	3	6	Sporadic dust/odour nuisance could occur once every 10 000 days - probability low due to incorporation into soil	None required
Surface water	6.1			0	Not applicable to physical properties	None required
	6.2			0		None required
Groundwater	7.1			0	It is assumed that the physical properties of WTR would not impact groundwater	None reqiured.
Grazing animals	8.1			0	It is assumed that the physical properties of WTR would not impact grazing animals	None reqiured.
	8.2			0		
	8.3			0		
	8.4			0		
	8.5	2	4	8	Inhalation of dust is assumed to be a recoverable condition with a 1:1000 day probability of happening	Not required
	8.6			0	It is assumed that the physical properties of WTR would not impact grazing animals	Not required
Fauna	9.1			0	It is assumed that the physical properties of WTR would not impact fauna	Not required
	9.2			0		
	9.3			0		
	9.4			0		
	9.5	2	3	6	Some intervention may be required to maintain yield and biodiversity, probability 1:10 000	Not required
	9.6			0	It is assumed that the physical properties of WTR would not impact fauna	Not required

Risk identification matrix
Physical characteristics

Particle size, particle density

Disposal

Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Workers	1.1			0	Assume compliance with OSH Act and Equip worker with PPE	None required
	1.2			0		
	1.3			0		
General population	2.1	1	4	4	No impact expected in terms of the physical characteristics. The general public are not frequently in touch with the waste.	None required
	2.2	3	2	6	Dust is assumed to be a recoverable condition but exposure should be rare events.	Buffer zones between DLD sites and dwellings. Dust suppression measures in windy season
	2.3			0	Not applicable to physical properties	None required
	2.4			0		
	2.5			0		
	2.6			0		
	2.7			0		
	2.8			0		
	2.9			0		
	2.10			0		
Soil	3.1	2	3	6	Consequence are managable, probability is low. Increase soil water retention, porosity, plant available water, saturated hydraulic conductivity.	None required
Vegetation	4.1			0	It is assumed that the physical properties of WTR would not impact vegetation	None required
	4.2			0		
	4.3			0		
Air	5.1	3	5	15	Sporadic dust/odour nuisance may occur once every 100 days	Dust suppression measures will need to be implemented during dust incidents. Buffer zones between DLD sites and dwellings
	5.2	2	3	6	Sporadic dust/odour nuisance could occur once every 10 000 days	None required
Surface water	6.1			0	Not applicable to physical properties.	None required
	6.2			0		
Groundwater	7.1			0	It is assumed that the physical properties of WTR would not impact groundwater	None reqiured.
Grazing animals	8.1			0	It is assumed that the physical properties of WTR would not impact grazing animals	None reqiured.
	8.2			0		
	8.3			0		
	8.4			0		
	8.5	2	3	6	Inhalation of dust is assumed to be a recoverable condition with a 1:10 000 day probability of happening	Not required
	8.6			0	It is assumed that the physical properties of WTR would not impact grazing animals	Not required
Fauna	9.1			0	It is assumed that the physical properties of WTR would not impact fauna	Not required
	9.2			0		
	9.3			0		
	9.4			0		
	9.5	2	4	8	Some intervention may be required to maintain yield and biodiversity, probability 1:1000	Not required
	9.6			0	It is assumed that the physical properties of WTR would not impact fauna	Not required

Risk identification matrix **Land application (Agriculture & beneficial use)**

Nutrients P, Ca, K, N, Mg, S

Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Workers	1.1			0	Assume compliance with OSH Act and Equip worker with PPE	None required
	1.2			0		
	1.3			0		
General population	2.1	1	4	4	No impact expected in terms of the nutrients.	None required
	2.2	1	4	4	No impact expected in terms of inhalation of nutrients in dust.	None required
	2.3			0	NA	NA
	2.4	1	4	4	Impact/consequence of nutrients ingested from plants grown on WRT amended soil are low (1), probability is 4	None required
	2.5	1	4	4	Impact/consequence of nutrients ingested from animals grazing on WRT amended soil are low (1), probability is 4	None required
	2.6	2	3	6	It is assumed that the consequence and probability will be low (1:10 000) of surface water pollution with limited impact on general public.	None required
	2.7	1	3	3	Impact/consequence of nutrients ingested from eating fish from surface water impacted by WRT amended soil are low (1), probability is 3	None required
	2.8			0	NA	None required
	2.9	2	3	6	It is assumed that the consequence and probability will be low (1:10 000) of groundwater pollution with limited impact on general public.	None required
	2.10	1	3	3	No impact expected in terms of the nutrients.	None required
Soil	3.2	1	3	3	No impact on soil even if application rates are high. Increase nutrients & organic C content.	None required
Vegetation	4.1	1	3	3	No impact on vegetation even if application rates are high. Increased yields	None required
	4.2	1	3	3	No impact on commercial crops even if application rates are high. Increased yields	None required
	4.3	1	3	3	No impact on grazing crops even if application rates are high. Increased yields.	None required
Air	5.1			0	NA	None required
Surface water	6.1	3	3	9	Elevated P content of WTR might cause eutrophication of surface water resources.	Buffer zones between application site and surface water resource
	6.2	3	3	9		
Groundwater	7.1	2	2	4	Impact of nutrients in WTR not high enough to cause negative impact on groundwater.	None required
Grazing animals	8.1	1	1	1	No consequences for animals ingesting plants grown on WTR ammended soils, probability is 1:100.	None required
	8.2	2	3	6	The consequences for animals ingesting WTR amended soils may cause recoverable effects, probability is 1:10 000.	None required
	8.3	1	1	1	Elevated P content of WTR might cause eutrophication of surface water resources, but will not impact on animals.	None required
	8.4	1	1	1	Impact of nutrients in WTR not high enough to cause negative impact on groundwater, therefore will not impact on animals.	None required
	8.5			0	NA	
	8.6	2	2	4	The consequences for animals ingesting WTR may cause recoverable effects, probability is 1:100 000 (it will be incorporated into the soil, dilution effect).	None required
Fauna	9.1	1	5	5	No consequences for fauna ingesting plants grown on WTR ammended soils, probability is 1:100.	None required
	9.2	2	3	6	The consequences for fauna ingesting WTR amended soils may cause recoverable effects, probability is 1:10 000.	None required
	9.3	1	1	1	Elevated P content of WTR might cause eutrophication of surface water resources, but will not impact on animals.	None required
	9.4	1	1	1	Impact of nutrients in WTR not high enough to cause negative impact on groundwater, therefore will not impact on animals.	None required
	9.5			0	NA	
	9.6	2	2	4	The consequences for fauna ingesting WTR may cause recoverable effects, probability is 1:100 000 (it will be incorporated into the soil, dilution effect).	None required

Risk identification matrix **Disposal**

Nutrients P, Ca, K, N, Mg, S

Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Workers	1.1			0	Assume compliance with OSH Act and Equip worker with PPE	None required
	1.2			0		
	1.3			0		
General population	2.1	1	3	3	No impact expected in terms of the nutrients. Low likelihood of General population coming into contact with WTR on DLD sites.	None required
	2.2	1	3	3	No impact expected in terms of inhalation of nutrients in dust. Low likelihood of General population coming into contact with WTR on DLD sites.	None required
	2.3			0	NA	NA
	2.4	1	3	3	No Impact/consequence of nutrients ingested from plants grown on WRT amended soil, probability is low.	None required
	2.5	1	3	3	No Impact/consequence of nutrients ingested from animals grazing on WRT amended soil, low likelihood.	None required
	2.6	2	4	8	It is assumed that the consequence will be low of surface water pollution with limited impact on general public.	None required
	2.7	1	3	3	Assumed to be no impact/consequence of nutrients ingested from eating fish from surface water impacted by WRT amended soil, probability is 3.	None required
	2.8	1	1	1	No impact through dermal contact with nutrients	None required
	2.9	1	3	3	No impact expected in terms of the nutrients through dermal contact.	None required
	2.10	1	3	3	It is assumed that the consequence and probability will be low (1:10 000) of groundwater pollution with limited impact on general public.	None required
Soil	3.2	2	4	8	Manageable degradation impacts may be observed after a long time of high application rates, probability is 1:1000 sites. Increase in fertility and organic C content of soil (positive).	None required. Limits on soil metal content might be considered
Vegetation	4.1	1	3	3	No impact on vegetation even if application rates are high. Increased yiels (positive)	None required
	4.2	1	3	3	No impact on commercial crops even if application rates are high. Increased yields.	None required
	4.3	1	3	3	No impact on grazing crops even if application rates are high. Increased yield.	None required
Air	5.1			0	It is assumed that nutrients will not have an impact on air quality/odours.	None required
Surface water	6.1	3	3	9	Elevated P in some WTR may cause eutrophication of surface water resources	Buffer zones between application sites and surface water. Bund walls to protect surface water.
	6.2	3	4	12		
Groundwater	7.1	3	4	12	Elevated nutrient concentrations might impact on groundwater when applied at high rates/disposed	
Grazing animals	8.1	1	1	1	No consequences for animals ingesting plants grown on WTR ammended soils, probability is 1:100.	None required
	8.2	2	3	6	The consequences for animals ingesting WTR amended soils may cause recoverable effects, probability is 1:10 000.	None required
	8.3	1	3	3	Elevated P content of WTR might cause eutrophication of surface water resources, but will not impact on animals.	None required
	8.4	1	3	3	Impact of nutrients in WTR not high enough to cause negative impact on groundwater, therefore will not impact on animals.	None required
	8.5			0	NA	
	8.6	2	2	4	The consequences for animals ingesting WTR may cause recoverable effects, probability is 1:100 000 (it will be incorporated into the soil, dilution effect).	None required
Fauna	9.1	1	1	1	No consequences for fauna ingesting plants grown on WTR ammended soils, probability is 1:100.	None required
	9.2	2	3	6	The consequences for fauna ingesting WTR amended soils may cause recoverable effects, probability is 1:10 000.	None required
	9.3			0	Elevated P content of WTR might cause eutrophication of surface water resources, but will not impact on animals.	None required
	9.4			0	Impact of nutrients in WTR not high enough to cause negative impact on groundwater, therefore will not impact on animals.	None required
	9.5			0	NA	
	9.6	2	2	4	The consequences for fauna ingesting WTR may cause recoverable effects, probability is 1:100 000 (it will be incorporated into the soil, dilution effect).	None required

Risk identification matrix **Land application (Agriculture & beneficial use)**

Micro elements B, Cu, Fe, Zn High TCLP Mn values

Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Workers	1.1			0	Assume compliance with OSH Act and Equip worker with PPE	None required
	1.2			0		
	1.3			0		
General population	2.1	1	3	3	It is assumed that the low concentrations of micro-elements in WTR will not case any harm to the general public via direct contact. The general public could come into direct contact with WTR (1: 10 000).	None required
	2.2	3	3	9	It is assumed that the low concentrations of micro-elements in WTR will not case harm to the general public via inhalation of dust, except Mn which may cause recoverable conditions. The general public could inhale dust originating from WTR (1: 10 000).	Buffer zones between land application sites and dwellings
	2.3			0	NA	NA
	2.4	2	3	6	Mn is phytotoxic. Effect on humans assumed to be negligeable.	None required
	2.5	2	2	4	Pathway very long. Mn is phytotoxic. Effect on humans assumed to be negligeable.	None required
	2.6	2	2	4	It is assumed that the consequence will be low of surface water pollution with limited impact on general public.	None required
	2.7	1	3	3	Assumed to be no impact/consequence of micro elements ingested from eating fish from surface water impacted by WRT amended soil, probability is 3.	None required
	2.8	1	1	1	No impact through dermal contact with micro elements	None required
	2.9	1	1	1	Leaching of Mn in soil is low, especially at high pH levels. Impact on humans through dermal contact neglegible	None required
	2.10	3	1	3	Impact neglegible	None required
Soil	3.1				NA	NA
	3.2	2	4	8	The consequences are manageable (elevated Mn concentrations) and the probability is 1:1 000.	Application restrictions / soil limits.
	3.3			0	NA	NA
Vegetation	4.1	2	3	6	Some intervention may be required to maintain biodiversity if acsess concentrations of Mn are added to crops, could happen (1:10 000).	Application restrictions.
	4.2	2	3	6		
	4.3	2	3	6		
Air	5.1				It is assumed that micro-elements will not have an impact on air quality/odours	None required
Surface water	6.1	3	4	12	Elevated Mn concentrations may impact on surface water due to run-off	Buffer zones between application sites and surface water. Bund walls to protect surface water.
	6.2	3	4	12		
Groundwater	7.1	3	2	6	Leaching of micro elements (especially high Mn) in soil is low, especially at high pH levels. Impact neglegible.	None required
Grazing animals	8.1	2	2	4	The consequences for animals ingesting plants with high Mn levels may cause effects that are recoverable, the probability is 1:100 000.	None required
	8.2	2	3	6	The consequences for animals ingesting WTR amended soils with high Mn may cause effects that are recoverable, the probability is 1:10 000.	None required
	8.3	3	2	6	Elevated Mn concentrations may impact on surface water due to run-off but the impact on animals is assumed to be neglegible.	Incorporate WTR into soil (dilution effect)
	8.4	3	2	6	Leaching of micro elements (especially high Mn) in soil is low, especially at high pH levels. Impact on animals neglegible.	None required
	8.5			0	NA	NA
	8.6	2	3	6	The consequences for animals ingesting WTR with high micro-elements (Mn) levels may cause recoverable effects, probability is 1:10 000.	Application restrictions, incorporate WTR into the soil (dilution effect).
Fauna	9.1	2	2	4	The consequences for animals ingesting plants with high Mn levels may cause effects that are recoverable, the probability is 1:100 000.	None required
	9.2	2	3	6	The consequences for animals ingesting WTR amended soils with high Mn may cause effects that are recoverable, the probability is 1:10 000.	None required
	9.3	3	2	6	Elevated Mn concentrations may impact on surface water due to run-off but the impact on animals is assumed to be neglegible.	None required
	9.4	3	2	6	Leaching of micro elements (especially high Mn) in soil is low, especially at high pH levels. Impact on animals neglegible.	None required
				0	NA	NA
	9.6	2	3	6	The consequences for animals ingesting WTR with high micro-elements (Mn) levels may cause recoverable effects, probability is 1:10 000.	Application restrictions, incorporate WTR into the soil (dilution effect).

Risk identification matrix

Micro elements B, Cu, Fe, Zn High TCLP Mn values **Disposal**

Receptor	Pathway no	Risk to receptor: Consequence	Probability	Risk rating	Notes	Mitigating factors
Workers	1.1			0	Assume compliance with OSH Act and Equip worker with PPE	None required
	1.2			0		
	1.3			0		
General population	2.1	1	2	2	It is assumed that the low concentrations of micro-elements in WTR will not case any harm to the general public via direct contact. The probability for the general public to come into direct contact with WTR at DLD sites are rare (1: 100 000).	None required
	2.2	2	2	4	It is assumed that the low concentrations of micro-elements in WTR will not case harm to the general public via inhalation of dust, except Mn which may cause recoverable conditions. The probability for the general public to come into contact with dust from WTR at DLD sites are rare (1: 100 000).	None required
	2.3			0	NA	NA
	2.4	2	3	6	Mn is phytotoxic. Effect on humans assumed to be negligeable.	None required
	2.5	2	2	4	Pathway very long. Mn is phytotoxic. Effect on humans assumed to be negligeable. Probability ingesting plants grown on DLD sites is rare	None required
	2.6	2	3	6	It is assumed that the consequence will be low of surface water pollution with limited impact on general public.	None required
	2.7	1	4	4	Assumed to be no impact/consequence of micro elements ingested from eating fish from surface water impacted by WRT amended soil.	None required
	2.8	1	2	2	No impact through dermal contact with micro elements	None required
	2.9	1	2	2	Leaching of Mn in soil is low, especially at high pH levels. Impact on humans through dermal contact neglegible	None required
	2.10	2	2	4	Impact neglegible	None required
Soil	3.1				NA	NA
	3.2	2	4	8	The consequences are manageable (elevated Mn concentrations) and the probability is 1:1 000.	Application restrictions / soil limits.
	3.3	1	3	3	NA	None required
Vegetation	4.1	2	5	10	Some intervention may be required to maintain biodiversity if access concentrations of Mn are added to vegetation, could happen (1:100).	Maximum load restrictions / soil limits.
	4.2			0	NA to DLD	NA
	4.3	2	3	6	NA to DLD	NA
Air	5.1			0	It is assumed that micro-elements will not have an impact on air quality/odours	NA
Surface water	6.1	3	4	12	Elevated Mn concentrations may impact on surface water due to run-off	Buffer zones between application sites and surface water. Bund walls to protect surface water.
	6.2	3	4	12		
Groundwater	7.1	3	2	6	Leaching of micro elements (especially high Mn) in soil is low, especially at high pH levels. Impact neglegible.	None required
Grazing animals	8.1	2	4	8	The consequences for animals ingesting plants with high Mn levels may cause effects that are recoverable, the probability is 1:1 000.	No grazing allowed on DLD sites with high, potentially toxic concentrations of micro-elements
	8.2	2	4	8	The consequences for animals ingesting WTR amended soils with high Mn may cause effects that are recoverable, the probability is 1:1 000.	No grazing allowed on DLD sites with high, potentially toxic concentrations of micro-elements
	8.3	3	2	6	Elevated Mn concentrations may impact on surface water due to run-off but the impact on animals is assumed to be neglegible.	Incorporate WTR into soil (dilution effect)
	8.4	3	2	6	Leaching of micro elements (especially high Mn) in soil is low, especially at high pH levels. Impact on animals neglegible.	None required
	8.5			0	NA	NA
	8.6	2	3	6	The consequences for animals ingesting WTR with high micro-elements (Mn) levels may cause recoverable effects, probability is 1:10 000.	Application restrictions, incorporate WTR into the soil (dilution effect).
Fauna	9.1	2	4	8	The consequences for animals ingesting plants with high Mn levels may cause effects that are recoverable, the probability is 1:10 000.	None required
	9.2	2	4	8	The consequences for animals ingesting WTR amended soils with high Mn may cause effects that are recoverable, the probability is 1:10 000.	None required
	9.3	3	2	6	Elevated Mn concentrations may impact on surface water due to run-off but the impact on animals is assumed to be neglegible.	Incorporate WTR into soil (dilution effect)
	9.4	3	2	6	Leaching of micro elements (especially high Mn) in soil is low, especially at high pH levels. Impact on animals neglegible.	None required
				0	NA	NA
	9.6	2	3	6	The consequences for animals ingesting WTR with high micro-elements (Mn) levels may cause recoverable effects, probability is 1:10 000.	Application restrictions, incorporate WTR into the soil (dilution effect).

Risk identification matrix **Land application (Agriculture & beneficial use)**

Metals As, Cd, Cr, Co, Ni, Hg, Pb, V **Disposal**

Receptor	Pathway no	Risk to receptor: Consequence	Risk to receptor: Probability	Risk to receptor: Risk rating	Notes	Mitigating factors
Workers	1.1			0		
	1.2			0	Assume compliance with OSH Act and Equip worker with PPE	None required
	1.3			0		
General population	2.1	1	2	2	No impact expected in terms of the metals (low concentrations). Direct contact by general population with WTR are rare at DLD sites	None required
	2.2	1	4	4	No impact expected in terms of inhalation of metal elements in dust. General population may possibly inhale dust originating from WTR DLD sites.	None required
	2.3			0	NA	NA
	2.4	1	2	2	Impact/consequence of metals ingested from plants grown on WRT amended soil are low (1), probability is rare from DLD sites	None required
	2.5	1	4	4	Impact/consequence of metals ingested from animals grazing on WRT amended soil are low (1), probability is rare from DLD sites. (long pathway)	None required
	2.6	1	3	3	Low concentrations of metals in available fraction, impact negligible.	None required
	2.7	1	2	2	Low concentrations of metals in available fraction, impact negligible (long pathway).	None required
	2.8	1	2	2	Low concentrations of metals in available fraction, impact of dermal contact negligible.	None required
	2.9	**1**	2	2	Low concentrations of metals in mobile fraction limits groundwater contamination, impact of dermal contact negligible.	None required
	2.10	1	2	2	Low concentrations of metals in mobile fraction limits groundwater contamination, impact negligible.	None required
Soil	3.1				NA	NA
	3.2	2	5	10	Manageable degradation due to high application rates over a long time at DLD sites even though the metal content of WTR is low, probability (1:100 sites)	Maximum load restrictions based on potentially toxic metals. Soil limits.
	3.3	1	2	2	NA	NA
Vegetation	4.1	2	5	10	Phytotoxic effects may occur at DLD sites due to high loading rates even though the metal content is low, the probability is 1:1000 (4).	Maximum load restrictions for DLD sites. Soil limits.
	4.2			0	NA to DLD	NA
	4.3			0	NA to DLD	NA
Air	5.1				It is assumed that metals will not have an impact on air quality/odours.	None required
Surface water	6.1	1	2	2	Low concentrations of metals in mobile / available fraction - limited impact on surface water	None required
	6.2	1	2	2		
Groundwater	7.1	1	3	3	Low concentration of mobile metals limits groundwater contamination	None required
Grazing animals	8.1	1	3	3	No impact on grazing animals eating crops grown on WTR ammended soils (low metal content of WTR), probability is 1:10 000 days	None required
	8.2	2	4	8	Recoverable effects on grazing animals eating crops grown on DLD sites (low metal content of WTR), probability is 1:1000 animals	No grazing allowed at DLD sites where metal content of WTR are known to be high
	8.3	1	2	2	Low concentrations of metals in available fraction, impact negligible (long pathway).	None required
	8.4	1	2	2	Low concentrations of metals in mobile fraction limits groundwater contamination, impact on animals negligible.	None required
	8.5			0	NA	NA
	8.6	2	4	8	The consequences for animals ingesting WTR may cause recoverable effects, probability is 1:10 000.	Incorporate WTR into the soil (dilution effect).
Fauna	9.1	2	3	6	No impact on animals eating crops grown on WTR ammended soils (low metal content of WTR), probability is 1:10 000 days	None required
	9.2	2	3	6	No impact on animals eating WTR ammended soils (low metal content of WTR), probability is 1:10 000 days	None required
	9.3	2	1	2	Low concentrations of metals in available fraction, impact negligible (long pathway).	None required
	9.4	2	1	2	Low concentrations of metals in mobile fraction limits groundwater contamination, impact on animals negligible.	None required
				0	NA	NA
	9.6	2	4	8	The consequences for animals ingesting WTR may cause recoverable effects, probability is 1:10 000.	Incorporate WTR into the soil (dilution effect).

APPENDIX B

Analytical procedures

Method for the determination of total metal content of WTR and soil samples (*aqua regia* digestion)

The method is summarized below.

- Weigh 3 g of the <150 µm sludge or soil sample into a 250 ml reaction vessel.
- Moisten with 0.5-1 ml water and add, while mixing, 21 ml hydrochloric acid followed by 7 ml nitric acid, drop by drop if necessary to reduce foaming.
- Stand for 16 h at room temperature
- Boil under reflux for 2 h
- Decant the sediment-free supernatant into 100 ml flask through filter paper
- Fill the flask to the mark with 0.5 mol/l nitric acid

The full method can be found in the reference below.

Reference: ISO 11466: 1995(E). Soil quality: extraction of trace elements soluble in aqua regia.

Toxicity Characteristic Leaching Procedure (TCLP) extraction method (USEPA Method 1311)

Summary of method

- For liquid wastes (containing <0.5% dry solid material), the waste, after filtration through a 0.6 to 0.8 µm glass fiber filter, is defined as the TCLP extract
- For wastes containing ≥ 0.5% solids, the liquid, if any, is separated from the solid phase and stored for later analyses.

Apparatus

- Agitation apparatus capable of rotating the extraction vessel in an end-over-end fashion at 30 ± 2 r.p.m.
- Extraction bottles for inorganics. These may be constructed from various materials. Borosilicate glass bottles are highly recommended. Polytetrafluoroethylene (PTFE), high density polyethylene (HDPE), polypropylene (PP), Polyvinyl chloride (PVC) and stainless steel bottles may also be used

TCLP solution 1

- Add 5.7 ml glacial Acetic Acid to 500 ml of reagent quality water (double distilled water).
- Add 64.3 ml of 1N NaOH.
- Dilute to a volume of 1 litre.
- When correctly prepared, the pH of this solution will be 4.93 ± 0.05.

TCLP solution 2

- Dilute 5.7 ml glacial acetic acid with double distilled water to a volume of 1 litre
- When correctly prepared, the pH of this solution will be 2.88 ± 0.05

Samples

- The sample must be a minimum of 100 grams.
- The sample must be able to pass through a 9.5 mm sieve, i.e. particle size of the solid must be smaller than 10 mm

TCLP extractions

Note that the TCLP test requires that a waste be pre-tested for its acid neutralization capacity. Those with low acid neutralization capacity are extracted with TCLP solution 1 (0.1 M Sodium Acetate Buffer, pH 4.93±0.05) and those with high acid neutralization capacity are extracted with TCLP solution 2 (0.1 M Acetic Acid, pH 2.88±0.05).

A. Preliminary evaluation:

This part of the extraction procedure must be performed to determine which TCLP (No . 1 or 2) solution should be used (see extraction solutions).

1. Weigh out 5.0 grams of the dry waste into a 500 ml beaker or Erlenmeyer flask.(In this exercise the particle size of the 5 grams should be 1 mm or less).

2. Add 96.5 ml of double distilled water, cover with a watch glass and stir vigorously for 5 minutes with a magnetic stirrer.

3. Measure the pH.

4. If the pH is less than 5.0, then use TCLP solution – No 1.

5. If the pH is greater than 5.0, then proceed as follows:

- 5.1 Add 3.5 ml 1N HCL and stir briefly.
- 5.2 Cover with a watch glass, heat to 50°C and hold at 50°C for ten minutes.
- 5.3 Let cool to room temperature and record the pH.

9. If the pH is less than 5.0, then use TCLP solution – No 1.

10. If the pH is less than 5.0, then use TCLP solution – No 2.

B. Extraction for analysis of contaminants:

1. Weigh out 100 gram of the dry waste, which passes through a 9.5 mm sieve, and quantitatively transfer it to the extraction bottle.

2. Add two litres (2 l) of the appropriate TCLP solution (No. 1 or 2 as determined by preliminary evaluation) and close bottle tightly.

3. Rotate in agitation apparatus at 30 r.p.m. for 20 hours. Temperature of room in which extraction takes place should be maintained at 23 ± 2°C.

4. Filter through a glass fibre filter and collect filtrate. Record pH of filtrate.

5. Take aliquot samples from the filtrate for determination of metal concentrations.

6. Immediately acidify each aliquot sample with nitric acid to a pH just less than 2.

7. Analyse by AA or other sensitive and appropriate techniques for different metals.

8. If analysis cannot be performed immediately after extraction, then store the acidified aliquots at 4°C, until analysis (as soon as possible).

Reference; USEPA Test Methods SW-846 On-line; www.epa.gov/epaoswer/hazwaste/test/pdfs/1311.pdf

Surface and groundwater analyses required for monitoring purposes

Characteristic	Parameter	Guidance on methodology and/or recommended extraction method
Water chemistry	pH	Direct measurement
	EC	Direct measurement
	PO_4	Standard method 4500-P[1]
	NH_4	Standard method 4500-NH_4[1]
	NO_3	Standard method 4500-NO_3[1]
	COD	Standard method 5220D[1]
Water microbiology	Faecal coliforms	Membrane filter/ m-FC medium[1]
	E Coli	Standard method 9221B[1]

[1] Standard Methods for the Examination of Water and Wastewater, 20th edition (1998) or latest, by Leonore S. Clesceri, Arnold E. Greenbert and R. Rhodes Trussell

Soil analyses required for monitoring purposes

Nutrients

Kjeldahl digestion to determine N

REAGENTS: Concentrated Sulphuric Acid,(H_2SO_4) Digestion Mixture: Potassium sulphate (AR) very finely ground (1500 g) mixed with 4 g finely ground (AR) Cu $SO_4 \cdot 5H_{20}$.

Weigh out 1.000 g of WTR into a digestion tube, and mix it with 2.0 g of the digestion mixture. Place this on a block at 360ºC, covered with glass “pears”. Digest for 2 hours or until solution is clear. Do not allow to dry. Remove from the block and cool slightly, then add 5 mℓ deionised water before cooling completely. Once cooled, rinse into a 100 ml volumetric flask, bringing it up to volume. Filter using Whatman no 2 filter paper.

***Reference**: Croll BT, Tomlinson T and Whitfield RW. 1985. Determination of Kjeldahl nitrogen in sewage effluents, trade effluent and sewage sludge. Analyst 110:861-866.*

Bray 1 P extraction

Reagents

- Ammonium fluoride stock solution: Dissolve 185.5 g NH4F(AR) in about 4 dm3 de-ionised water. Mix and make up to 5 dm^3
- Bray-1 extracting solution: Decant 600 cm^3 NH_4F solution in a 20 dm^3 aspirator bottle. Add 10 dm^3 de-ionised water and 50 cm^3 concentrated HCl (AR) (32%). Dilute to 20 dm^3 with de-ionised water and mix well
- Flocculant: Add 100 mg Superfloc N-100 or N-127 slowly to 100 cm^3 lukewarm de-ionised water. Stir at 400 rpm or shake gently till dissolved
- 1-amino-2-naphthol-4-sulfonic acid (ANSA) stock solution: Dissolve 137 g $Na_2S_2O_5$ and 5 g Na_2SO_3 in 800 cm^3 warm de-ionised water. Add 2.5 g ANSA and dilute to 1 250 cm^3 with de-ionised water. Filter into an amber glass bottle and store in a cool place
- ANSA working reagent: Dilute 100 cm^3 stock solution to 1dm^3 with de-ionised water. For best results make up fresh daily
- Ammonium molybdate/Sulphuric acid: Dissolve 7.5 g ammonium molybdate in 800 cm^3 de-ionised water containing 53 cm^3 concentrated sulphuric acid. After cooling make up to 1dm^3 in a volumetric flask. The reagent must be clear

Procedure

- Place 6.67 g soil (< 2 mm) in an extraction bottle
- Add 50 cm^3 Bray-1 solution (20 °C)

- Stopper the bottle and shake contents manually (up and down) for 60 seconds
- Add 2 drops flocculant
- Filter immediately through Whatman no 2V filter paper into a suitable bottle

***Reference**: Non-affiliated Soil Analysis Work Committee. 1990. Handbook of Standard Soil Testing Methods for advisory purposes. Soil Science Society of South Africa. ISBN: 0-620-14800-4.*

Trace elements and Metals

Method for the determination of NH_4NO_3 extractable (available) metal content of soil samples (DIN 19730)

Place 20 g air dry soil in a shaking bottle (100-150 mℓ), add exactly 50 mℓ ammonium nitrate solution (1 mol/ℓ) and shake for 2 hours at 20 rpm at room temperature. Then allow the solid particles to settle for 15 min. Decant the supernatant solution and filter (0,45 µm). Dispose the first 5 mℓ of the filtrate. Collect the remaining solution in a 50 mℓ bottle for analysis.

***Reference**: DIN [Deutsches Institut für Normung Hrsg.] 19730 (1997-06): Extraction of trace elements in soils using ammonium nitrate solution — Beuth Verlag, E DIN 19730: Berlin.*

APPENDIX C

Sampling procedures

WATER SAMPLING[1] PROCEDURE

Sampling equipment needed

- Equipment to collect microbiological samples

  - Sterile sample bottles (glass bottle needed)
  - Sealed container or cool box which can be kept cool (preferably with ice)

- Equipment to collect chemical and physical samples

  - Plastic bottles with plastic cap without liner / Glass bottles
  - Cooler box with ice (if necessary)

Special precautions

- Microbiological water samples

  - Keep sample bottle closed and in a clean condition up to the point where it has to be filled with the water to be sampled.
  - Do not rinse bottle with any water prior to sampling.
  - When samples for chemical and microbiological analysis are to be collected from the same location, the microbiological sample should be collected first to avoid the danger of microbiological contamination of the sampling point.
  - The sampler (person taking the sample) should wear gloves (if possible) or wash his/her hands thoroughly before taking each sample. Avoid hand contact with the neck of the sampling bottle.

- Chemical water samples

  - Some plastic caps or cap liners may cause metal contamination of the water sample. Please consult with the laboratory on the correct use of bottle caps.
  - Keep sample bottle closed and in a clean condition up to the point where it has to be filled with the water to be analysed.
  - Never leave the sample bottles (empty or filled with the water sample) unprotected in the sun.
  - After the sample has been collected the sample bottle should be placed directly in a cooled container (e.g. portable cooler box). Try and keep cooled container dust-free.

Surface water sampling technique

The following procedures should be followed when taking water samples in rivers and streams:

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[1] For more detail on the water sampling procedure, consult the following documents:

Department of Water Affairs and Forestry. 1998. Waste Management Series. Minimum Requirements for Water Monitoring at Waste Management Facilities.

WRC. 2000. Quality of domestic water supplies. Volume 2: Sampling Guide. WRC no TT 117/99.

- At the sampling point remove cap of sample bottle but do not contaminate inner surface of cap and neck of sample bottle with hands.
- Take samples by holding bottle with hand near base and plunge the sample bottle, neck downward, below the water surface (wear gloves to protect your hands from contact with the water).
- Turn bottle until neck points slightly upward and mouth is directed toward the current (can also be created artificially by pushing bottle forward horizontally in a direction away from the hand).
- Fill sample bottle without rinsing and replace cap immediately.
- Before closing the sample bottle, preserve the sample (if applicable) and leave ample air space in the bottle (at least 2.5 cm) to facilitate mixing by shaking before examination.
- Label the sample
- Submit for analysis to a reputable analytical laboratory.

Composite Borehole Water Sampling

Composite water sampling is done by pumping water from a borehole. The recommended procedure for composite sampling is as follows:

- Activate the pump and remove (purge) at least three times the volume of water contained in the hole.
- Collect a water sample in a clean container.
- Filter and preserve the sample (if applicable) and submit for analysis to a reputable analytical laboratory.

Various types of pumps may be used. As a portable system, a submersible pump may be considered. Submersible pumps are generally available in South Africa. For sampling, a small submersible pump that yields 1 l/sec would be sufficient for most sampling applications.

Where low-yielding monitoring boreholes are pumped, the borehole could temporarily run dry while being purged. In such instances, samples should be taken of the newly accumulated groundwater after recovery or partial recovery of the water level in the holes. It may be necessary to sample such boreholes a day or more after having purged the hole.

SOIL SAMPLING[2]

Sampling equipment needed

- Soil auger
- Plastic sheets
- Plastic or glass containers (bottles or bags) that can be closed tightly
- Tags and a permanent marker to label the samples

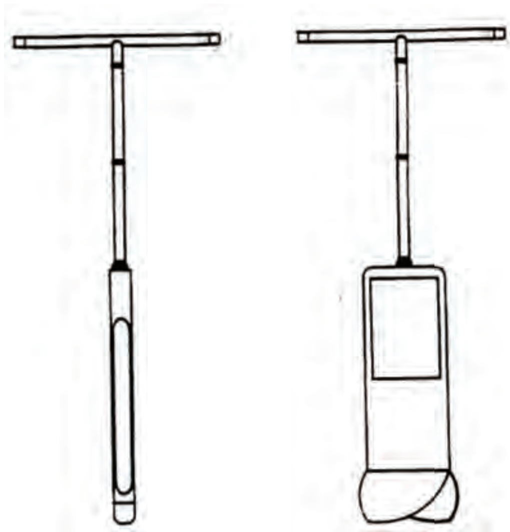

Figure C1: Soil augers

Number of samples

For mono-fills, waste piles and lagoons at least 4 composite samples of each disposal area at each depth will be required. For DLD sites the number of samples will vary according to the size of the disposal site and different soil types present at the disposal site. At least three composite samples for each depth increment for every hectare of the DLD site are required.

Sampling procedure

The **soil auger** is used to bore a hole to a desired sampling depth, and is then withdrawn. The sample may be collected directly from the auger. The following procedure is recommended:

1. Clear the area to be sampled of any surface debris (e.g. twigs, rocks, litter).
2. Begin augering and after reaching the desired depth, slowly and carefully remove the auger from the hole. Deposit the soil onto a plastic sheet spread near the hole. For soil monitoring at disposal sites these depths are 0-100 mm, 100-200 mm, 200-300 mm, 300-400 mm and 400-500 mm.

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[2] For more information on soil sampling procedures, consult the following documents:

USEPA Environmental Response Team. 2000. Standard operating procedures: Soil sampling

USEPA 1989. Soil sampling quality assurance: User's Guide. EPA 600/8-89/046

3. Place the samples into plastic or other appropriate containers, secure the caps tightly and label the sample.
4. If composite samples are to be collected, place a sample from another sampling site into the same container and mix thoroughly. When compositing is complete, place the sample into appropriate, labelled containers and secure the caps tightly.
5. Preserve the samples as recommended in the table below and submit to a reputable laboratory

Table C1: Recommended soil sample containers, preservation and holding times

Contaminant	Container	Preservation	Holding Time
Acidity	Plastic/Glass	Cool, 4^oC	14 days
Ammonia	Plastic/Glass	Cool, 4^oC	28 days
Sulfate	Plastic/Glass	Cool, 4^oC	28 days
Nitrate	Plastic/Glass	Cool, 4^oC	48 hours
Organic Carbon	Plastic/Glass	Cool, 4^oC	28 days
Chromium VI	Plastic/Glass	Cool, 4^oC	48 hours
Mercury	Plastic/Glass	Cool, 4^oC	28 days
Other Metals	Plastic/Glass	Cool, 4^oC	6 months

Soil samples can also be collected from a **test pit or trench excavation**. The following procedure is recommended:

1. A shovel is used to remove a one to two inch layer of soil from the vertical face of the pit where sampling is to be done.
2. Samples are taken using a trowel, scoop, or coring device at the desired intervals. Be sure to scrape the vertical face at the point of sampling to remove any soil that may have fallen from above, and to expose fresh soil for sampling.
3. Place the samples into plastic or other appropriate containers, secure the caps tightly and label the sample.
4. If composite samples are to be collected, place a sample from another sampling site into the same container and mix thoroughly. When compositing is complete, place the sample into appropriate, labelled containers and secure the caps tightly.
5. Preserve the samples as recommended in Table C1 and submit to a reputable laboratory

DEFINITIONS AND DESCRIPTION OF KEY TERMS

Acceptable exposure:	The concentration of a substance that will have minimal effect on the environment or human health.
Agricultural land:	Land on which a food crop, a feed crop, or a fibre crop is grown. This includes grazing land and forestry.
Agronomic rate:	The WTR application rate (dry-weight basis) designed (i) to provide the amount of nitrogen needed by the food crop, feed crop, fibre crop, cover crop, or vegetation grown on the land and (ii) to minimise the amount of nitrogen in the WTR that passes below the root zone of the crop or vegetation grown on the land to the groundwater.
Agricultural use:	The use of WTR to produce agricultural products. It excludes the use of WTR for aquaculture and as an animal feed.
Aquifer:	A geological formation which has structures or textures that hold water or permit appreciable water movement through them.
Assimilative capacity:	This represents the ability of the receiving environment to accept a substance without risk.
Attenuation:	The process of reducing the concentration of a substance by means of natural physical, chemical and biochemical processes such as dilution, oxidation and cell synthesis. Natural systems have an attenuation capacity, which may render small volumes of contaminants insignificant. However, when this capacity is exceeded, pollution results.
Available metal content (Soil):	Metal fraction extracted with ammonium nitrate in soil samples, simulating the plant available fraction.
Beneficial uses:	Use of WTR with a defined benefit, such as a soil amendment.
Bioavailability:	Availability of a substance for uptake by a biological system.
Biological oxygen demand (BOD):	An indirect measure of the concentration of biologically degradable material present in organic wastes. It usually reflects the amount of oxygen consumed in five days by biological processes breaking down organic waste.
Borehole:	A well, excavation or any artificially constructed or improved underground cavity which can be used for the purpose of: • intercepting, collecting or storing water in or removing water from an aquifer; • observing and collecting data and information on water in an aquifer; or • recharging an aquifer.
Bund wall:	A properly engineered and constructed run-off interception device around a waste disposal site or down slope of a waste disposal site.
Chemical oxygen demand (COD):	A measure of the amount of oxygen consumed for chemical oxidation of pollutants.
Coagulant:	A substance that causes fine particles to stick together to be more easily settle or be removed by filters.
Coagulation:	A separation or precipitation from a dispersed state of suspension particles resulting from their growth.
Co-disposal (liquid with dry waste):	The mixing of high moisture content or liquid waste with dry waste. This affects the water balance and is an acceptable practice on a site equipped with leachate management measures.
Co-disposal (dewatered WTR with dry waste):	The mixing of dewatered WTR with dry waste in a general landfill site or hazardous landfill site without affecting the water balance of the site.
Contaminate:	The addition of foreign matter to a natural system. This does not necessarily result in pollution, unless the attenuation capacity of the natural system is exceeded.
Controlled access:	Where public or livestock access to WTR application areas is restricted or controlled, such as via fences or signage, for a period of time stipulated by this guideline.
Cradle-to-grave:	A policy of controlling a Hazardous Waste from its inception to its ultimate disposal.
Cumulative pollutant loading rate:	The maximum amount of a pollutant that can be applied to a unit area of land.
Cut-off trench:	A properly engineered and constructed trench to intercept and collect run-off.
Dedicated land disposal:	Sites that receive repeated applications of WTR for the sole purpose of final disposal.

Delisting:	If the estimated environmental concentration (EEC) is less than the Acceptable Risk Level (ARL) which is 10% of the LC_{50}, the waste can be delisted, *i.e.* be moved to a lower Hazard Rating or even disposed of at a General Waste landfill with a leachate collection system.
Dewatering:	Dewatering processes reduce the water content of WTR to minimise the volumes for transport and improve handling characteristics. Typically, dewatered WTR can be handled as a solid rather than as liquid matter.
Disinfection:	A process that destroys, inactivates or reduces pathogenic microorganisms.
Disposal:	The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into the environment (land, surface water, ground water, and air).
Disposal site:	A site used for the accumulation of waste with the purpose of disposing or treatment of such waste. See also Waste Disposal Site.
Dose:	In terms of monitoring exposure levels, the amount of a toxic substance taken into the body over a given period of time. See also LD_{50}
Domestic waste:	Waste emanating, typically, from homes and offices. Although classified as a General Waste, this waste contains organic substances and small volumes of hazardous substances.
Dose-response:	How an organism's response to a toxic substance changes as its overall exposure to the substance changes. For example, a small dose of carbon monoxide may cause drowsiness; a large dose can be fatal.
Drying:	A process to reduce the water content further than a dewatering process. The solids content after a drying process is typically > 75%.
Dry-weight (DW) basis:	The method of measuring weight where, prior to being weighed, the material is dried at 105ºC until reaching a constant mass (i.e. essentially 100% solids content).
Dump:	A land site where wastes are discarded in a disorderly or haphazard fashion without regard to protecting the environment. Uncontrolled dumping is an indiscriminate and illegal form of waste disposal. Problems associated with dumps include multiplication of disease-carrying organisms and pests, fires, air and water pollution, unsightliness, loss of habitat, and personal injury.
E. coli:	A group of bacteria normally found in the intestines of humans and animals. Most types of *e. coli* are harmless, but some active strains produce harmful toxins and can cause severe illness. In sanitary bacteriology, *Escherichia coli* is considered the primary indicator of recent faecal pollution.
Ecotoxicity:	Ecotoxicity is the potential to harm animals, plants, ecosystems or environmental processes.
Environment:	The surroundings within which humans exist and that are made up of-- • the land, water and atmosphere of the earth; • micro-organisms, plant and animal life; • any part or combination of the above and the interrelationships among and between them; and • the physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being.
Environmental Impact Assessment (EIA):	An investigation to determine the potential detrimental or beneficial impact on the surrounding communities, fauna, flora, water, soil and air arising from the development or presence of a waste disposal site.
Estimated Environmental Concentration (EEC):	The Estimated Environmental Concentration represents the concentration of a substance in the aquatic environment when introduced under worst case scenario conditions, i.e. directly into a body of water. It is used to indicate possible risk, by comparison with the minimum concentration estimated to adversely affect aquatic organisms or to produce unacceptable concentrations in biota, water or sediment.
Exposure:	The amount of a hazardous substance available to man or living matter.
Feasible:	Acceptable, capable of being used or implemented successfully, without unacceptably damaging the environment.
Flocculation:	The intentional grouping of very small particles or colloids in a suspension in water or other liquids, the purpose being to increase the settlement rate of the solids.

Hazard:	A source of or exposure to danger.
Hazard Rating:	A system for classifying and ranking Hazardous waste according to the degree of hazard they present.
Hazardous waste:	Waste that may, by circumstances of use, quantity, concentration or inherent physical, chemical or infectious characteristics, cause ill health or increase mortality in humans, fauna and flora, or adversely affect the environment when improperly treated, stored, transported and disposed of.
Infectious Substances:	Micro-organisms including those which have been genetically modified, pathogens, cells, cell cultures and human endoparasites which have the potential to provoke infection, allergy or toxic effects.
Integrated Environmental Management (IEM):	A code of practice ensuring that environmental considerations are fully integrated into the management of all activities in order to achieve a desirable balance between conservation and development.
Land application:	The spraying or spreading of WTR onto the land surface; the injection of WTR below the land surface; or the incorporation of WTR into the soil so that the WTR can either condition the soil or fertilise crops or vegetation grown in the soil.
Land disposal:	Application of WTR where beneficial use is not an objective. Disposal will normally result in application rates that exceed agronomic nutrient requirements or cause significant contaminant accumulation in the soil.
Landfill:	To dispose of waste on land, whether by use of waste to fill in excavation or by creation of a landform above ground, where the term “fill” is used in the engineering sense.
LC_{50}:	The median lethal dose is a statistical estimate of the amount of chemical, which will kill 50% of a given population of aquatic organisms under standard control conditions. The LC_{50} is expressed in mg/l.
LD_{50}:	The median lethal dose is a statistical estimate of the amount of chemical, which will kill 50% of a given population of animals (e.g. rats) under standard control conditions.
Leachate:	An aqueous solution with a high pollution potential, arising when water is permitted to percolate through decomposing waste.
Liner:	A layer of low permeability placed beneath a landfill and designed to direct leachate to a collection drain or sump, or to contain leachate. It may comprise natural materials, synthetic materials, or a combination thereof.
Maximum available threshold (MAT):	The maximum available (NH_4NO_3 extractable) metal concentration allowed for soils receiving WTR.
Maximum permissible level (MPL):	The maximum total metal concentration allowed in soils at WTR disposal sites. Soil remediation would not be necessary except if this level is exceeded.
Minimum Requirement:	A standard by means of which environmentally acceptable waste disposal practices can be distinguished from environmentally unacceptable waste disposal practices.
Monthly average:	The arithmetic mean of all measurements taken during a given month.
Off-site:	WTR disposal site outside the boundaries of the water treatment plant (WTP).
On-site:	WTR disposal site within the boundaries of the water treatment plant (WTP).
pH:	The logarithm of the reciprocal of the hydrogen ion concentration. The pH measures acidity/alkalinity and ranges from 0 to 14. A pH of 7 indicates the material is neutral. Moving a pH of 7 to 0, the pH indicates progressively more acid conditions. Moving from a pH of 7 to 14, the pH indicates progressively more alkaline conditions.
Pollution:	The direct or indirect alteration of the physical, chemical or biological properties of a (water) resource so as to make it less fit for any beneficial purpose for which it may reasonably be expected to be used; or harmful or potentially harmful to the welfare, health or safety of human beings; to any aquatic or non-aquatic organisms; to the resource quality; or to property.
Qualified person:	A person is suitably qualified for a job as a result of one, or any combination of that person’s formal qualifications, prior learning, relevant experience; or capacity to acquire, within a reasonable time, the ability to do the job.
Receptor:	Sensitive component of the ecosystem that reacts to or is influenced by environmental stressors.
Recycle:	The use, re-use, or reclamation of a material so that it re-enters the industrial process rather than becoming a waste.

Rehabilitation:	Restoring a waste site for a new industrial function, recreational use, or to a natural state.
Remediation:	The improvement of a contaminated site to prevent, minimize or mitigate damage to human health or the environment. Remediation involves the development and application of a planned approach that removes, destroys, contains or otherwise reduces the availability of contaminants to receptors of concern.
Residue:	A substance that is left over after raw material or a waste has been treated or destroyed.
Responsible authority:	In relation to a specific power or duty in respect of water uses, means the catchment management agency or the Minister.
Responsible person:	A person(s), who takes professional responsibility for ensuring that all or some of the facets of the handling and disposal of Hazardous Waste are properly directed, guided and executed, in a professionally justifiable manner.
Risk:	The scientific judgement of probability of harm. This basic and important concept has two dimensions: the consequences of an event or set of circumstances and the likelihood of particular consequences being realised. Both dimensions apply to environmental risk management with it generally being taken that only adverse consequences are relevant
Risk assessment:	The evaluation of the results of risk analysis against criteria or objectives to determine acceptability or tolerability of residual risk levels, or to determine risk management priorities (or the effectiveness or cost-effectiveness of alternative risk management options and strategies).
Risk management:	The systematic application of policies, procedures and practices to identify hazards, analysing the consequences and the likelihood associated with those hazards, estimating risk levels, assessing those risk levels against relevant criteria and objectives, and making decisions and acting to reduce risk levels to acceptable environmental and legal standards.
Sedimentation:	The separation of a dilute suspension of solid particles into a supernatant liquid and a concentrated slurry.
Sludge:	Solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Wastewater sludge includes, but is not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and material derived from wastewater sludge in a wastewater sludge incinerator. It does not include the grit and screenings generated during preliminary treatment of domestic wastewater in a treatment works.
Soil organisms:	A broad range of organisms, including microorganisms and various invertebrates living in or on the soil.
Supplier:	A person or organisation that produces and supplies WTR for use.
Surface water interception mechanism:	A mechanism placed between the disposal site and the surface water body to intercept possible run-off from the disposal site before it can reach the water body.
Sustainability:	Being able to meet the needs of present and future generations by the responsible use of resources.
Sustainable use:	The use of nutrients in WTR at or below the agronomic loading rate and/or use of the soil conditioning properties of WTR. Sustainable use involves protection of human health, the environment and soil functionality.
Total investigative level (TIL):	The total metal concentration in soils where further investigation is necessary before further WTR application can commence.
Total load capacity:	The capacity of a landfill site to accept a certain substance or the amount of a substance, which can be safely disposed of at a certain site. The total load capacity is influenced by the concentration levels and mobility of the waste, and by the landfill practice and design.
Total metal content:	Metal fraction extracted using an *aqua regia* solution (HCl/HNO_3 solution).
Total trigger value (TTV):	The total metal concentration in soils at disposal sites indicating that additional management options should be implemented to reduce the impact on the soil.
Toxic:	Poisonous.
Toxicity:	An intrinsic property of a substance which can cause harm or a particular adverse effect to humans, animals or plants at some dose.
Toxicity Characteristic	A test developed by the USA Environmental Protection Agency to measure the ability of a substance to leach from the waste into the environment. It thus measures the risk

Leaching Procedure (TCLP):	posed by a substance to groundwater.
Transporters:	A person, organisation, industry or enterprise engaged in or offering to engage in the transportation of waste.
Treatment:	Treatment is used to remove, separate, concentrate or recover a hazardous or toxic component of a waste or to destroy or, at least, to reduce its toxicity in order to minimise its impact on the environment.
Waste:	An undesirable or superfluous by-product, emission, or residue of any process or activity, which has been discarded, accumulated or stored for the purpose of discarding or processing. It may be gaseous, liquid or solid or any combination thereof and may originate from a residential, commercial or industrial area. In terms of the NWA, it includes any solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted.
Waste disposal site:	Any place at which more than 100 kg of a Waste is stored for more than 90 days or a place at which a dedicated incinerator is located.
Water board	An organ of state established of the NWA to perform as its primary activity a public function.
Watercourse:	• a river or spring; • a natural channel in which water flows regularly or intermittently; • a wetland, lake or dam into which, or from which, water flows, and • any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse, and • a reference to a watercourse includes, where relevant, its bed and banks.
Water resource:	Includes a watercourse, surface water, estuary, or aquifer.
Water services	Water supply services and sanitation services.
Water service authority (WSA)	Any municipality, including a district or rural council as defined in the Local Government Transition Act, 1993 (Act No. 209 of 1993). Responsible for ensuring access to water services.
Water services institution	A water services authority, water services provider, water board or a water services committee.
Water service provider (WSP)	Any person who provides water services to consumers or to another water services institution.
Wet weight:	Weight measured of material that has not been dried (see Dry-weight basis).