A SCOPING REPORT TOWARDS THE DEVELOPMENT OF GUIDELINES FOR THE DISPOSAL OF WATER TREATMENT RESIDUE TO LAND

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A scoping report towards the development of guidelines for the disposal of water treatment residue to land

Report to the
WATER RESEARCH COMMISSION

by

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DISCLAIMER

EXECUTIVE SUMMARY

1 Introduction

1.1 Terminology

The waste material referred to herein as "water treatment residue" has often been termed 'water treatment sludge'. This latter term is too close to wastewater sludge/sewage sludge and similar materials that are absolutely and fundamentally different to the waste from water treatment works that produce potable water.

1.2 Background

A primary objective in producing potable water for human consumption from turbid sources is to remove suspended solids and other contaminants. Chemical precipitants such as aluminium sulfate (alum), ferric salts, lime and poly-electrolytes are added to the turbid waters received at the inflow of the water treatment facility. Once flocculated, the solid fraction which settles under gravity is transferred to drying beds, while the supernatant is filtered and clarified for domestic consumption. The dewatered solids (WTR) are regarded as an industrial waste and must be disposed of accordingly.

The traditional method of disposal has been by landfilling but given the economic constraints associated with landfill maintenance, together with the expansion of most urban peripheries, alternative methods have to be considered. A disposal option that is gaining increased acceptance internationally is the application of the residue directly onto land, termed land disposal or land treatment. Land treatment has a number of advantages over landfill, most notably economic. It also constitutes an open system that offers the potential for waste treatment, as opposed to simply waste disposal such as is associated with landfill.

A recent Water Research Commission (WRC) report (Hughes *et al*., 2005) is the only detailed study carried out on WTR in South Africa and it was estimated that over 5 million cubic metres of wet WTR are produced per annum in South Africa. The data strongly suggested that land disposal would be possible and even advantageous in certain circumstances. The study by Hughes *et al*. (2005) concluded "*that land application of WTR is safe and is likely to have no negative impacts on soils, vegetation or groundwater*". It was also 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. The work showed that the classification of WTR as a waste material that is reasonably likely to pollute water resources should be reconsidered and that its disposal under a general authorization allowed by the National Water Act be permitted. This would largely remove the present restrictions on its use and disposal. However, if WTR is to be applied to land, be it for agricultural use or other beneficial purposes (mined areas or recreational land), consideration needs to be given to the nature of the WTR to determine any potential negative impacts the material may have.

Hughes *et al*. (2005) were, however, unable to propose formal guidelines for their disposal, due to the scope of the work. It was to initiate the process of developing these guidelines that the present project was undertaken.

1.3 Aims

This project had four main objectives i.e.:

1. to carry out a gap analysis to consolidate and review the information and data collected to date in order to highlight gaps in our current knowledge set against a proposed framework for the guidelines for land application of WTR. Such guidelines will ultimately allow regulatory bodies to distinguish between wastewater sludge and WTR in their land disposal requirements. Both agricultural land application (and other beneficial uses) and dedicated land disposal (DLD) were to be addressed.

2. to produce an up-to-date review of existing guidelines and knowledge of WTR disposal available internationally;

3. to analyse a few WTRs from around South Africa to obtain an indication of spatial variability; and

4. to produce a report to indicate the way forward in order to achieve disposal guidelines.

2. International views and guidelines on land application of water treatment residue

Among the few countries that have guidelines for land application of WTR are the USA, Australia and New Zealand.

In the USA, the U.S. Environmental Protection Agency (EPA) has not established any regulations that are specifically directed at water treatment plant residuals. Applicable regulations are those associated with a number of acts and 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.

In Australia, WTRs (mainly alum residues) have been 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 have been identified, including low bulk density, high infiltration rate, some available nitrogen, a neutral to alkaline pH, and modest calcium carbonate equivalence.

In South Australia, the Environment Protection Act, 1993, 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. Maximum permissible contaminant levels are suggested (equivalent to Grade B Biosolids) and WTR that is applied to agricultural land should not exceed these levels.

Until very recently (before 1997) no guidelines for land application/disposal of WTR existed in New Zealand. 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 discuss the types of water treatment process used in New Zealand that produces a waste, and all the disposal scenarios.

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.

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 if their sludge contains any substances that could affect the soil or plants. There does not appear to be any chemical reason to constrain disposal of water supply sludges at New Zealand landfills.

3. Characterisation of water treatment residues

3.1 Introduction

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. In addition, as part of the current project, additional laboratory analyses were conducted on two alum WTRs from Blackheath (Cape Municipality) and Ixopo (KwaZulu-Natal), as well as new samples from Faure (Cape Municipality), Panfontein (Rand Water) and Midmar (Umgeni Water) to compare with the earlier samples collected in 2000 (Midmar) and 2001 (Faure and Rand Water).

It should be noted that in preparing the risk assessment the only data available were those from Hughes *et al.* (2005) and Titshall and Hughes (2005). The more recent data were gathered concurrently with the risk assessment and gap analysis.

The Rand Water WTRs (RWTR) were lime-softening residues with high amounts of CaO, as well as $FeCl_3$, long-chain organic polymer (LCP), activated silica and CO_2 being added. The Midmar and Amatola Water WTRs were LCP and lime residues. The Midvaal Water WTR was an $Al_2(SO_4)_3.nH_2O$, $FeCl_3$, lime and LCP residue and the Faure WTRs were $Fe_2(SO_4)_3$, activated charcoal, lime and LCP residues at different dosages. The Faure Water Treatment Plant had changed its source of chemicals and so a new sample was obtained. Attention was given to a wide range of physical, chemical and biological properties of the WTRs.

3.2 Physical characteristics

In general, residues exhibit high clay and silt fractions, though this property is only seen if complete dispersion is achieved since the residues are formed by coagulation of fine particles into larger, stable aggregates. 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. 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 densities of the dry WTRs ranged from 2.02 to 2.43 g cm^{-3}. Plant available water ranged considerably from 8.66 to 197.72 g kg^{-1}, but was generally low.

A concern for the risk assessment was that the fine particles in the WTR, once dried, may result in air-borne dust. However, one of the features of all WTRs is that when dry they form very hard aggregates. It is the strength of these aggregates that makes achieving full dispersion for particle size analysis so difficult. Thus risks from dust would likely be negligible.

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. A consideration for the risk analysis was that such properties could render such WTR unsuitable for land application since it could lead to reduction in infiltration rate or permeability of the soil. As commented above, many WTRs harden on drying. The dry aggregates are resistant to water and appear to break down in soil only under conditions of alternate wetting and drying. Large thicknesses 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 thicknesses of wet material (Hughes *et al*., 2000).

It thus appears that neither the risk of dust nor possible pozzolanic properties is sufficiently serious to render the application of WTR to land unfeasible.

3.3 Chemical characteristics

The chemical characteristics of WTR that may have an impact on its environmental impact during and after land application and DLD are pH, nutrients, trace elements, organic pollutants and pathogens.

3.3.1 pH

The pH(H_2O) values of South African WTRs range from 6.2 to 9.2. This pH range is not a characteristic that is of concern for land application of WTR.

3.3.2 Organic carbon

The organic carbon content ranges from 1.2 to 10.3% and will have a positive impact on soils. This is therefore not a constituent of concern.

3.3.3 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.

3.3.3.1 *Nitrogen*

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}. Total N concentrations ranged from 200 to 5 200 mg kg^{-1}. This indicates that a considerable proportion of the N is bound in less soluble (or less available) forms in the WTRs, except in the Rand WTR, where NO_3-N and NH_4-N accounted for about 60% of the total nitrogen, even though the total concentration was low. Little information on the actual impact of N from WTR on groundwater and surface water is available and therefore it is handled as a constituent of concern. However, data from Umgeni Water suggest that at their disposal site leaching of N is not a problem. Similar findings, based on data from soil water collectors, were reported by Hughes *et al.* (2005).

3.3.3.2 *Phosphorus*

The AMBIC extractable P was generally low, except for the Midvaal and Faure 2 WTRs. 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.

3.3.3.3 *Major cations (Ca, Mg, K and Na)*

These elements are not constituents of concern due to their low concentrations and the fact that they are essential plant nutrients (with the exception of Na).

3.3.3.4 *Cation exchange capacity (CEC)*

The CEC gives an indication of the material's potential to hold plant nutrients and other cations. The CEC of the WTRs ranged from 15.9 to 41.8 $cmol_c$ kg^{-1} and, with the exception of the Rand WTR, all were above 25 $cmol_c$ kg^{-1}. 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.

3.3.3.5 *Trace elements and metals*

The trace element and metal content of WTR may have negative impacts on several receptors when present in high concentrations. The plant available fraction was determined with DTPA extraction and the leachable fraction by the toxicity characteristic leaching procedure (TCLP).

Manganese, Cu, Ni, Co, As, F, B, and Zn are among a number of potentially phytotoxic elements. The concentration of elements in edible plant parts is not dangerous to humans because the element is harmful to the plant at lower element concentration than required to result in risk if consumed.

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. Strongly acidic soils allow these elements to become phytotoxic, while adding enough lime to make the soil alkaline prevents phytotoxicity. 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.

Plant available fraction

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. The DTPA extractable metal concentrations were low, although Fe and Mn concentrations were elevated in most of the WTRs due mainly to their concentration in the treatment chemicals. Copper concentrations were elevated in the Midvaal and Midmar samples.

The pH of the WTR (6.5-9.0) would reduce the toxicity of the trace elements for plants and will also immobilize the elements and protect the groundwater. The impact of the trace elements on surface water due to erosion of solid particles would have to be investigated. Therefore, these elements are not constituents of concern for plants and groundwater but may potentially be of concern for surface water contamination.

Leachable fraction

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. However, importantly, it takes no account of any readsorption of the 'leached' elements that may occur as a result of interaction with the soil.

The TCLP extractable metal concentrations indicate that Mn in all the WTRs exceeds the acceptable exposure level (AE) according to DWAF (1998; 2005), as does Zn in the Midvaal and Faure 1 WTR. The reason for the elevated concentrations is almost certainly the high concentrations of these elements in the chemicals used during the treatment of the raw water.

It is likely that under the recommendations of the Minimum Requirements (DWAF, 1998; 2005) most of these WTRs would not be considered as non-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.

Manganese

The major constituent of concern in the WTR seems to be Mn. The common valence states found in most soils are Mn^{2+}, Mn^{3+}, and Mn^{4+}, 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. Manganese toxicity is normally associated with soils of pH 5.5 or lower. 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.

Other elements

The concentrations of all the other elements in the WTR are low and they are therefore not constituents of concern.

3.3.4 Organic pollutants and infectious substances

There were no data available in South Africa on either of these constituents in WTR. The literature review also indicated that they are not monitored internationally. Although organic compounds were not considered, constituents of concern and therefore did not receive further attention, the samples collected as part of this project were screened for pesticides and none were detected.

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 WTRs collected as part of this project were analysed for indications of the presence of some infectious substances (see Section 3.4.6).

3.4 Physical and chemical analyses of recent water treatment residues

Two alum residues and new samples from Faure, Midmar and Rand Water were analysed to see what changes have occurred over time.

3.4.1 Particle size and general chemical characteristics

The particle size data were obtained after various dispersion procedures to demonstrate the importance of obtaining full dispersion. All were dominated by clay with only RWTR having a moderate amount of silt.

The pH, amounts of extractable cations and CECs of the samples from Midmar and Rand are very similar to the earlier samples. The major differences are found in amounts of total carbon, nitrogen and sulphur. The alum residues have pH values within the range for the other WTRs (Section 3.3.1). The Blackheath WTR has higher extractable Ca and the sample from Ixopo has higher Na and K, and also has much higher total N, C, and S than the other WTRs. These latter elements may reflect the origin of this WTR within a largely agricultural community. The CEC of the Blackheath sample is within the same range as found before but the Ixopo sample has a CEC of only 9.75 $cmol_c\ kg^{-1}$, the lowest of any of the WTRs analysed.

3.4.2 Ammonium nitrate extractable elements

This method was used in place of the TCLP. For TCLP only Mn (and occasionally Zn) exceeded the AE limits but in the ammonium extract all the WTRs also had values for Cu and Pb that exceed the AE limits. Amounts of Mn extracted seem to be much lower, while those of Zn are slightly higher.

3.4.3 Heavy metals

A direct comparison with earlier data is not possible as the data for the 2006 samples were obtained through batch extraction and not sequentially due to time constraints. This means that the amount of element extracted subsequent to $MgCl_2$ may be inflated by some proportion of the previous extracted amount. However, in many instances the values are similar.

3.4.4 Total major element composition

The X-ray fluorescence spectrometry data largely reflect the treatment process used at the respective plants. The alum residues from Blackheath and Ixopo have the highest amounts of total Al and interestingly the highest amounts of P, the Faure residues the highest amount of Fe and the Rand WTR the highest amount of Ca. The differences between the two Midmar WTRs are minor, the most obvious being the lower amount of Ca in the 2006 sample – a reflection presumably of the plant using less lime in the process. The two RWTRs are also similar but with the 2006 sample containing slightly less Mg and Ca and slightly more Al than the 2001 sample.

3.4.5 Trace/minor element composition

These results obtained by inductively coupled plasma-mass spectrometry are very similar to those obtained previously with the only somewhat high values being those for Cu and Zn in the Blackheath alum WTR.

3.4.6 Organic constituents and possible infectious substances

The WTRs contain no pesticides or nematodes and have very low total aerobic plate counts. These data appear to justify the decision not to consider these substances as a cause for concern (Section 3.3.4).

3.5 Discussion and conclusions

Water treatment residue is largely a natural material (plus chemicals added during the treatment process), consisting mainly of clays that originate within the catchment area of the raw water source. Returning it to the land ought not to be such a major concern as land disposal of wastes that consist of anthropogenically produced materials such as wastewater sludge or industrial waste.

A comparison between the WTR data and those for wastewater sludge (DWAF, 2005; WRC, 2006), indicates the following:

- The TCLP extractable element concentrations in WTR are appreciably lower than those of wastewater sludge. No data are available for the TCLP extractable Mn concentrations in wastewater sludge.
- The total (ICP-MS) concentrations of the elements of concern (except Mn) in the WTR are much lower than the total (*aqua regia*) concentration of these elements in wastewater sludge.

- The elevated TCLP concentrations of Mn, Pb and Zn in WTR would hamper DLD, because it is governed by the Minimum Requirements (DWAF, 1998; 2005), but would not prevent it.
- The total element contents of WTR are significantly lower than the limits set for wastewater sludge destined for unrestricted agricultural use, except for Mn.

From most of the characteristics analysed, WTRs can be seen to be innocuous waste materials. The Mn content of South African WTR stands out as the main reason for concern for land application and DLD. However, the pH of the WTR (>6.2) would render Mn insoluble in many soils since it is only soluble at pH < 5.5 (Section 3.3.3.5). Internationally, Mn is handled as a non-issue since the risk to the environment is perceived to be minimal. Thus although Mn levels may be high, whether it is really an environmental concern in South Africa remains unclear. The analyses conducted in this report show that there also remains uncertainty as to the best methods to use to characterise these particular waste materials.

However, although the constituent materials are natural, land disposal of the WTR concentrates these materials onto a much smaller area of land. It was to consider the possible effects of such disposal that a full risk assessment was carried out and within this assessment all the elements were considered. Similarly the pozzolanic properties of WTR have not been addressed in other studies and, since information is limited, it was assumed that application of liquid WTR (slurry) to soil, without appropriate management, could result in crust formation and a decrease in the permeability of soils. The risk assessment therefore represents the worst-case scenario.

4. Receptors, exposure pathways and the risk ranking matrix

4.1 Receptors

Nine receptors were identified that could be impacted by the application of WTR to land.

4.1.1 Workers

Workers at the water treatment plant and at the land application site are in daily contact with the WTR, either through direct contact or inhalation of air-borne dust particles and volatile pollutants (but see Section 3.2). It is assumed that the workers comply with the Occupational Health and Safety Act, 1993 and are equipped with personal protective equipment. The impact of the WTR on workers would therefore be covered by this Act and is not considered to be a WTR disposal issue. Workers were therefore omitted as a receptor during this study.

4.1.2 General public

The general public can either be directly exposed to WTR at or near the land application site or indirectly exposed through:

- ingesting plants grown on WTR-treated land;
- ingesting meat of animals that grazed on land application sites;
- drinking, or being in direct contact with, surface or groundwater impacted by WTR; and
- eating fish from impacted surface water.

4.1.3 Soil

Most studies have indicated that land application of WTR can have positive effects on the soil. The application of WTR to soil may negatively affect soil structure, soil chemical properties and fertility as well as soil microbiological characteristics, depending on the constituents in the WTR. However, Hughes *et al*. (2005) found no such negative effects either in the field or in the laboratory.

4.1.4 Vegetation

Constituents in the WTR, especially phytotoxic elements, may have negative effects on natural vegetation, commercial crops as well as grazing crops at land application sites. International studies indicate that land application of WTR, when managed properly, will not have negative effects on vegetation.

4.1.5 Air

The residues are formed by the coagulation of fine particles into larger aggregates. However, the fine particles may lead to excessive dust during application and may have negative effects on air quality during and after land application (but see Section 3.2). This may also include air-borne pollutants in the WTR that may, when present, lead to negative impacts on the receiving environment. These risks are not considered to be great.

4.1.6 Surface water

Surface water bodies in close proximity to land application sites may be impacted negatively by runoff after application of WTR or due to direct runoff from WTR if it is stored before application. This latter has been specifically not recommended (Hughes *et al*., 2000) and such a management recommendation could apply to other land disposal sites. The 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. The potential for WTR to be eroded remains to be investigated and thus its potential to cause significant turbidity is likewise unknown.

4.1.7 Groundwater

Constituents of concern in WTR could leach through the soil and negatively impact the groundwater resource. It appears that in general most metals are not readily exchangeable. Extraction with a weak acid, however, showed increases in the concentration of most metals from all samples indicating that these elements may become mobile under acid conditions.

4.1.8 Grazing animals and other fauna

Fauna can be impacted directly through ingesting WTR and soil at application sites or indirectly through ingesting vegetation at application sites as well as inhalation of air-borne dust and pollutants (but see Section 3.2). Animals can also be affected by impacted surface and groundwater.

4.2 Exposure pathways

The identified receptors (Section 4.1) may be impacted by land application of WTR through various pathways. A total of 36 pathways were considered for the risk matrix. Some of these pathways have multiple barriers to cross (three receptors before the final receptor) and the negative impact to the final receptors may be insignificant.

4.3 Population of the risk ranking matrix

A risk ranking matrix was developed to systematically evaluate the significance of different aspects and identify matters that will need to be managed through guidelines. This process also highlights knowledge gaps. The matrix represents a systematic thought process of each of the characteristics of the source for all possible pathways and receptors. Although this is a subjective evaluation, it is a method to systematically evaluate all possible issues related to the land application of WTR and eliminates issues that are insignificant. The risk ranking matrix is based on the probability/frequency that a specific consequence will occur and the consequence that the source may have for a given receptor.

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 DLD, have been identified for high risks.

4.3.1 Workers

As stated earlier, it was decided to exclude workers from the risk ranking matrix.

4.3.2 General public

Ten pathways were considered though these generally have several barriers with the human receptor being the third or fourth receptor. Exposure from the consumption of crops grown on WTR amended soil represents the most critical pathway, followed by ingestion of contaminated drinking water.

The main constituents of concern 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 DLD of WTR is low. The high Mn content of the WTR may pose a health problem to the general public. Manganese 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.

Mitigating factors that could be implemented to protect the general public are:

- access restrictions to land application and DLD sites;
- buffer zones between land application sites and dwellings;
- application restrictions to protect vegetation and indirectly protect the general public; and
- buffer zones or trenches between land application sites and surface water bodies.

The impact of WTR on surface water and groundwater needs to be determined before the risk through these pathways to the general population can be evaluated.

4.3.3 Soil

The application of WTR to land can have many positive effects on soil properties. However, negative effects are also possible due to constituents that may be present in high concentrations in WTR. Even though the metal and nutrient contents of the South African WTRs analysed are low, high application rates at DLD sites may cause soil degradation after several years of application.

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.

The pozzolanic properties of certain types of WTR may render them unsuitable for land application due to the impact on the soil physical properties.

Such negative effects are manageable and mitigating factors could include:

- application restrictions for agricultural use;
- setting maximum loads for DLD sites;
- setting management controls to ensure that application of WTR cannot cause crusting or impaired soil structure (e.g. Hughes *et al.*, 2000).

Additional work is also recommended to (i) determine the long-term impact of Mn and other elements on WTR amended soils, especially at DLD sites; and (ii) determine the effect of the pozzolanic properties of WTR on soil physical properties and plant growth.

4.3.4 Vegetation

Vegetation is vulnerable to several of the constituents present in WTR (e.g. nutrients, trace elements, metals). The high concentration of Mn in South African WTRs may have a negative impact on vegetation. However, the pH of most WTRs immobilizes the Mn and renders it generally unavailable for plant uptake.

The pozzolanic properties (crust forming) of certain types of WTR may impact on seed germination and growth of certain crops.

The same mitigating factors and additional research are suggested as for soil.

4.3.5 Air

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 DLD sites may be higher (1 in 10 - 100 days).

If dust is a problem suppression measures may need to be implemented during the windy season or in areas where regular dust problems occur. Odour problems could occur 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, and buffer zones may be needed between DLD sites and dwellings. It is recommended that a national survey of water treatment plants be conducted to determine the extent to which odour might be a problem in areas with eutrophic raw water.

4.3.6 Surface water

Surface water quality could be impacted via runoff from soil amended with WTR (land application) or via direct runoff from WTR (DLD sites). The major aspects of concern are the fine particles (clay and silt) and soluble constituents in the WTR (especially Mn). 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) show that no such contamination has occurred.

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

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

In South Africa and internationally, whether applied as a liquid/slurry or in the dried state, the risks that WTR may pose to surface water are purely speculative and so further research into the erosion and runoff behaviour of WTR is recommended.

4.3.7 Groundwater

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 WTRs are not excessively high, the possibility for leaching, especially of N, still exists, especially at DLD sites. The high Mn content in WTR is also a potential concern. The relatively high pH of the WTR will immobilise Mn but movement may still be possible if the pH of the soil decreases. Particularly at DLD sites the attenuation capacity of soils may be exceeded after several years of high application rates. Data from a borehole at Brookdale Farm monitored since September 2002 reveal no increase in organic pollutants, Mn, or NO_3.

Possible mitigating factors (should the risk to groundwater be high) could include (i) application restrictions based on the elements of concern for land application; (ii) depth restrictions to groundwater; and (iii) maximum load restrictions for DLD sites.

Information on the impact of WTR on groundwater resources in South Africa is limited and therefore predicting the risk is speculative. Further research is recommended, especially at DLD sites that represent the worst case scenario.

4.3.8 Grazing animals and other fauna

Fauna may be impacted by ingesting WTR amended soil, by ingesting plants with high concentrations of potentially toxic elements and by drinking water impacted by WTR application. The pathways through which they 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 vulnerability of natural fauna would have to receive case-specific attention.

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

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

Since the impact of the WTR on fauna is mainly through the surface water and groundwater pathways, the impact of WTR on these receptors need to be investigated (see Sections 4.3.6 and 4.3.7).

5. General discussion

Guidelines for land application of WTR need to be developed to manage this disposal option in an environmentally sound manner. The disposal of WTR on dedicated land should also receive attention in the guidelines since it is currently practiced in South Africa. An internationally acceptable process to develop guidelines is by means of a risk assessment. During the risk assessment, knowledge gaps that need to be investigated are also identified.

Some of the major sources of WTR have been characterised in terms of a wide range of properties. Knowledge gaps were identified where limited information was available.

The nine receptors identified could be impacted through 36 different pathways ranging from direct impact to there being multiple barriers between the WTR and the end receptor. The risk posed to the end receptor reduces with every barrier between the source and the receptor.

5.1 Knowledge gaps and need for further research

The following gaps have been identified:

- Characterisation of WTR

  - The WTR from only five water treatment plants have been studied in detail and a further two (Blackheath and Ixopo) for some properties. It is not known how typical these residues are of WTR produced across the country. Further investigation is recommended to determine the differences between small, medium and large facilities as well as facilities using the same treatment but with different raw water qualities. Similarly the temporal variation in WTR produced at any single plant (especially seasonally) needs further investigation.

- The organic pollutant content and microbiological characterisation of WTR is very incomplete. Although it can be assumed from the few available data that no volatile or semi-volatile organic compounds, pesticides or infectious substances would be present in WTR, further analyses are recommended.
- Although there is a considerable amount of international data available on alum residues, in South Africa data are restricted to the two residues discussed in this report. Blackheath represents the largest single water treatment plant in South Africa that produces alum residue, while Ixopo was chosen to represent a small plant within an agricultural community. Only partial characterisation of these residues was possible within the timeframe of this project and further information is required for these WTRs and those from other plants that produce alum residues.
- The influence of WTR with pozzolanic properties on soil and vegetation should be investigated. Such behaviour was not shown to be a problem with the organic polymer WTR studied in the greatest detail under both field and laboratory conditions. Recommended management for the disposal of this WTR (Hughes *et al.*, 2000) was also specifically designed to, *inter alia*, alleviate any potential for soil crusting. The potential for other forms of WTR to adversely affect this aspect of soil is unknown and the international literature also makes no reference to this aspect.
- The Mn content of South African WTR is high (though this is likely to be a result of treatment chemicals used at the water treatment works) and the consequence on the receptors should be studied in more detail. Speciation of Mn in WTR and fate and transport predictions is needed to identify the risks of Mn to the different receptors. No data could be obtained on the Mn content of WTR in other countries.

• Mobility of constituents present in WTR

  - Information on the potential for erosion of WTR aggregates and runoff behaviour of WTR (liquid/slurry and dried state) is unknown. Further research is recommended to collect data that could be used to determine the impact of WTR on surface water.
  - The mobility of organic pollutants (if present) and other constituents in WTR should be investigated to determine the potential risk for groundwater pollution. Special attention should be given to identify/evaluate analytical methods to determine the mobile fraction of constituents present in WTR. Analytical data could be used to model the mobility of constituents. This information would be valuable to determine the pollution risk for groundwater and to identify applicable mitigating factors to protect the environment.

• Mitigating factors were identified but the application restrictions/buffer zones for land application would have to be investigated. Due to differences in the properties of different types of WTR (and differences within the same type of WTR from different plants, and even from the same plant over time), a blanket application recommendation would not be feasible. Differences in soil properties also need to be taken into account when land application is considered.

5.2 Conclusions and recommendations

From the information gathered during this scoping report it can be concluded that guidelines for the land application and DLD of WTR in South Africa cannot be developed at this stage due to insufficient information on the following:

- the characteristics of all types of WTR produced nationally from different raw water sources with different water treatment processes and their variability over time (e.g. seasonal variations);
- the impact of different types of WTR on soil properties;
- the potential impact of WTR on surface water and groundwater; and
- the organic pollutant and infectious substance contents of sufficient representative samples of the variety of WTRs produced nationally and any seasonal variability.

In the interim it is recommended that:

- WTR be considered for agricultural use due to its low to medium risk to all receptors.
- DLD at or near the water treatment plant should be managed in such a way that all receptors will be protected.
- Disposal of WTR to landfill remains possible if land disposal is considered impracticable at a local level. Since WTR is largely a natural material, instead of dumping the WTR into a landfill, consideration should be given to using it as part of the capping material both on a daily basis and in the final cover material on closure.

The studies conducted by Hughes *et al*. (2005) and by the current project team show that all of the gaps identified above would require filling if national guidelines (modifiable to local conditions) are to be produced for WTR disposal to land in South Africa. While the interim proposals given here may suffice in the short term, for long-term sustainable management of WTR further steps will need to be taken.

A final recommendation is that in order to take this matter further, the Water Research Commission should convene a workshop at the earliest possible time to which all interested parties should be invited. We believe that such a forum would enable those stakeholders most involved with the management and disposal of WTR to decide on the way forward.

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The Reference Group responsible for this project consisted of the following persons:

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CHAPTER 1

INTRODUCTION

1.1 Terminology

The waste material referred to herein as "water treatment residue" has often been termed 'water treatment sludge'. This latter term is too close to wastewater sludge/sewage sludge and similar materials that are absolutely and fundamentally different to the waste from water treatment works that produce potable water. The term 'water treatment residual' is used by some workers, especially in the United States of America, to distinguish between these materials. However, the slightly shorter "water treatment residue" is preferred (Hughes *et al.*, 2005).

1.2 Background

A primary objective in producing potable water for human consumption from turbid sources is to remove suspended solids and other contaminants. 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 "*accumulated solids*" are the result of chemical coagulation, flocculation, and sedimentation of raw water (Pandit and Das, 1998). The choice and concentration of chemical(s) and the procedures followed depend on the quality of the raw water. Chemical precipitants such as aluminium sulfate (alum), ferric salts, lime and poly-electrolytes are added to the turbid waters received at the inflow of the water treatment facility. Once flocculated the solid fraction which settles under gravity is transferred to drying beds, while the supernatant is filtered and clarified for domestic consumption. The dewatered solid (WTR) is regarded as an industrial waste and must be disposed of accordingly.

The traditional method of disposal has been by landfilling but given the economic constraints associated with landfill maintenance, together with the expansion of most urban peripheries, alternative methods have to be considered. A disposal option that is gaining increased acceptance internationally is the application of the residue directly onto land, termed land disposal or land treatment. Land disposal is based upon a fundamental tenet that the 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. To validate this principle with regard to WTR requires rigorous scientific information since, given the wide variety and therefore the different characteristics of residue produced, it is inappropriate and potentially risky to transfer guidelines across waste disposal systems (Cameron *et al.*, 1997). Land treatment has a number of advantages over landfill, most notably economic. It also constitutes an open system that offers the potential for waste treatment, as opposed to simply waste disposal such as is associated with landfill.

A recent Water Research Commission (WRC) report (Hughes *et al.*, 2005) is the only detailed study carried out on WTR in South Africa and it was estimated that over 5 million cubic metres of wet WTR are produced per annum in South Africa. The data strongly suggested that land disposal would be possible and even advantageous in certain circumstances. Similar results have been shown by workers in other countries (e.g. Rengasamy *et al.*, 1980; Elliott and Singer, 1988; Ahmed *et al.*, 1997; Basta *et al.*, 2000; Dayton and Basta, 2001).

1.3 Land disposal of water treatment residue in South Africa: a legal perspective

In terms of the National Water Act (NWA, Act 36 of 1998), WTR is classified as a waste as follows: "*"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*". Land disposal would require, at the very least, a general authorization. The responsibility for regulating the final disposal of waste to a landfill site is assigned to the Department of Water Affairs and Forestry (DWAF), in terms of Section 20 of the Environment Conservation Act, 1989 (Act 73 of 1989; and Act 50 of 2003: Environment Conservation Amendment Act (Government Gazette, 2004)). In terms of Section 20, no person may dispose of waste unless under the authority of a permit issued in terms of these Acts. A water use license, guided by the Minimum Requirement Series for Waste Disposal that informs users in terms of waste disposal standards, waste classification and monitoring (DWAF, 1998; 2005) would be needed for disposal of WTR. However, the NWA is not only concerned with dedicated land disposal (DLD)[1] of waste 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*".

The study by Hughes *et al*. (2005) concluded "*that land application of WTR is safe and is likely to have no negative impacts on soils, vegetation or groundwater*". It was also 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. The work reported by Hughes *et al*. (2005) and Titshall and Hughes (2005) shows that the classification of WTR as a waste material that is "*reasonably likely*" to pollute water resources should be reconsidered and that its disposal under a general authorization allowed by the NWA be permitted. This would largely remove the present restrictions on its use and disposal. However, if WTR is to be applied to land, be it for agricultural use or other beneficial purposes (mined areas or recreational land), consideration needs to be given to the nature of the WTR to determine any potential negative impacts the material may have.

Despite producing a wealth of information on some South African WTRs and showing their potential for land application, Hughes *et al*. (2005) were unable to propose formal guidelines for their disposal, due to the scope of the work. It was to initiate the process of developing these guidelines that the present project was undertaken.

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[1] **Dedicated land disposal** refers to repeated application of waste to land for the sole purpose of final disposal. It includes, but is not restricted to, disposal by landfill.

1.4 Aims

This project had four main objectives i.e.,

1. to carry out a gap analysis to consolidate and review the information and data collected to date in order to highlight gaps in our current knowledge set against a proposed framework for the guidelines for land application of WTR. 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 DLD were to be addressed;

2. to produce an up-to-date review of existing guidelines and knowledge of WTR disposal available internationally with a view to their relevance within the South African context;

3. to analyse a few WTRs from around South Africa to obtain an indication of spatial variability; and

4. to produce a report that outlines the framework for the future disposal guidelines and that indicates the way forward in order to achieve such guidelines.

1.5 General approach and methodology

Much of the data and information contained in the present report are based on the previous work by Hughes *et al*. (2005) and it is strongly advised that it be read in conjunction with that earlier report. To supplement the data given in the previous report a literature search was conducted to review the international literature specifically for existing information on guidelines for disposal of WTR. The results of this survey are presented in Chapter 2. To extend the earlier characterisation of WTRs within South Africa some more samples were collected both from the same treatment plants as sampled before and also samples from other works, notably two that use alum. Some of the earlier data together with the recent analyses are given in Chapter 3.

Chapter 4 presents the results of the risk assessment. It was decided by the project team that the best way to develop guidelines to protect human health as well as the environment was to follow the protocol adopted by the USEPA in their development of Part 503 Rule for the land application of wastewater sludge. In 1988 the EPA conducted the National Sewage Sludge Survey, which sampled municipal sludge from 200 cities across the nation and tested for about 400 different pollutants. Most of these pollutants were found at only very low levels. The EPA used this survey information and national research data to select pollutants for the risk assessment under the 40 CFR 503 rules. The EPA risk assessment looked at 14 possible pathways by which land application of sludge could impact the environment. The EPA risk assessment evaluated the health risk to the general population as well as to a highly exposed individual, such as a person who would have direct contact with sludge land application sites for a lifetime.

At this stage the current risk assessment for disposal of WTR is used to identify the information gaps that would need to be investigated as well as to identify possible mitigating factors where high risks are identified.

The risk assessment includes the following steps:

- source characterisation (Chapter 3);
- receptor identification;
- pathway identification between source and receptor;
- population of risk ranking matrix to identify pathways with high risk to the receptors; and
- identification of gaps and/or mitigating factors.

The available South African and international data on the different properties of WTR were sourced (Chapter 2) to give an indication of the constituents of concern that may be present in WTR. Receptors were identified which might be impacted by the land application and DLD of the WTR. The pathways that may lead to the different receptors being impacted were identified and evaluated by means of a risk ranking matrix. During the population of the risk ranking matrix the risks were evaluated and insignificant issues were eliminated. Knowledge gaps were also identified during this stage. Some of the typical pathways and receptors are shown in Figure 1.1.

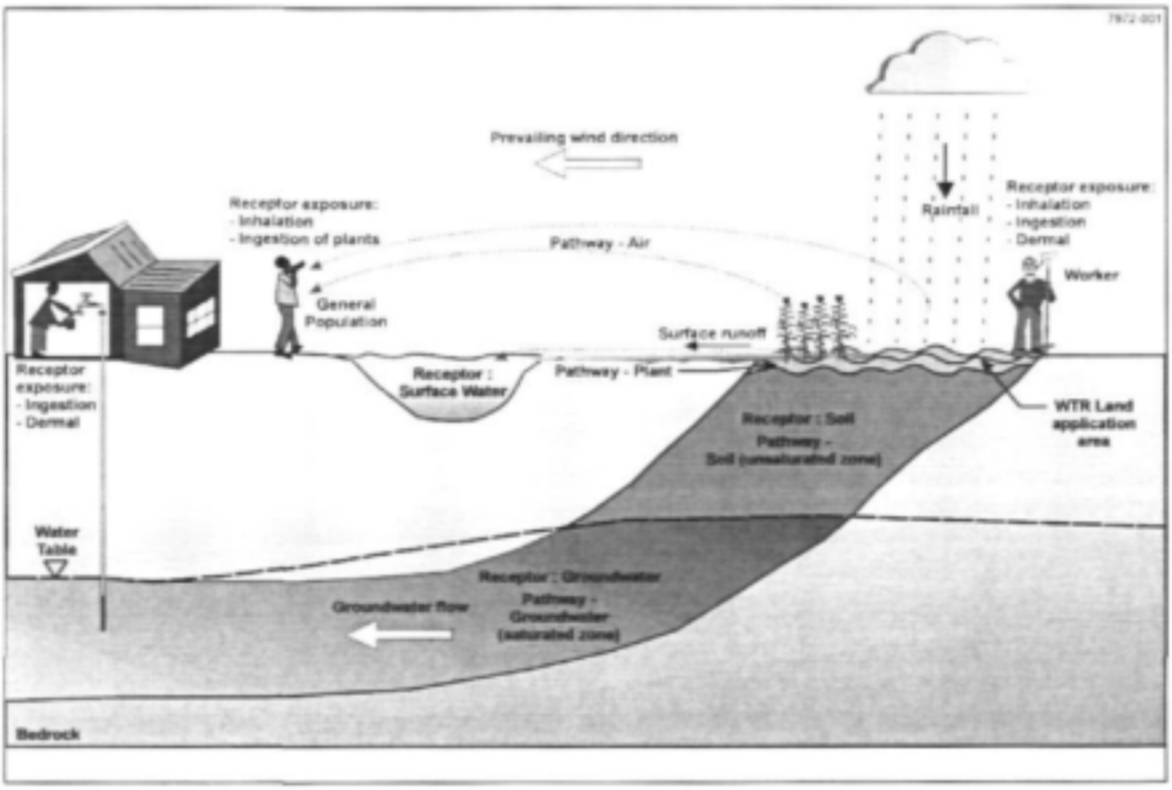

Figure 1.1 Schematic representation of some of the receptors and pathways during land application of water treatment residue.

Chapter 5 highlights the major knowledge gaps identified from the risk assessment and aspects that therefore need further research. This final Chapter concludes with suggestions as to the way forward in the short term with interim proposals for disposal of WTR both to agricultural land, by DLD, and to landfill should this be the most practicable disposal route, and includes a final recommendation with regard to the need for a workshop of all interested parties to decide on the way forward in the long term.

CHAPTER 2

INTERNATIONAL VIEWS AND GUIDELINES ON LAND APPLICATION OF WATER TREATMENT RESIDUE

2.1 Introduction

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. It is clear that there is very little information available in the international literature concerning either water treatment residues or their disposal. The sections that follow summarise the information found for those countries that make reference specifically to these materials within their legislation.

2.2 United Kingdom and European Union

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.

2.3 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 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 2.1), the waste is considered hazardous and so cannot be disposed of on land. The quality of water treatment plant sludge 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.*" (USEPA, 1996).

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 DLD 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 DLD than other land application practices. Sites need to be carefully designed, managed and monitored (USEPA, 1996).

2.4 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).

Table 2.1 Constituents and regulatory limits as determined by the toxicity characteristic leaching procedure for land application of water treatment residue in the USA (USEPA, 1996)

Constituent	Regulatory limit (mg L^{-1})
Arsenic	5.0
Barium	100.0
Benzene	0.5
Cadmium	1.0
Carbon tetrachloride	0.5
Chlordane	0.03
Chlorobenzene	100.0
Chloroform	6.0
Chlorium	5.0
o-Cresol	200.0
m-Cresol	200.0
p-Cresol	200.0
Cresol *	200.0
2,4-D	10.0
1,4-Dichlorobenzene	7.5
1,2-Dichloroethylene	0.5
1,1-Dichloroethylene	0.7
2,4-Dinitrotoluene	0.13
Endrin	0.02
Heptachlor (and its hydroxide)	0.008
Hexachlorobenzene	0.13
Hexachloro-1,3-butadiene	0.5
Hexachloroethane	3.0
Lead	5.0
Lindane	0.4
Mercury	0.2
Methoxychlor	10.0
Methyl ethyl ketone	200.0
Nitrobenzene	2.0
Pantachlorophenol	100.0
Pyridine	5.0
Selenium	1.0
Silver	5.0
Tetrachloroethydene	0.7
Toxaphene	0.5
Trichlorethylene	0.5
2,4,5-Trichlorophenol	400.0
2,4,6-Trichlorophenol	2.0
2,4,5-TP (Silvex)	1.0
Vinyl chloride	0.2

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

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 2.2) 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. Analysis for organics and pathogens is not undertaken in South Australia as this is not required under the current guidelines and the assumption is that they would not be present in any noticeable concentration. Those organics that have been tested for i.e., DDT/DDD/DDE, aldrin, chlordane, dieldrin, heptachlor, HCB, PCB were found to be below proposed guideline values (M. Makestas, SA Water, pers. comm.).

Table 2.2 Maximum permissible contaminant levels in Australian water treatment residue

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 downslope.

- 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 DLD 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 NSW, 1996).

2.5 New Zealand

Until 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 sludge 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 water treatment plant sludge at a landfill is considered afresh. Most landfill operators at this stage are only interested in whether the sludge is "*spadeable*". With respect to water treatment plant sludges, 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 water supply sludges at New Zealand landfills (New Zealand Water and Waste Association, 1997).

Large earthen basins, termed lagoons, have been used as a method of sludge thickening as well as a means of ultimate disposal. Sludge 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 sludge, 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 sludge at the surface forms a crust, giving the appearance that the lagoon is now filled with dry sludge. 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 sludge 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).

CHAPTER 3

CHARACTERISATION OF WATER TREATMENT RESIDUES

3.1 Introduction

As stated earlier (Section 1.2), the properties of WTR are influenced by the quality of the raw water and the coagulants used in the water treatment process. The different coagulants can include aluminium sulfate (alum), ferric chloride, ferrous sulfate, organic polymers and lime. Lime is added to raise the pH resulting in the chemical combination of cations with hydroxide ions, sulfate ions and carbonate ions to form insoluble compounds. The WTR consists primarily of the precipitated hydroxides of the water treatment chemicals along with the material removed from the raw water (sand, silt, clay, humic compounds and dissolved matter) (Hughes *et al*., 2005). 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 two alum WTRs from Blackheath (Cape Municipality) and Ixopo (KwaZulu-Natal), as well as new samples from Faure (Cape Municipality), Panfontein (Rand Water) and Midmar (Umgeni Water) to compare with the earlier samples collected in 2000 (Midmar) and 2001 (Faure and Rand Water). The results for these recent analyses will be discussed later in this Chapter.

It should be noted that in preparing the risk assessment (Chapter 4) the only data available were those from Hughes *et al*. (2005) and Titshall and Hughes (2005). The more recent data were gathered concurrently with the risk assessment and gap analysis. However, the latest results are commented upon if they greatly influence the findings of the risk and gap analyses.

The WTRs used for the study are thus those from five different water treatment plants described in Hughes *et al*. (2005) and Titshall and Hughes (2005). The Rand Water WTR (RWTR) was a lime-softening residue with high amounts of CaO, as well as $FeCl_3$, long-chain organic polymer (LCP), activated silica and CO_2 being added. The Midmar and Amatola Water WTRs were LCP and lime residues. The Midvaal Water WTR was an $Al_2(SO_4)_3.nH_2O$, $FeCl_3$, lime and LCP residue and the Faure WTRs were $Fe_2(SO_4)_3$, activated charcoal, lime and LCP residues at different dosages. The limitation of using these results to characterise the source is that the data are based on a few, localised water treatment plants and may not be extrapolated to cover all the different raw water qualities and treatment processes in South Africa. It was to partially extend the data bank that the further analyses were conducted, especially on the two alum WTRs. To study the temporal effect the new samples of RWTR and Midmar were collected. The Faure Water Treatment Plant had changed its source of chemicals and so a new sample was obtained from there also.

It appears from the literature that mainly alum residues are produced internationally; therefore it was the only type of residue where international data were available. Attention was given to the following parameters (see Appendix 2):

- Physical characteristics (particle density, bulk density, particle size distribution, pozzolanic properties, odours etc.); and

- Chemical characteristics i.e.,
  - cation exchange capacity (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 (VOC), semi volatile organic compounds (sVOC), pesticides, endocrine disruptors, and polychlorinated biphenyls); and
  - infectious substances (total plate counts, faecal coliforms, *Escherichia coli*, and specific pathogens).

3.2 Physical characteristics

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 (A. van Niekerk, Golder Associates, pers. comm.). 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 (Table 3.1). The particle densities of the dry WTRs ranged from 2.02 to 2.43 g cm^{-3}. Plant available water ranged considerably from 8.66 to 197.72 g kg^{-1}, but was generally low.

Table 3.1 Some physical properties of the water treatment residues from five of South Africa's water treatment facilities

Property		Rand	Midmar	Midvaal	Amatola	Faure 1	Faure 2
Particle	Sand (0.053 - 2 mm)	1.2	91.6	37.5	67.5	91.0	14.4
size	Coarse silt (0.02 - 0.053 mm)	1.6	2.4	2.0	1.1	1.3	5.7
distribution	Fine silt (0.002 - 0.02 mm)	34.3	2.5	31.4	2.1	4.3	61.2
(%)	**Clay (<0.002 mm)**	62.9	3.5	29.1	29.3	3.4	18.7
Particle density (g cm^{-3})		2.43	2.23	2.09	2.02	2.02	nd
Plant available water (g kg^{-1})		18.17	53.81	40.46	8.66	29.64	197.72

nd - not determined.

A concern for the risk assessment was that the fine particles in the WTR once dried may result in air-borne dust and that any potentially harmful constituents in the dust may pose risks to some receptors. However, one of the features of all WTRs is that when they dry they do so to very hard aggregates. It is the strength of these aggregates that makes achieving full dispersion for particle size analysis so difficult. Thus risks from dust would likely be negligible.

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), that fall outside the terms of reference for this scoping report. A consideration for the risk analysis was that such properties could render such WTR unsuitable for land application since it could lead to reduction in infiltration rate or permeability of the soil. As commented above, many WTRs harden on drying. The dry aggregates are resistant to water and appear to break down in soil only under conditions of alternate wetting and drying (Skene *et al*., 1995; Ahmed *et al*., 1997; Moodley, 2001). 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 (see also comment by New Zealand Water and Waste Association (1997); Section 2.3) 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).

It thus appears that neither the risk of dust nor possible pozzolanic properties is sufficiently serious to render the application of WTR to land unfeasible.

A risk considered in detail by Moodley (2001) is that of the disintegration of the WTR releasing clay that could lead to pore blockage and thus soil structure deterioration. That study showed no such effects occurred within the 5 years of the field trial using a polyacrylamide WTR. The field conditions that could result in total breakdown of this and other types of WTR are not known, although it is considered that sensible loading rates applied to suitable soils would minimise any risk of soil structure degradation.

3.3 Chemical characteristics

The chemical characteristics of WTR that may have an impact on its environmental impact during and after land application and DLD 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.

3.3.1 pH

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. This pH range is not a characteristic that is of concern for land application of WTR.

3.3.2 Organic carbon

The organic carbon content ranges from 1.2 to 10.3% and will have a positive impact on soils. This is therefore not a constituent of concern.

3.3.3 Nutrients

The nutrient concentrations in the WTRs are presented in Table 3.2. 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.

Table 3.2 Nutrient concentrations of the water treatment residues from five of South Africa's water treatment facilities with some comparative data from Oklahoma, USA

Property		**Rand**	**Midmar**	**Midvaal**	**Amatola**	**Faure 1**	**Faure 2**	**Oklahoma***
Total S (mg kg^{-1})		10	210	130	320	1 200	nd	nd
Total N (mg kg^{-1})		200	1 000	2 800	2 600	5 200	4 800	1 300 - 18 400
NO_3-N (mg kg^{-1})		94.23	16.80	12.76	31.80	9.65	11.53	3.5 - 123
NH_4-N (mg kg^{-1})		26.33	170.15	358.38	62.40	108.48	32.10	22 - 140
AMBIC P (mg kg^{-1})		4.70	4.46	31.51	0.74	6.33	21.50	4 - 49[#]
Extractable cations ($cmol_c\ kg^{-1}$)	Ca	4.54	31.01	38.28	28.49	25.29	37.31	0.90 - 104.8
	Mg	15.75	9.13	14.33	8.76	13.42	22.12	0.07 – 10.13
	Na	1.37	0.52	0.56	0.88	0.66	0.81	nd
	K	0.38	0.51	0.78	0.39	0.30	0.14	0.05 - 0.71
Cation exchange capacity ($cmol_c\ kg^{-1}$)		15.85	26.59	41.81	25.38	33.47	35.79	13.6 - 56.5

nd - not determined.
* from Dayton and Basta (2001); 14 alum and 3 polyaluminium chloride WTRs, all with added lime;
[#] Olsen-extractable P.

3.3.3.1 Nitrogen

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}. Total N concentrations ranged from 200 to 5 200 mg kg^{-1} (Table 3.2). This indicates that a considerable proportion of the N is bound in less soluble (or less available) forms in the WTRs, except in the RWTR, where NO_3-N and NH_4-N accounted for about 60% of the total nitrogen, even though the total concentration was low. Little information on the actual impact of N from WTR on groundwater and surface water is available and therefore it is handled as a constituent of concern. However, although further research is recommended, data from Umgeni Water (Sections 4.4.6.1 and 4.4.7.1) suggest that at their disposal site leaching of N is not a problem. Similar findings, based on data from soil water collectors, were reported by Hughes *et al*. (2005) from their field experiment.

3.3.3.2 Phosphorus

The AMBIC extractable P was generally low, except for the Midvaal and Faure 2 WTRs. 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 potential for erosion of WTR from its site of application is an aspect recommended for further research.

3.3.3.3 Major cations (Ca, Mg, K and Na)

Extractable Ca concentrations were low in the RWTR, while the other WTRs showed considerably higher Ca concentrations, the highest being recorded for the Midvaal WTR (Table 3.2). Magnesium concentrations were lower than the Ca concentrations, except for the RWTR. The RWTR had a Ca: Mg ratio of about 1:3, whilst the remaining WTRs were 2:1 or

3:1. Potassium and Na concentrations were low for all WTRs. These elements are not constituents of concern due to their low concentrations and the fact that they are essential plant nutrients (with the exception of Na).

3.3.3.4 Cation exchange capacity (CEC)

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, but smectitic clay with high amounts of OM would have a much greater capacity to hold cations.

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 15.9 to 41.8 $cmol_c\ kg^{-1}$ and, with the exception of the RWTR, all were above 25 $cmol_c\ kg^{-1}$. 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.

3.3.3.5 Trace elements and 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. These analytical results are presented in Table 3.3.

Table 3.3 DTPA and TCLP extractable metals ($mg\ kg^{-1}$) from six South African water treatment residues and the acceptable exposure limit ($mg\ kg^{-1}$)

Element	AE*	Rand		Midmar		Amatola		Midvaal		Faure 1		Faure 2	
		DTPA	TCLP	DTPA	TCLP	DTPA	TCLP	DTPA	TCLP	DTPA	TCLP	DTPA	TCLP
Cd	0.031	0.66	bd	0.42	bd	0.45	bd	0.50	bd	bd	bd	0.30	nd
Co	6.9 (0.97)	0.42	bd	0.63	bd	0.70	bd	1.06	bd	1.82	bd	2.59	nd
Cr	4.7	1.16	bd	1.18	bd	1.45	bd	1.86	bd	bd	bd	bd	nd
Cu	0.1 (0.13)	1.76	bd	5.78	bd	1.39	bd	7.16	bd	0.41	bd	0.29	nd
Fe	9.0	48.70	bd	87.70	bd	63.30	bd	246	5.50	65.00	7.90	42.70	nd
Mn	0.30	38.80	**310**	88.90	**235**	13.23	**44.8**	22.10	**539**	725	**849**	420	nd
Ni	1.14 (0.75)	0.56	bd	1.34	bd	0.61	bd	3.39	bd	bd	bd	bd	nd
Pb	0.1 (0.12)	0.20	bd	1.07	bd	2.67	bd	1.43	bd	0.79	bd	1.64	nd
Zn	0.7 (0.83)	1.48	bd	3.01	bd	2.04	bd	8.64	**23.70**	10.27	**2.51**	10.89	nd

* acceptable exposure limit for TCLP extractable metals according to DWAF (1998; 2005 proposed limits in brackets). Results that exceed these limits are shaded.
bd – below detection nd – not determined

Manganese, Cu, Ni, Co, As, F, B, and Zn are among a number of potentially phytotoxic elements. The concentration of elements in edible plant parts is not dangerous to humans (lifetime chronic exposure) because the element is harmful to the plant at lower element concentration than required to result in risk if consumed. Plants suffering phytotoxicity have visible symptoms (such as yellowing of leaves; necrosis of leaf tips and leaf margins; stunting; death) and low yields.

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.

Among food crops, the spinach/beet family and lettuce are known to accumulate Zn, Cu, Ni, and Mn more strongly than other crops but there is no evidence that plant accumulated elements can cause risk to consumers (Eastern Research Group, 2001).

Plant available fraction

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.

The DTPA extractable metal concentrations were low (Table 3.3), although Fe and Mn concentrations were elevated in most of the WTRs. The Midvaal WTR had the highest concentration of Fe. The two Faure WTRs had exceptionally high Mn values (420 and 725 mg kg^{-1}) 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.

The pH of the WTR (6.5-9.0) would reduce the toxicity of the trace elements for plants and will also immobilize the elements and protect the groundwater. The impact of the trace elements on surface water due to erosion of solid particles would have to be investigated. Therefore, these elements are not constituents of concern for plants and groundwater but may potentially be of concern for surface water contamination.

Leachable fraction

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 hence concentration of a potentially toxic element 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; 2005). However, importantly, it takes no account of any readsorption of the 'leached' elements that may occur as a result of interaction with the soil.

The TCLP extractable metal concentrations (Table 3.3) indicate that Mn in all the WTRs exceeds the acceptable exposure level (AE) according to DWAF (1998; 2005), as does Zn in the Midvaal and Faure 1 WTR. The reason for the elevated concentrations is almost certainly the high concentrations of these elements in the chemicals used during the treatment of the raw water.

The AE values refer to the LC50 x 0.1 and are compared to the estimated environmental concentration (EEC). The LC50 is 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 (DWAF, 2005) 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.

It is likely that under the recommendations of the Minimum Requirements (DWAF, 1998; 2005) most of these WTRs would not be considered as non-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.

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 lower (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.

Other elements

The concentrations of all the other elements in the WTR are low and they are therefore not constituents of concern.

3.3.4 Organic pollutants

There were no data available in South Africa on the organic pollutants in WTR (see Section 3.4.6). 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 (Table 3.4) 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. Although none of these organic compounds were considered constituents of concern and therefore did not receive further attention, the samples collected as part of this project were screened for pesticides (see Section 3.4.6).

3.3.5 Infectious substances

There were no data available in South Africa on the infectious substances in WTR (see Section 3.4.6). The literature review also indicated that these constituents in WTR are not monitored internationally. The concentration of infectious substances in WTR would be dependant 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 WTRs collected as part of this project were analysed for indications of the presence of some infectious substances (see Section 3.4.6).

Table 3.4 Organic compounds considered during evaluation of the water treatment residues

Volatile and semi-volatile organic compounds	Synthetic organic compounds	Pesticide compounds (continued)
Benzene	Acrylamide*	1,2-Dibromo-3-Chloropropane
Benzo(a)pyrene	Edetic Acid (EDTA)	1,2-Dibromo-3-Chloropropane
Carbon Tetrachloride	Epichlorohydrin*	1,2-Dibromoethane
1,2-Dichlorobenzene	Nitrilotriacetic acid (NTA) *	1,2-Dichloropropane
1,4-Dichlorobenzene	Polychlorinated Biphenyls	1,2-Dichloropropane
1,2-Dichloroethane	PCB - 1016	1,3-Dichloropropene*
1,1-Dichloroethane	PCB - 1221	Dichloroprop*
1,2-Dichloroethene	PCB - 1232	Dimethoate*
cis-1,2-Dichloroethene	PCB - 1242*	Endrin
cis-1,2-Dichloroethene	PCB - 1248*	Fenoprop
trans-1,2-Dichloroethene	PCB – 1254	Isoproturon*
Dichloromethane	PCB - 1260*	Lindane
Di(2-ethylhexyl)phthalate	**Pesticide compounds**	MCPA*
Ethylbenzene	Alachor	Mecoprop*
Formaldehyde*	Alachor (P/GAC)	Methoxychlor
Hexachlorobutadiene	Aldicarb	Metolachlor
Microcystin-LR*	Aldrin	Molinate*
Styrene	Dieldrin	Pendimethalin*
Tetrachloroethene	Atrazine	Pentachlorophenol
Toluene	Carbofuran	Pyriproxyfen*
Toluene	Chlordane	Simazine
Total Recoverable Phenolics	Chlordane (P/GAC)	2,4,5-T*
Trichloroethene	Chlorotoluron*	Terbuthylazine*
Vinyl Chloride*	Chlorpyrifos*	2,4,6-Trichlorophenol
o-Xylene	Cyanazine*	Trifluralin*
m-Xylene	2,4-D	
p-Xylene	2,4-DB*	
Xylenes (Total)	DDT & Metabolites	

3.4 Physical and chemical analyses of recent water treatment residues

As stated earlier, as part of this project some WTRs were collected for analysis. These included two alum residues as this type of material was not investigated as part of the study conducted by Hughes *et al*. (2005). In addition new samples from Faure, Midmar and Rand Water were analysed to see what changes have occurred over time. The results are presented in Tables 3.5 to 3.10. Also in these tables, where possible, the results for the earlier analyses are given to enable easy comparison. Some of these have also been presented earlier.

3.4.1 Particle size and general chemical characteristics

The particle size data (Table 3.5) demonstrate the importance of full dispersion of the WTRs. All the samples, except that from Rand Water, treated in the normal way after air-drying have a predominance of sand particles. The same samples analysed without drying show a preponderance of silt-sized particles. However, if the pH of the dispersion is adjusted to

>10.5 then all are dominated by clay-size particles. It is likely that even these data underestimate the clay percentage.

Table 3.5 Particle size distribution and some chemical characteristics of eight water treatment residues

Property	Blackheath 2006	Ixopo 2006	Faure 2006	Faure 1 2001	Rand 2006	Rand 2001	Midmar 2006	Midmar 2000
Particle size distribution (%)								
Dry sample								
Sand (0.053 - 2 mm)	97.13	90.98	85.93	91.00	8.40	1.20	96.83	91.60
Silt (0.002 - 0.053 mm)	0.00	6.20	7.36	5.60	42.31	35.90	1.58	4.90
Clay (<0.002 mm)	2.87	2.82	6.71	3.40	49.29	62.90	1.59	3.50
Wet sample								
Sand (0.053 - 2 mm)	nd	0.63	17.03	nd	0.68	nd	0.19	nd
Silt (0.002 - 0.053 mm)	nd	97.63	81.39	nd	97.91	nd	99.12	nd
Clay (<0.002 mm)	nd	1.74	1.58	nd	1.41	nd	0.69	nd
pH adjusted to >10.5								
Sand (0.053 - 2 mm)	nd	0.00	0.02	nd	0.27	nd	0.00	6.00
Silt (0.002 - 0.053 mm)	nd	17.66	15.01	nd	31.02	nd	8.25	10.00
Clay (<0.002 mm)	nd	82.34	84.97	nd	68.71	nd	91.75	84.00
pH (H_2O)	7.08	6.29	5.86	6.60	8.37	8.50	7.54	7.70
pH (supernatant)	nd	6.82	nd	nd	nd	nd	7.90	nd
EC (supernatant) (mS m^{-1})	nd	17.4	nd	nd	nd	nd	23.2	nd
Extractable cations ($cmol_c$ kg^{-1})								
Ca	42.60	12.24	39.80	25.29	10.36	4.54	28.20	31.01
Mg	9.96	9.34	9.44	13.42	17.06	15.75	4.94	9.13
Na	1.72	4.54	1.74	0.66	0.82	1.37	1.53	0.52
K	0.09	2.54	0.06	0.30	0.47	0.38	0.38	0.51
Cation exchange capacity	33.74	9.75	34.24	33.47	20.81	15.85	24.20	26.59
Total N (%)	0.398	2.103	0.344	0.520	0.091	0.020	1.599	0.100
Total C (%)	9.32	15.80	11.89	11.89	6.84	8.22	11.74	4.88
Total S (%)	0.305	0.948	0.162	0.120	0.011	0.001	0.178	0.021
AMBIC P (mg kg^{-1})	6.00	27.45	2.00	6.33	11.00	4.70	4.00	4.46

nd - not determined

The pH of the samples from Midmar and Rand are very similar to the earlier sample, as are the amounts of extractable cations and the CECs. The major differences are found in amounts of total C, N and S. The alum residues have pH values within the same range as the other WTRs discussed earlier (Section 3.3.1). The Blackheath WTR has higher extractable Ca than the rest including those from Rand Water, despite an order of magnitude less total Ca in the sample (Table 3.8). This suggests that Blackheath uses a more soluble form of lime in the treatment process compared to the dolomitic lime used by Rand Water (indicated by the higher amounts of extractable and total Mg (Table 3.8) in the latter). The sample from Ixopo has higher Na and K, and also has much higher extractable P and total N, C, and S than the other WTRs (Table 3.5). These latter elements may reflect the origin of this WTR within a largely agricultural community. The CEC of the Blackheath sample is within the same range as found before but the Ixopo sample has a CEC of only 9.75 $cmol_c\ kg^{-1}$, the lowest of any of the WTRs analysed so far.

3.4.2 Ammonium nitrate extractable elements

This method (DIN 19730) was used in place of the TCLP used previously as it is recommended in the latest edition of the guidelines for the disposal of wastewater sludge (WRC, 2006). The results are given in Table 3.6.

Table 3.6 Ammonium nitrate extraction of six water treatment residues. Concentrations are given in $mg\ kg^{-1}$

Element	AE*	Blackheath 2006	Ixopo 2006	Faure 2006	Rand 2006	Midmar 2006	Midmar 2000
Cd	0.031	0.10	bd	0.02	bd	bd	bd
Co	6.9 (0.97)	0.15	bd	0.68	bd	bd	0.13
Cr	4.7	bd	0.03	bd	bd	bd	bd
Cu	0.1 (0.13)	**0.31**	**0.54**	**0.18**	**0.23**	**3.21**	**0.75**
Fe	9.0	1.09	7.78	6.43	0.27	3.69	0.38
Mn	0.30	**8.39**	**29.15**	**262.75**	**0.53**	**4.53**	**4.83**
Ni	1.14 (0.75)	0.33	0.55	0.50	0.28	0.49	0.49
Pb	0.1 (0.12)	**1.38**	**2.05**	**1.53**	**1.20**	**1.20**	**1.93**
Zn	0.7 (0.83)	**1.24**	0.47	**5.47**	0.15	0.19	0.22

* acceptable exposure limit for TCLP extractable metals according to DWAF (1998; 2005 proposed limits in brackets). Results that exceed these limits are shaded.
bd - below detection

For TCLP only Mn (and occasionally Zn) exceeded the AE limits (Table 3.3) but in the ammonium extract all the WTRs also showed values for Cu and Pb that exceed the AE limits (Table 3.6). Amounts of Mn extracted seem to be much lower, while those of Zn are slightly higher. It appears from these data that the comparability of the ammonium nitrate extraction method needs to be checked against the TCLP for these types of waste materials.

3.4.3 Heavy metals

These were extracted using the 5-step fractionation technique (Elliott *et al*., 1990), except that the residual fraction was not determined. The results are given in Table 3.7.

It is important to realise that, due to time constraints, the data for the 2006 samples were obtained through batch extraction and not sequentially. This means that the amount of element extracted subsequent to $MgCl_2$ may be inflated by some proportion of the previous extracted amount. Thus the earlier data are not strictly comparable with those for the 2006 samples although in many instances the values are similar. The major surprise in these results is the amount of easily extractable Mn in the Faure 2006 sample. It was expected that with the change in chemicals used by the plant that this value and the weak acid extractable fractions would be much less than those in the earlier sample. However, the total of these two fractions, although slightly lower, is similar. This is despite the fact that total MnO content of the later sample is much lower than the 2001 sample (0.38% vs 0.96%; Table 3.8).

Table 3.7 Heavy metals extracted from eight water treatment residues by the fractionation procedure of Elliott *et al.* (1990). Concentrations are given in mg kg^{-1}

Blackheath 2006					**Ixopo 2006**				
Element	$MgCl_2$	Weak Acid	Fe/Mn bound	Organic bound	Element	$MgCl_2$	Weak Acid	Fe/Mn bound	Organic bound
Cd	0.9	0.3	bd	bd	Cd	0.3	bd	bd	bd
Co	0.4	0.3	2.7	bd	Co	bd	5.1	5.5	bd
Cr	bd	bd	5.1	bd	Cr	bd	1.9	1.9	5.8
Cu	bd	0.9	bd	bd	Cu	bd	5.5	7.3	9.4
Fe	0.8	601.7	6748.0	678.8	Fe	1.1	3815.2	8340.0	8070.0
Mn	16.9	39.7	167.3	36.3	Mn	49.4	91.2	168.1	36.2
Ni	bd	bd	8.0	bd	Ni	bd	5.0	9.1	3.7
Pb	bd	4.4	4.0	bd	Pb	bd	8.0	12.2	bd
Zn	25.8	506.1	1330.6	235.8	Zn	2.6	14.3	13.3	11.7
Faure 2006					**Faure 1 2001**				
Element	$MgCl_2$	Weak Acid	Fe/Mn bound	Organic bound	Element	$MgCl_2$	Weak Acid	Fe/Mn bound	Organic bound
Cd	0.7	bd	bd	bd	Cd	0.1	0.3	1.6	bd
Co	2.9	4.9	19.5	17.8	Co	bd	1.8	10.0	5.4
Cr	bd	0.2	bd	12.0	Cr	bd	bd	16.0	47.4
Cu	bd	2.5	15.1	16.1	Cu	bd	0.2	7.4	2.6
Fe	7.4	6048.0	149740.0	160540.0	Fe	7.9	1111.4	91241.8	2111.6
Mn	192.1	928.0	851.0	1540.2	Mn	498.4	897.1	1847.0	991.4
Ni	bd	3.2	17.1	20.5	Ni	3.7	6.6	20.6	bd
Pb	bd	1.4	9.0	22.3	Pb	bd	11.2	bd	bd
Zn	97.3	126.9	357.6	321.8	Zn	bd	63.3	134.2	44.3
Rand 2006					**Rand 2001**				
Element	$MgCl_2$	Weak Acid	Fe/Mn bound	Organic bound	Element	$MgCl_2$	Weak Acid	Fe/Mn bound	Organic bound
Cd	bd	0.1	bd	bd	Cd	bd	2.9	0.4	8.2
Co	bd	1.4	bd	bd	Co	bd	5.2	bd	bd
Cr	bd	3.5	bd	0.2	Cr	bd	bd	bd	2.6
Cu	bd	6.5	4.3	0.4	Cu	0.1	7.8	9.0	8.8
Fe	2.8	1159.5	3096.0	216.5	Fe	bd	62.6	4908.8	2004.4
Mn	5.6	1100.8	1341.4	133.7	Mn	bd	941.8	1541.4	141.8
Ni	bd	10.1	10.0	0.2	Ni	3.6	13.3	bd	bd
Pb	bd	13.6	bd	2.0	Pb	bd	84.8	4.0	bd
Zn	0.2	4.5	bd	1.5	Zn	bd	8.9	0.9	bd
Midmar 2006					**Midmar 2000**				
Element	$MgCl_2$	Weak Acid	Fe/Mn bound	Organic bound	Element	$MgCl_2$	Weak Acid	Fe/Mn bound	Organic bound
Cd	bd	bd	bd	bd	Cd	bd	bd	bd	bd
Co	bd	0.7	9.0	bd	Co	bd	0.3	bd	bd
Cr	bd	bd	bd	0.8	Cr	bd	bd	bd	21.4
Cu	1.0	8.9	48.0	21.4	Cu	bd	4.5	15.2	0.6
Fe	9.4	1052.8	13922.0	4082.0	Fe	bd	244.5	14373.5	4962.4
Mn	33.1	6464.0	6834.0	1448.2	Mn	23.3	1026.7	6869.6	1668.4
Ni	bd	6.5	17.6	2.0	Ni	1.2	bd	bd	bd
Pb	bd	4.1	11.8	0.4	Pb	bd	26.4	bd	bd
Zn	0.5	23.6	19.4	14.0	Zn	bd	3.6	bd	bd

bd – below detection

3.4.4 Total major element composition

These data (Table 3.8) largely reflect the treatment process used at the respective plants. The alum residues from Blackheath and Ixopo have the highest amounts of total Al and interestingly the highest amounts of P, the Faure residues the highest amount of Fe and the RWTR the highest amount of Ca. The differences between the two Midmar WTRs are minor, the most obvious being the lower amount of Ca in the 2006 sample – a reflection presumably of the plant using less lime in the process. The two RWTRs are also similar but with the 2006 sample containing slightly less Mg and Ca and slightly more Al than the 2001 sample.

Table 3.8 Total major element analysis of eight water treatment residues by X-ray fluorescence spectrometry

Element oxide (%)	Blackheath 2006	Ixopo 2006	Faure 2006	Faure 1 2001	Rand 2006	Rand 2001	Midmar 2006	Midmar 2000
SiO_2	44.74	30.04	26.24	29.93	31.97	24.36	53.84	54.57
Al_2O_3	43.09	57.70	10.34	8.70	13.59	9.89	26.39	22.60
Fe_2O_3	6.01	8.55	56.94	53.80	5.97	4.85	11.06	11.95
MnO	0.09	0.09	0.38	0.96	0.57	0.66	2.37	1.53
MgO	0.36	0.34	0.36	0.72	3.79	5.25	1.03	1.92
CaO	3.15	0.56	3.11	3.15	41.60	53.19	1.87	4.20
Na_2O	0.25	0.40	0.34	bd	0.12	0.61	0.33	0.15
K_2O	1.07	0.68	1.02	0.93	1.18	0.82	1.25	1.47
TiO_2	0.39	0.44	0.49	0.78	0.36	0.31	0.77	0.86
P_2O_5	0.65	1.50	0.26	0.39	0.12	0.09	0.48	0.24
Cr_2O_3	0.0200	0.0138	0.0073	nd	0.0371	nd	0.0234	nd
NiO	0.0020	0.0000	0.0022	nd	0.0020	nd	0.0079	nd
Total	99.81	100.33	99.49	99.36	99.31	100.03	99.47	99.49
L.O.I	41.24	63.59	58.25	43.07	33.83	36.93	37.62	23.91

bd - below detection
nd - not determined
L.O.I. - loss on ignition

3.4.5 Trace/minor element composition

The results for the 2006 samples of WTR, and those for the RWTR and the Midmar WTR collected in 2001 and 2000, respectively, are given in Table 3.9. The only surprisingly high values are for Cu and Zn in the Blackheath alum WTR.

3.4.6 Organic constituents and possible infectious substances

As can be seen from the results in Table 3.10, the WTRs contain no pesticides or nematodes and very low total aerobic plate counts. These data appear to justify the decision given earlier (Section 3.3.4) not to consider these substances as a cause for concern.

Table 3.9 Trace/minor element analysis of seven water treatment residues by inductively coupled plasma-mass spectrometry

Element	Blackheath	Faure	Ixopo	Rand		Midmar	
($mg\ kg^{-1}$)	2006	2006	2006	2006	2001	2006	2000
Ag	0.4	0.0	2.4	0.0	nd	0.0	0.0
As	15.9	2.0	9.6	5.5	1.7	7.9	17.0
B	1.7	1.0	12.8	1.7	nd	5.8	0.0
Ba	76.8	38.2	69.7	377.4	398.4	236.9	1007.0
Be	1.3	0.8	0.6	0.9	nd	1.9	2.1
Bi	0.2	0.0	0.0	0.2	nd	0.2	0.4
Cd	0.4	0.2	0.0	0.0	nd	0.2	4.0
Ce	26.6	30.6	18.3	20.1	5.1	54.9	96.0
Co	5.4	17.0	7.9	7.9	3.5	22.2	39.0
Cs	1.3	1.0	1.1	2.9	nd	3.7	3.9
Cu	95.4	19.6	26.2	21.6	5.4	72.1	44.0
Dy	1.7	2.0	0.9	1.5	nd	2.9	3.7
Er	1.0	1.0	0.4	0.7	nd	1.5	1.8
Eu	0.4	0.4	0.2	0.4	nd	0.8	1.0
Ga	7.6	4.4	9.2	10.1	8.9	15.9	20.0
Gd	2.5	2.6	1.1	2.0	nd	4.6	5.1
Hf	0.4	0.2	0.2	0.2	nd	0.2	0.0
Ho	0.4	0.4	0.2	0.2	nd	0.6	0.6
I	7.6	5.0	8.7	2.4	nd	7.0	1.2
La	10.3	13.0	6.4	10.3	bd	21.5	19.0
Li	14.9	10.6	8.5	20.1	nd	28.0	38.1
Lu	0.2	0.2	0.0	0.0	nd	0.2	0.2
Mo	1.0	1.2	0.8	0.0	nd	0.0	0.2
Nd	11.7	13.6	6.2	10.0	bd	22.4	25.0
Pb	58.9	8.4	6.8	6.6	5.8	8.9	37.0
Pr	2.3	2.6	1.3	2.0	nd	4.3	5.3
Rb	11.7	10.4	12.1	48.7	38.1	39.4	94.0
Sc	2.5	3.8	4.9	8.3	13.5	13.1	33.0
Sm	2.3	2.6	1.3	1.8	nd	4.3	5.1
Sn	0.6	1.0	0.8	0.2	nd	0.6	0.2
Sr	90.2	97.1	13.2	259.7	273.4	14.3	71.0
Tb	0.4	0.4	0.2	0.2	nd	0.6	0.6
Th	4.4	6.0	1.7	2.8	5.0	7.5	10.0
Tl	0.2	0.2	0.2	0.4	nd	0.4	0.6
Tm	0.2	0.2	0.0	0.2	nd	0.2	0.2
U	14.7	5.6	0.0	5.5	nd	6.2	2.9
V	20.1	23.6	48.0	46.8	61.1	76.2	154.0
Y	9.7	9.8	4.3	7.6	38.1	15.7	27.0
Yb	1.0	1.0	0.4	0.7	nd	1.5	1.6
Zn	2737.0	421.1	40.5	110.0	33.1	80.6	84.0
Zr	15.9	15.6	7.7	10.0	32.2	7.2	126.0

nd – not determined
bd – below detection

Table 3.10 Pesticide screening and infectious substances in six water treatment residues sampled in 2006

Property	Blackheath	Ixopo*	Faure	Rand#	Midmar*
Nematodes	None detected	None detected	None detected	None detected	None detected
Total Helminth ova (g^{-1} dry mass)	0	0	0	0	0
Viability	0	0	0	0	0
Total aerobic plate count (cfu g^{-1})	970	187	1 830	1 320/1 800	>300
Faecal coliforms (cfu g^{-1})	0	0	0	0	0
Pesticide screening (mg kg^{-1})	None detected	None detected	None detected	None detected	None detected

* slurry samples

two separate sub-samples submitted for analysis hence two results for plate counts

3.5 Discussion and conclusions

The rationale behind not using the term "sludge" to describe water treatment residue is that it tends to associate WTR with sewage sludge/wastewater sludge/biosolids (see Section 1.1). The disposal of the material then becomes governed by the same criteria as for wastewater sludge. Water treatment residue is largely a natural material (plus chemicals added during the treatment process), consisting mainly of clays and silts that originate within the catchment area of the raw water source. As such, returning it to the land ought not to be as problematic as land disposal of wastes that consist of anthropogenically produced materials such as wastewater sludges or industrial wastes.

A comparison between the WTR data given above and those for wastewater sludge (DWAF, 2005; WRC, 2006), indicates the following (Table 3.11):

- The TCLP extractable element concentrations in WTR are appreciably lower than those of wastewater sludge. No data are available for the TCLP extractable Mn concentration in wastewater sludge.
- The total (ICP-MS) concentrations of the elements of concern (except Mn) in the WTR are much lower than the total (*aqua regia*) concentration of these elements in wastewater sludge, despite the ICP-MS measurement being a more absolute total than the *aqua regia* extraction.
- The elevated TCLP concentrations of Mn, Pb and Zn in WTR would hamper DLD, because it is governed by the Minimum Requirements (DWAF, 1998; 2005), but would not prevent it.
- The total element contents of WTR are significantly lower than the limits set for wastewater sludge destined for unrestricted agricultural use, except for Mn.

Table 3.11 Comparison between water treatment residue and wastewater sludge for eight metals determined by the toxicity characteristic leaching procedure and inductively coupled plasma-mass spectrometry, and sludge guideline values for land disposal

	TCLP extractable		ICP-MS		Sludge guideline values	
	WTR	Sludge	WTR	Sludge	TCLP *	Aqua regia #
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	none given	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

* for dedicated land disposal (DWAF, 2005)
# for unrestricted agricultural use (WRC, 2006)
bd - below detection

From most of the characteristics analysed WTRs can be seen to be innocuous waste materials. The Mn content of South African WTR stands out as the main reason for concern for land application and DLD. Although the total Mn contents of the WTR are elevated, the pH of the WTR (>6.2) would render it insoluble in many soils since Mn is only soluble at pH < 5.5 (Section 3.3.3.5). Internationally, Mn is handled as a non-issue since the risk to the environment is perceived to be minimal. Thus although Mn levels may be high, whether it is really an environmental concern in South Africa remains unclear. The analyses conducted in this report show that there also remains uncertainty as to the best methods to use to characterise these particular waste materials.

However, although the constituent materials are natural, land disposal of the WTR concentrates these materials onto a much smaller area of land, and it is this aspect that may produce concerns as to its effects. It was to consider these possible effects that a full risk assessment was carried out and within this assessment all the elements were considered. Similarly the pozzolanic properties of WTR were not addressed during earlier studies and, since information is limited, it was assumed that application of liquid WTR (slurry) to soil, without appropriate management, could result in crust formation and a decrease in the permeability of soils. The risk assessment that follows therefore was carried out to represent the worst-case scenario.

CHAPTER 4

RECEPTORS, EXPOSURE PATHWAYS AND THE RISK RANKING MATRIX

4.1 Introduction

A risk ranking matrix was developed to systematically evaluate the significance of different aspects and identify matters that will need to be managed through guidelines. This process also highlights knowledge gaps. The matrix represents a systematic thought process of each of the characteristics of the source for all possible pathways and receptors. Although this is a subjective evaluation, it is a method to systematically evaluate all possible issues related to the land application of WTR and eliminates issues that are insignificant.

The risk ranking matrix is based on the probability/frequency that a specific consequence will occur (frequent to highly unlikely; Appendix 1) and the consequence that the source may have for a given receptor (very severe to neutral; Appendix 1). The consequence and probability should be determined for each pathway that may impact a receptor. For example, at DLD sites the probability of soils being impacted by application of WTR are frequent (regular application), but the consequence of WTR application to soils are low to moderate, resulting in a low risk.

All the properties of the WTR that could pose a risk to the environment were considered, even when little or no local evidence could be found that the specific property would have a negative impact on the receptors. Throughout the risk assessment the worst-case scenario for all the receptors was considered.

4.2 Receptors

Nine receptors were identified that could be impacted by the application of WTR to land.

4.2.1 Workers

Workers at the water treatment plant and at the land application site are in daily contact with the WTR, either through direct contact or inhalation of air-borne dust particles and volatile pollutants (but see Sections 3.2, 3.3.4 and 3.3.5). It is assumed that the workers comply with the Occupational Health and Safety Act (OHSA), 1993 and are equipped with personal protective equipment (PPE). The impact of the WTR on workers would therefore be covered by this Act and is not considered to be a WTR disposal issue. Workers were therefore omitted as a receptor during this study.

4.2.2 General public

The general public can either be directly or indirectly exposed to WTR. Direct exposure includes the members of the public present at or near the land application site. They may either be in direct contact with the WTR during application and/or inhale air-borne dust and volatile pollutants during land application (but see Sections 3.2, 3.3.4 and 3.3.5).

The general public can also be indirectly exposed through:

- ingesting plants grown on WTR-treated land;
- ingesting meat of animals that grazed on land application sites;
- drinking 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.

4.2.3 Soil

The effects of land application of WTR have been studied extensively internationally. Most of the studies have indicated that land application of WTR can have positive effects on the soil (Hughes *et al*., 2005). 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. However, the study conducted by Hughes *et al*. (2005) showed no such negative effects, either in the field or in the laboratory.

4.2.4 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. International studies indicated that land application of WTR, when managed properly, will not have negative effects on vegetation, a finding supported by Hughes *et al*. (2005).

4.2.5 Air

The residues are formed by the coagulation of fine particles into larger aggregates. However, the fine particles may lead to excessive dust during application and may have negative effects on air quality during and after land application (but see Sections 3.2, 3.3.4 and 3.3.5). This may also include air-borne pollutants in the WTR that may, when present, lead to negative impacts on the receiving environment. These risks are not considered to be great.

4.2.6 Surface water

Surface water bodies in close proximity to land application sites may be impacted negatively as a result of runoff after application of WTR or due to direct runoff from WTR if it is stored before application. This latter has been specifically not recommended (Hughes *et al*., 2000) and such a management recommendation could apply to any other land disposal sites. The 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. It is germane to recognize that the WTR originated from surface waters and so apart from chemicals used in the treatment process nothing new would be added to the surface water. It, however, remains problematic that larger concentrations of soluble elements could be added to nearby surface waters. The potential for WTR to be eroded remains to be investigated and thus its potential to cause significant turbidity is likewise unknown.

4.2.7 Groundwater

Constituents of concern in WTR could migrate through the soil and negatively impact the groundwater resource. Hughes *et al*. (2005) conducted a five-step fractionation of WTR that 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. Similar results are given in Table 3.7 for more recent WTR samples.

4.2.8 Grazing animals

Grazing animals can be impacted directly through ingesting WTR and soil at application sites or indirectly through ingesting vegetation at application sites as well as inhalation of air-borne dust and pollutants (but see Sections 3.2, 3.3.4 and 3.3.5). Grazing animals can also be affected by impacted surface and groundwater.

4.2.9 Other fauna

Similarly to grazing animals, other fauna can also be impacted through direct ingestion of WTR and soil at application sites or through ingesting vegetation grown on application sites and inhalation of air-borne dust and pollutants (but see Sections 3.2, 3.3.4 and 3.3.5). These fauna can also be affected by impacted surface and groundwater.

4.3 Exposure pathways

The identified receptors (Section 4.2) may be impacted by land application of WTR through various pathways. A total of 36 pathways were considered for the risk matrix (Table 4.1). Some of these pathways have multiple barriers to cross (three receptors before the final receptor) and the negative impact to the final receptors may be insignificant.

An example is the ingestion by the general public of meat from animals that grazed on soil to which WTR has been applied: 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 reach the human receptor.

4.4 Population of the risk ranking matrix

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 (Appendix 2). Mitigating factors, for agricultural land application and DLD, have been identified for high risks.

The sections that follow summarise 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. The discussion for each receptor includes:

- a statement on the relative vulnerability of the receptor;
- aspects that could be of concern;

- possible mitigating management options available (can the risk be effectively managed based on the available information?); and
- additional work required/recommended to gain additional information to manage risk effectively.

Table 4.1 Exposure pathways considered during the risk assessment

Receptors		Possible pathways
Workers	1.1	WTR → Ingestion/dermal absorption of toxic constituents
	1.2	WTR → Dust → Human (Inhalation)
	1.3	WTR → Air → Human (Inhalation of volatile pollutants)
General population	2.1	WTR → Ingestion/dermal absorption of toxic constituents
	2.2	WTR → Dust → Human (Inhalation)
	2.3	WTR → Air → Human (Inhalation of volatile pollutants)
	2.4	WTR → Soil → Plant → Human
	2.5	WTR → Soil → Plant → Animal → Human
	2.6	WTR → Soil → Surface water → Human (Ingestion)
	2.7	WTR → Soil → Surface water → Fish → Human
	2.8	WTR → Soil → Surface water → Human (Direct contact)
	2.9	WTR → Soil → Groundwater → Human (Direct contact)
	2.10	WTR → Soil → Groundwater → Human (Ingestion)
Soil	3.1	WTR → Soil (physical properties)
	3.2	WTR → Soil (chemical properties and fertility)
	3.3	WTR → Soil (microbiological characteristics)
Vegetation	4.1	WTR → Soil → Natural vegetation
	4.2	WTR → Soil → Commercial crops
	4.3	WTR → Soil → Grazing crops
Air	5.1	WTR → Air
	5.2	WTR → Soil → Air
Surface water	6.1	WTR → Soil → Surface water
	6.2	WTR → Surface water (Direct run-off)
Groundwater	7.1	WTR → Soil → Groundwater
Grazing animals	8.1	WTR → Soil → Plant → Animal
	8.2	WTR → Soil → Animal (Ingestion of soil)
	8.3	WTR → Soil → Surface water → Animal
	8.4	WTR → Soil → Groundwater → Animal
	8.5	WTR → Soil → Animal (Inhalation of dust)
	8.6	WTR → Animal
Other fauna	9.1	WTR → Soil → Plant → Animal
	9.2	WTR → Soil → Animal (Ingestion of soil)
	9.3	WTR → Soil → Surface water → Animal
	9.4	WTR → Soil → Groundwater → Animal
	9.5	WTR → Soil → Animal (Inhalation of dust)
	9.6	WTR → Animal

4.4.1 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.

4.4.2 General public

4.4.2.1 Vulnerability of the receptor

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 4.1). 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.

4.4.2.2 Aspects of concern

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 DLD of WTR is low (1 in 10 000).

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 (risk rating < 6 (no risk)). 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).

4.4.2.3 Possible mitigating management options available

Mitigating factors that could be implemented to protect the general public are:

- access restrictions to land application and DLD sites;
- buffer zones between land application sites and dwellings;
- application restrictions to protect vegetation and indirectly protect the general public; and
- buffer zones or trenches between land application sites and surface water bodies.

4.4.2.4 Additional work recommended

The impact of WTR on surface water and groundwater need to be determined before the risk through these pathways to the general population can be evaluated.

4.4.3 Soil

4.4.3.1 Vulnerability of the receptor

Soil is the most vulnerable receptor for land application and DLD of WTR since it is the first line of defense. 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 DLD sites may cause soil degradation after several years of application.

4.4.3.2 Aspects of concern

These include Mn (and the cumulative effect of other trace elements and metals) and the pozzolanic properties that certain types of WTR may have.

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.

The pozzolanic properties of certain types of WTR may render it unsuitable for land application due to its impact on the soil physical properties (formation of hard-setting soils).

The breakdown of WTR to clay-size particles could result in degradation of soil structure.

4.4.3.3 Possible mitigating management options available

Negative effects are manageable and mitigating factors could include:

- application restrictions for agricultural use;
- setting maximum loads for DLD sites;
- setting maximum permissible metal levels for the receiving soil for both land application and DLD sites; and

- setting management controls to ensure that application of WTR cannot cause crusting or impaired soil structure (e.g. Hughes *et al.*, 2000).

4.4.3.3 Additional work recommended

Additional work is also recommended to:

- determine the long-term impact of Mn and other elements on WTR amended soils, especially at DLD sites where high application rates are common; and
- determine the effect of the pozzolanic properties of WTR on soil physical properties and plant growth. In cases where WTR is applied as slurry and the area is not ploughed it may form a crust on top of the soil.

4.4.4 Vegetation

4.4.4.1 Vulnerability of the receptor

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.

4.4.4.2 Aspects of concern

The high concentration of Mn in South African WTRs may have a negative impact on vegetation. Manganese is a phytotoxic element that may decrease yield and food quality when present in high concentrations in WTR applied to agricultural land. Natural vegetation at DLD 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 pozzolanic properties (crust forming) of certain types of WTR may impact on seed germination and growth of certain crops.

4.4.4.3 Possible mitigating management options available

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

- application restrictions for agricultural use to protect commercial crops;
- setting maximum load restrictions at DLD 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).

4.4.4.4 Additional work recommended

Additional research that is recommended to broaden the knowledge on vegetation as receptor include:

- determination of the concentration of Mn in WTR that would be phytotoxic to crops; and

- determination of the effect of pozzolanic properties (crust forming) of WTR on seed germination and plant growth.

4.4.5 Air

4.4.5.1 Vulnerability of the receptor

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 DLD sites may be higher (1 in 10 - 100 days). The risk rating is medium to low (<10).

4.4.5.2 Aspects of concern

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.

4.4.5.2 Possible mitigating management options available

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 DLD sites and dwellings to alleviate odour problems.

4.4.5.3 Additional work recommended

It is recommended that a national survey of water treatment plants be conducted to determine the extent to which odour might be a problem in areas with eutrophic raw water.

4.4.6 Surface water

4.4.6.1 Vulnerability of the receptor

Surface water quality could be impacted via runoff from soil amended with WTR (land application) or via direct runoff from WTR (DLD 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) show that no such contamination is affecting a small dam immediately downslope 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.).

4.4.6.2 Aspects of concern

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; 2005). The concentration of Mn in South African WTR is thus of concern and should be investigated further.

4.4.6.3 Possible mitigating management options available

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

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

4.4.6.4 Additional work recommended

Information on erosion and runoff behaviour of WTR in South Africa (and internationally) whether as a liquid/slurry or in the dried state is currently unknown and therefore the risks that WTR may pose to surface water are purely speculative. Further research into the erosion and runoff behaviour of WTR is recommended.

4.4.7 Groundwater

4.4.7.1 Vulnerability of the receptor

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 DLD 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 DLD 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 (see Section 4.3.6) monitored since September 2002 reveal no increase in organic pollutants (all <5.00 :g L^{-1}), Mn all <0.02 mg L^{-1}, and NO_3 almost always below 0.05 mg N L^{-1} (N. McNab, Umgeni Water, pers. comm.).

4.4.7.2 Aspects of concern

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.

4.4.7.3 Possible mitigating management options available

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 DLD sites.

4.4.7.4 Additional work recommended

Information on the impact of WTR on groundwater resources in South Africa is limited and therefore predicting the risk is speculative. Further research is recommended, especially at DLD sites that represent the worst-case scenario, to determine the actual impact of WTR on groundwater. Further investigation should specifically include:

- Mn speciation at different depths in soil receiving WTR; and
- Mn fate and transport modelling in soil receiving WTR.

4.4.8 Grazing animals

4.4.8.1 Vulnerability of the receptor

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).

4.4.8.2 Aspects of concern

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.

4.4.8.3 Possible mitigating management options available

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

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

4.4.8.4 *Additional work recommended*

Since the impacts of the WTR on grazing animals are mainly through the surface water and groundwater pathways, the impacts of WTR on these receptors need to be investigated (see Sections 4.4.6 and 4.4.7).

4.4.9 Other fauna

4.4.9.1 *Vulnerability of the receptor*

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 DLD is practiced.

4.4.9.2 *Aspects of concern*

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.

4.4.9.3 *Possible mitigating management options available*

The impact is manageable and mitigation factors can include:

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

4.4.9.4 *Additional work recommended*

Since the impacts of the WTR on natural fauna are mainly through the surface water and groundwater pathways, the impacts of WTR on these receptors need to be investigated (see Sections 4.4.6 and 4.4.7).

CHAPTER 5

GENERAL DISCUSSION

One of the main conclusions of the research by Hughes *et al.* (2005), conducted to characterise South African WTR and determine its impact on soil properties and plants, was that land application of WTR is a viable option in South Africa with mainly positive effects on soil properties, and no measurable negative impacts on the environment at the two field sites over a period of 5 years.

Guidelines for land application need to be developed to manage this disposal option in an environmentally sound manner. The disposal of WTR on dedicated land should also receive attention in the guidelines since it is currently practiced in South Africa. An internationally acceptable process to develop guidelines is by means of a risk assessment. For the risk assessment the potential pollution source needs to be characterised and receptors and pathways need to be determined. During the risk assessment, knowledge gaps that need to be investigated are also identified.

The population of the risk ranking matrix, based on consequences for receptors and probabilities of these consequences happening, is a systematic thought process for each of the characteristics of the source for all the receptors through all the pathways. Although the evaluation process is subjective, it is a method to systematically evaluate all possible issues related to land application and DLD of WTR and to thus eliminate issues that are insignificant.

Some of the major sources of WTR have been characterised in terms of physical properties (particle size distribution, pozzolanic properties, odours), chemical properties (pH, organic carbon, CEC, nutrients, trace elements and metals), organic pollutants (VOC, sVOC, pesticides) and infectious substances (faecal coliforms, helminth ova). Knowledge gaps were identified where limited information was available.

The receptors identified that could be affected by land application and DLD of WTR include:

- workers;
- general public;
- soil;
- vegetation;
- air;
- surface water;
- groundwater;
- grazing animals; and
- other fauna.

These receptors could be impacted through 36 different pathways ranging from direct impact (WTR → receptor) to there being multiple barriers between the WTR and the end receptor (WTR → receptor 1 → receptor 2 → receptor 3 → receptor 4). The risk posed to the end receptor reduces with every barrier between the source and the receptor.

During the risk assessment and population of the risk ranking matrices with the data available, it was determined that the risk rating of land application and DLD of WTR were <12 (low to medium risk) for all receptors. Areas were identified where more information is needed (knowledge gaps) to assess the risk to certain receptors (impact on surface and groundwater). The identified knowledge gaps and additional information/research needs are discussed in the following section.

5.1 Knowledge gaps and need for further research

The following gaps have been identified:

- Characterisation of WTR
  - The WTR from only five water treatment plants have been studied in detail (Hughes *et al*., 2005); and a further two (Blackheath and Ixopo) for some properties. It is not known how typical these residues are of WTR produced across the country. Further investigation is recommended to determine the differences between small, medium and large facilities as well as facilities using the same treatment but with different raw water qualities. Similarly the temporal variation in WTR produced at any single plant (especially seasonally) needs further investigation (e.g. Sharp *et al*., 2005).
  - The organic pollutant content and microbiological characterisation of WTR is incomplete. Although it can be assumed from the few available data that no VOC, sVOC, pesticides or infectious substances would be present in WTR, further research is recommended in this context, especially for the last named.
  - Although there is a considerable amount of international data available on alum residues, the characterisation of alum WTR in South Africa is restricted to the two residues discussed in this report i.e., Blackheath and Ixopo. The former represents the largest single water treatment plant in South Africa that produces alum residue, while the latter was chosen to represent a small plant within an agricultural community. Only partial characterisation of these residues was possible within the timeframe of this project and further information is required for these WTRs and those from other plants that produce alum residues.
  - The Mn content of South African WTR is high (though this is likely to be a result of treatment chemicals used at the water treatment works) and the consequence on the receptors should be studied in more detail. Speciation of Mn in WTR and fate and transport predictions is needed to identify the risks of Mn to the different receptors. No data could be obtained on the Mn content of WTR in other countries.
  - The influence of WTR with pozzolanic properties on soil and vegetation should be investigated. The possible pozzolanic properties of some WTRs could negatively impact the soil physical properties (infiltration rate, water retention) and could render the soil unable to sustain crops (seeds may not germinate due to crusting of soil). Such behaviour was not shown to be a problem with the organic polymer WTR studied in the greatest detail under both field and laboratory conditions. Recommended management for the disposal of this WTR (Hughes *et al*., 2000) was also specifically designed to, *inter alia*, alleviate any potential for soil crusting. The potential for other forms of WTR to adversely affect this aspect of soil is unknown and the international literature also makes no reference to this aspect.

- The effects of the breakdown of other WTRs to their natural clay-size particles on soil structure should be further investigated. The rate at which such breakdown may occur and the conditions that may enhance it, in particular soil properties and management practices should be further studied.

- Mobility of constituents present in WTR

  - Information on the potential for erosion of WTR aggregates and runoff behaviour of WTR (liquid/slurry and dried state) is unknown. The behaviour of different types of WTR would probably differ as would the behaviour before and after land application. Further research is recommended to collect data that could be used to determine the impact of WTR on surface water. The rate at which WTR breaks down in soils and the conditions that affect such breakdown are also relevant to this question.
  - The mobility of organic pollutants (if present) and other constituents in WTR should be investigated to determine the potential risk for groundwater pollution. Special attention should be given to identify/evaluate analytical methods to determine the mobile fraction of constituents present in WTR. Analytical data could be used to model the mobility of constituents. This information would be valuable to determine the pollution risk for groundwater and to identify applicable mitigating factors to protect the environment.

- Mitigating factors were identified but the application restrictions/buffer zones for land application would have to be investigated. The only international guidelines with buffer zones and restrictions are those of Australia (and these are designed for the perceived danger posed by alum WTR). This could serve as a guide when developing guidelines for South Africa. Due to differences in the properties of different types of WTR (and differences within the same type of WTR from different plants, and even from the same plant over time), a blanket application recommendation would not be feasible. Differences in soil properties also need to be taken into account when land application is considered.

5.2 Conclusions and recommendations

From the information gathered during this scoping report it can be concluded that guidelines for the land application and DLD of WTR in South Africa cannot be developed at this stage due to:

- limited information on the characteristics of all types of WTR produced nationally from different raw water sources with different water treatment processes and their variability over time (e.g. seasonal variations);
- insufficient information on the impact of different types of WTR on soil properties;
- insufficient information on the potential impact of WTR on surface water and groundwater; and
- lack of information on the organic pollutant and infectious substance contents of sufficient representative samples of the variety of WTR produced nationally and any seasonal variability.

In the interim it is recommended that:

- WTR be considered for agricultural use due to its low to medium risk to all receptors.
  - Appropriate management practices should be introduced to ensure protection of the receptors that may be at risk (surface and groundwater). This includes buffer zones, and soil depth and slope restrictions (WRC, 2006).
  - Soils should be monitored with samples taken before the planting season and analysed for constituents of concern (e.g. Zn and Pb) to ensure that concentrations will not reach toxic levels. The elements of most concern will vary between WTRs and so regular analyses of each particular WTR should be carried out. The soil data could be compared to the Total Investigation Levels and Total Maximum Thresholds set for soils receiving wastewater sludge (WRC, 2006). These levels indicate when further soil investigation is needed and when land application may need to cease.
- DLD at or near the water treatment plant should be managed in such a way that all receptors will be protected.
  - The Minimum Requirements (DWAF, 1998; 2005) should be consulted to determine the total load that could be disposed per surface area. The total load will depend on the concentration (TCLP test) of elements of concern in the WTR. Lime addition could be considered to decrease the mobility of the constituents to enable a higher load.
  - Appropriate management practices should be introduced to ensure protection of the receptors that may be at risk (surface and groundwater). This includes buffer zones (DWAF, 1998; 2005), soil depth and slope restrictions, and regular ploughing to prevent surface sealing of the soil.
  - Soils should be monitored on a regular basis (to a depth of 500 mm) and analysed for constituents of concern (e.g. Zn and Pb). The elements of most concern will vary between WTRs and so regular analyses of each particular WTR should be carried out. The analytical results will indicate when the constituents become mobile in the soil profile and disposal should be ceased. The soil data could also be compared to the Total Maximum Thresholds set for soils receiving wastewater sludge (WRC, 2006). These levels indicated when land application may need to be stopped.
- One final possibility should be considered and that is disposal of the WTR to landfill, should land disposal be considered impracticable at a local level. Since WTR is largely a natural material, instead of dumping the WTR into a landfill consideration should be given to using it as part of the capping materials both on a daily basis and in the final cover material on closure.

The studies conducted by Hughes *et al*. (2005) and by the current project team show that all of the gaps identified above would require filling if national guidelines (modifiable to local conditions) are to be produced for WTR disposal to land in South Africa. While the interim proposals given here may suffice in the short term, for long-term sustainable management of WTR further steps will need to be taken.

A final recommendation is that in order to take this matter further, the Water Research Commission should convene a workshop at the earliest possible time to which all interested parties should be invited. We believe that such a forum would enable those stakeholders most involved with the management and disposal of WTR to decide on the way forward.

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Appendix 1 Risk ranking matrix and probability classes

	1	2	3	4	5	6		Consequence Class
5	[illegible]	10	15	20	25	30	5	Very Severe
4	[illegible]	[illegible]	12	16	20	24	4	Severe
3	[illegible]	[illegible]	[illegible]	12	15	18	3	Moderate
2	[illegible]	[illegible]	[illegible]	[illegible]	10	12	2	Low
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	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							

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

KEY

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

APPENDIX 2 Risk ranking matrices

Appendix 2a Land application (agricultural and beneficial use) – Physical characteristics						
Physical characteristics		Particle size, odours				
Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Workers	1.1			0	Assume compliance with OHSA and equip workers 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 is 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	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	2.7			0	Not applicable to physical properties	None required
	2.8			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	2.9			0	Not applicable to physical properties	None required
	2.10			0		
Soil	3.1	2	3	6	Consequence are manageable, probability is rare. Pozzolanic properties and breakdown of WTR may have an influence.	Further research recommended
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.	Dust suppression measures will need to be implemented during dust incidents.
	5.2	2	3	6	Sporadic dust/odour nuisance could occur once every 10 000 days - probability low due to incorporation into soil.	Dust suppression measures will need to be implemented during dust incidents.
Surface water	6.1			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended. Buffer zone between disposal site and surface water
	6.2			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended. Buffer zone between disposal site and surface water
Groundwater	7.1			0	It is assumed that the physical properties of WTR would not impact groundwater.	None required

Appendix 2a (cont) Land application (agricultural and beneficial use) – Physical characteristics

Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Grazing animals	8 1			0	It is assumed that the physical properties of WTR would not impact grazing animals	None required
	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

Appendix 2b Dedicated land disposal – Physical characteristics						
Physical characteristics		Particle size, odours				
Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Workers	1.1			0	Assume compliance with OHSA and equip workers 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 is 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	
	2.4			0		
	2.5			0		
	2.6			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	2.7			0	Not applicable to physical properties.	
	2.8	1	2	2	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	2.9			0	Not applicable to physical properties	
	2.10			0		
Soil	3.1	2	3	6	Consequence are manageable, probability is low	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	5	10	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	Dust suppression measures will need to be implemented during dust incidents. Buffer zones between DLD sites and dwellings
Surface water	6.1			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended. Buffer zone between disposal site and surface water
	6.2			0		
Groundwater	7.1			0	It is assumed that the physical properties of WTR would not impact groundwater	None required

Appendix 2b (contd) Dedicated land disposal – Physical characteristics

Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Grazing animals	8.1			0	It is assumed that the physical properties of WTR would not impact grazing animals	None required
	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	Impact is case specific. 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

Appendix 2c Land application (agricultural and beneficial use) – Nutrients

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 OHSA and equip workers 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. General population may possibly come in contact with waste	None required
	2.2	1	4	4	No impact expected in terms of inhalation of nutrients in dust. General population may possibly come in contact with waste.	None required
	2.3			0	Not applicable	Not applicable
	2.4	1	4	4	Impact/consequence of nutrients ingested from plants grown on WTR amended soil is low.	None required
	2.5	1	4	4	Impact/consequence of nutrients ingested from animals grazing on WTR amended soil is low.	None required
	2.6			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	2.7	1	3	3	Impact/consequence of nutrients ingested from eating fish from surface water impacted by WTR amended soil is low	Buffer zones between WTR and surface water.
	2.8			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	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.	Further data collection needed. Application restrictions. Buffer zones (depth to groundwater)
	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.	None required
Vegetation	4.1	1	3	3	No impact on vegetation even if application rates are high.	None required
	4.2	1	3	3		
	4.3	1	3	3		
Air	5.1			0	It is assumed that nutrients will not have an impact on air quality/odours.	None required
Surface water	6.1			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	6.2			0		
Groundwater	7.1			0	Not much information on the impact of nutrients in WTR on groundwater.	Further research recommended

Appendix 2c (contd) Land application (agricultural and beneficial use) – Nutrients

Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Grazing animals	8.1	1	5	5	No consequences for animals ingesting plants grown on WTR amended 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	Application restrictions
	8.3			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	8.4			0	Not much information on the impact of nutrients in WTR on groundwater	Further research recommended
	8.5			0	Not applicable	Not applicable
	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 amended 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	Application restrictions
	9.3			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	9.4			0	Not much information on the impact of nutrients in WTR on groundwater	Further research recommended
	9.5			0	Not applicable	Not applicable
	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

Appendix 2d Dedicated land disposal – Nutrients

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 OHSA and equip workers 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	Not applicable	Not applicable
	2.4	1	3	3	No impact/consequence of nutrients ingested from plants grown on WTR amended soil, probability is low (DLD site).	None required
	2.5	1	3	3	No impact/consequence of nutrients ingested from animals grazing on WTR amended soil, low likelihood.	None required
	2.6			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended.
	2.7	1	3	3	Assumed to be no impact/consequence of nutrients ingested from eating fish from surface water impacted by WTR amended soil; probability is 3. Little information on run-off and erosion from WTR on DLD sites.	Further research recommended. Buffer zones between WTR and surface water.
	2.8			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	2.9	1	3	3	There is limited information on the pollution potential of WTR for groundwater. It is assumed that the consequence and probability will be low (1:10 000) of groundwater pollution with limited impact on general public.	Further data collection needed. Buffer zones (depth to groundwater)
	2.10	1	3	3	No impact expected in terms of the nutrients.	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.	None required
Vegetation	4.1	1	3	3	No impact on vegetation even if application rates are high.	None required
	4.2	1	3	3	No impact on commercial crops even if application rates are high.	None required
	4.3	1	3	3	No impact on grazing crops even if application rates are high.	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			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	6.2			0		

Appendix 2d (contd) Dedicated land disposal – Nutrients						
Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Groundwater	7.1			0	Not much information on the impact of nutrients in WTR on groundwater	Further research recommended
Grazing animals	8.1	1	5	5	No consequences for animals ingesting plants grown on WTR amended 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	Application restrictions
	8.3			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	8.4			0	Not much information on the impact of nutrients in WTR on groundwater	Further research recommended
	8.5			0	Not applicable	Not applicable
	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 amended 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	Application restrictions
	9.3			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	9.4			0	Not much information on the impact of nutrients in WTR on groundwater	Further research recommended
	9.5			0	Not applicable	Not applicable
	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

Appendix 2e Land application (agricultural and beneficial use) – Micro-elements

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

Receptor	Pathway no	Risk to receptor: Consequence	Risk to receptor: Probability	Risk to receptor: Risk rating	Notes	Mitigating factors
Workers	1.1			0	Assume compliance with OHSA and equip workers 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	2	3	6	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	Not applicable	Not applicable
	2.4	2	3	6	Mn is phytotoxic. Effect on humans assumed to be negligible	Further investigation may be needed. Application restriction for agriculture
	2.5	2	2	4	Pathway has several barriers. Mn is phytotoxic. Effect on humans assumed to be negligible. Further investigation may be needed	None required
	2.6			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	2.7			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	2.8			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	2.9			0	Leaching of Mn in soil is low, especially at high pH levels. Limited information on actual micro-element concentrations in groundwater	Further research recommended
	2.10	1	1	1	No impact	None required
Soil	3.1				Not applicable	Not applicable
	3.2	2	4	8	The consequences are manageable and the probability is 1:1 000	Application restrictions
	3.3	1	3	3	No effect on microbiological characteristics was observed	None required
Vegetation	4.1	2	3	6	Some intervention may be required to maintain biodiversity if access concentrations of Mn are added to crops, could happen (1:10 000)	Application restrictions
	4.2	2	3	6		
	4.3	2	3	6		

Appendix 2e (contd) Land application (agricultural and beneficial use) – Micro-elements						
Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Air	5.1				It is assumed that micro-elements will not have an impact on air quality/odours	None required
Surface water	6.1			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	6.2			0		
Groundwater	7.1			0	Not much information on the impact of micro-elements in WTR on groundwater	Further research recommended
Grazing animals	8.1	2	2	4	Pathway has several barriers. The consequences for animals ingesting plants with high Mn levels may cause effects that are recoverable; 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; probability is 1:10 000	None required
	8.3			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	8.4			0	Pathway has several barriers. Not much information on the impact of micro-nutrients in WTR on groundwater	Further research recommended
	8.5			0	Not applicable	Not applicable
	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	Pathway has several barriers. The consequences for animals ingesting plants with high Mn levels may cause effects that are recoverable; 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; probability is 1:10 000	None required
	9.3			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	9.4			0	Pathway has several barriers. Not much information on the impact of micro-nutrients in WTR on groundwater	Further research recommended
	9.5			0	Not applicable	Not applicable
	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)

Appendix 2f Dedicated land disposal – Micro-elements

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

Receptor	Pathway no	Risk to receptor: Consequence	Probability	Risk rating	Notes	Mitigating factors
Workers	1.1			0	Assume compliance with OHSA and equip workers 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 is 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 is rare (1: 100 000)	None required
	2.3			0	Not applicable	Not applicable
	2.4	2	3	6	Mn is phytotoxic. Effect on humans assumed to be negligible.	Further investigation may be needed. Access restrictions from DLD sites with known high concentrations of potentially phytotoxic and zoo-toxic micro-elements.
	2.5	2	2	4	Pathway has several barriers. Pathway very long. Mn is phytotoxic. Effect on humans assumed to be negligible. Probability ingesting plants grown on DLD sites is rare.	None required
	2.6			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	2.7			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	2.8			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	2.9			0	Leaching of Mn in soil is low, especially at high pH levels. Limited information on actual micro-element concentrations in groundwater.	Further research recommended
	2.10	1	1	1	No impact	None required
Soil	3.1				Not applicable	Not applicable
	3.2	2	4	8	The consequences are manageable and the probability is 1:1 000	Maximum load restrictions.
	3.3	1	3	3	No effect on microbiological characteristics was observed	None required

Appendix 2f (contd) Dedicated land disposal – Micro-elements						
Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Vegetation	4.1	2	4	8	Some intervention may be required to maintain biodiversity if excess Mn is added to vegetation, could happen (1:100 000)	Maximum load restrictions
	4.2			0	Not applicable to DLD	Not applicable
	4.3	2	3	6		
Air	5.1			0	Assumed that micro-elements will not impact on air quality/odours	None required
Surface water	6.1			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	6.2			0		
Groundwater	7.1			0	Not much information on the impact of micro-elements in WTR on groundwater	Further research recommended
Grazing animals	8.1	2	4	8	Pathway has several barriers. The consequences for animals ingesting plants with high Mn levels may cause effects that are recoverable, probability is 1:1 000	No grazing allowed on DLD sites with high, potentially toxic concentrations of micro-elements
	8.2	2	4	8	Consequences for animals ingesting WTR amended soils with high Mn may cause effects that are recoverable, probability is 1:1 000	No grazing allowed on DLD sites with high, potentially toxic concentrations of micro-elements
	8.3			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	8.4			0	Pathway has several barriers. Not much information on the impact of micro-nutrients in WTR on groundwater	Further research recommended
	8.5			0	Not applicable	Not applicable
	8.6	2	4	8	The consequences for animals ingesting WTR with high micro-elements (Mn) levels may cause recoverable effects; probability is 1:1 000	No grazing allowed on DLD sites with high, potentially toxic concentrations of micro-elements
Fauna	9.1	2	3	6	Pathway has several barriers. The consequences for animals ingesting plants with high Mn levels may cause effects that are recoverable, probability is 1:10 000. Impacts are case specific	None required
	9.2	2	3	6	The consequences for animals ingesting WTR amended soils with high Mn may cause effects that are recoverable, probability is 1:10 000. Impacts are case specific	None required
	9.3			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known. Impacts are case specific	Further research recommended
	9.4			0	Pathway has several barriers. Not much information on impact of micro-nutrients in WTR on groundwater. Impacts are case specific	Further research recommended
	9.5			0	Not applicable	Not applicable
	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. Impacts are case specific	None required

Appendix 2g Land application (agricultural and beneficial use) – Metals

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

Receptor	Pathway no	Risk to receptor: Consequence	Probability	Risk rating	Notes	Mitigating factors
Workers	1.1			0	Assume compliance with OHSA and equip workers with PPE	None required
	1.2			0		
	1.3			0		
General population	2.1	1	4	4	No impact expected in terms of the metals (low concentrations). General population may possibly come in contact with waste	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 land application.	None required
	2.3			0	Not applicable	Not applicable
	2.4	1	3	3	Impact/consequence of metals ingested from plants grown on WTR amended soil are low (1), probability is possible	None required
	2.5	1	3	3	Pathway has several barriers. Impact/consequence of metals ingested from animals grazing on WTR amended soil is low (1), probability is possible (long pathway)	None required
	2.6			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	2.7			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	2.8			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	2.9			0	Limited information on actual micro-element concentrations in groundwater. Low metals and high pH would probably protect groundwater	Further research recommended
	2.10	1	3	3	No impact expected in terms of the metals	None required
Soil	3.1				Not applicable	Not applicable
	3.2	2	4	8	No impact due to low metal content of WTR, probability (1:1000 sites)	Maximum load restrictions based on potentially toxic metals
	3.3	1	3	3	No effect on microbiological characteristics was observed	None required
Vegetation	4.1	1	4	4	No impact due to low metal content of WTR	None required
	4.2			0		
	4.3			0		
Air	5.1				It is assumed that metals will not have an impact on air quality/odours	None required
Surface water	6.1			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	6.2			0		

Appendix 2g (contd) Land application (agricultural and beneficial use) – Metals						
Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Groundwater	7.1			0	Not much information on the impact of micro-elements in WTR on groundwater	Further research recommended
Grazing animals	8.1	1	3	3	Pathway has several barriers. No impact on grazing animals eating crops grown on WTR amended soils (low metal content of WTR), probability is 1:10 000 days	None required
	8.2	1	3	3	No impact on grazing animals eating WTR amended soils (low metal content of WTR), probability is 1:10 000 days	None required
	8.3			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	8.4			0	Pathway has several barriers. Not much information on the impact of metals in WTR on groundwater. Assumed to be low	Further research recommended
	8.5			0	Not applicable	Not applicable
	8.6	2	3	6	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	1	3	3	Pathway has several barriers. No impact on fauna eating crops grown on WTR amended soils (low metal content of WTR), probability is 1:10 000 days	None required
	9.2	1	3	3	No impact on fauna eating WTR amended soils (low metal content of WTR), probability is 1:10 000 days	None required
	9.3			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	9.4			0	Pathway has several barriers. Not much information on the impact of metals in WTR on groundwater. Assumed to be low	Further research recommended
	9.5			0	Not applicable	Not applicable
	9.6	2	3	6	The consequences for fauna ingesting WTR may cause recoverable effects, probability is 1:10 000	Incorporate WTR into the soil (dilution effect)

Appendix 2h Dedicated land disposal – Metals

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

Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Workers	1.1			0	Assume compliance with OHSA and equip workers with PPE.	None required
	1.2			0		
	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 is 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	Not applicable	Not applicable
	2.4	1	2	2	Impact/consequence of metals ingested from plants grown on WTR amended soil is low (1); probability is rare from DLD sites	None required
	2.5	1	4	4	Pathway has several barriers. Impact/consequence of metals ingested from animals grazing on WTR amended soil is low (1); probability is rare from DLD sites. (long pathway).	None required
	2.6			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	2.7			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	2.8			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	2.9			0	Limited information on actual micro-element concentrations in groundwater. Low metals and high pH would probably protect groundwater	Further research recommended
	2.10	1	3	3	No impact expected in terms of the metals	None required
Soil	3.1				Not applicable	Not applicable
	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
	3.3	1	3	3	No effect on microbiological characteristics was observed	None required
Vegetation	4.1	2	4	8	Phytotoxic effects may occur at DLD sites due to high loading rates even though the metal content is low, probability is 1:1000	Maximum load restrictions for DLD sites
	4.2	2	4	8	Not applicable to DLD	None required
	4.3	2	4	8	Not applicable to DLD	None required
Air	5.1				It is assumed that metals will not have an impact on air quality/odours	None required

Receptor	Pathway no	Risk to receptor			Notes	Mitigating factors
		Consequence	Probability	Risk rating		
Surface water	6.1			0	Information on erosion and run-off behavior of WTR (liquid and dried state) is not known.	Further research recommended
	6.2			0		
Groundwater	7.1			0	Not much information on the impact of micro-elements in WTR on groundwater	Further research recommended
Grazing animals	8.1	2	4	8	Pathway has several barriers. Recoverable effects on grazing animals eating crops grown on DLD sites (low metal content of WTR), probability is 1:1 000 animals	No grazing allowed at DLD sites where metal content of WTR are known to be high.
	8.2	2	4	8	Recoverable effects on grazing animals eating crops grown on DLD sites (low metal content of WTR), probability is 1:1 000 animals	No grazing allowed at DLD sites where metal content of WTR are known to be high.
	8.3			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known	Further research recommended
	8.4			0	Pathway has several barriers. Not much information on the impact of metals in WTR on groundwater. Assumed to be low.	Further research recommended
	8.5			0	Not applicable	Not applicable
	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	4	8	Pathway has several barriers. Some intervention may be required to maintain biodiversity of fauna eating crops grown on DLD sites (low metal content of WTR); probability is 1:1 000 animals. Impacts are case specific.	Maximum load restrictions at DLD sites
	9.2	2	4	8	Some intervention may be required to maintain biodiversity of fauna eating crops grown on DLD sites (low metal content of WTR); probability is 1:1 000 animals. Impacts are case specific.	Maximum load restrictions at DLD sites
	9.3			0	Pathway has several barriers. Information on erosion and run-off behavior of WTR (liquid and dried state) is not known. Impacts are case specific.	Further research recommended
	9.4			0	Pathway has several barriers. Not much information on the impact of metals in WTR on groundwater. Assumed to be low. Impacts are case specific.	Further research recommended
	9.5			0	Not applicable	Not applicable
	9.6	2	4	8	The consequences for fauna ingesting WTR may cause recoverable effects, probability is 1:1 000. Impacts are case specific.	Incorporate WTR into the soil (dilution effect)

Appendix 2h (contd) Dedicated land disposal – Metals

Other related WRC reports available:

Effects of land application of water treatment residue.

Hughes JC; Titshall LW; Buyeye SM; Johnston MA; Moodley M; Pecku S

In order to produce potable water from turbid primary sources it is necessary to remove suspended and dissolved solids, organic matter and other contaminants. Although slight variability exists between the actual methods used in the water treatment process, the underlying principles remain the same. The ever-increasing demand for clean water has led to an increase in the number and size of water treatment facilities around the world. A consequence of this is an increase in the production of water treatment residue (WTR), which requires suitable disposal methods. In many parts of the world, including South Africa, WTR has conventionally been disposed of in landfill but due to increased costs land application is becoming the preferred disposal method. Land disposal is based upon a fundamental tenet that the 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. The aim with this project was thus to produce research data which will assist in the development of environmentally acceptable guidelines for South African conditions for the disposal of water treatment residues to land, and to study the effect of land disposal of water treatment residue on the physical, chemical and fertility properties of soils and on the chemistry of the local groundwater and nearby surface waters. For this purpose a number of WTRs were subjected to laboratory analysis and their interaction with soils evaluated in pot and field trials. This investigation has produced a considerable amount of data on the Midmar WTR and by extension on all similarly produced polymer WTRs. However, knowledge of the other WTRs investigated is restricted to the reported laboratory and glasshouse studies. The dangers of extrapolation from these to the field situation are indicated by the differences in phosphate and nitrate behaviour of the Midmar WTR in laboratory and field studies, problems experienced with Faure WTR in glasshouse studies due to high Mn levels and the high EC measured in the pot experiment using the Rand Water WTR. The problems with extrapolation to field situations are compounded for WTRs because they vary both spatially and temporally from the same treatment works. However, it is clear that the laboratory and glasshouse experiments exaggerate the problems and reflect worst-case conditions.

Despite this, it is also clear that all aspects of the work reported reveal a highly consistent result, i.e. that land application of WTR is safe and is likely to have no negative impacts on soils, vegetation or groundwater even at very high disposal rates that are unlikely to occur in the field. Indeed, it appears that the land application of WTR can have positive effects such as improving water retention in especially coarse-textured soils and increasing hydraulic conductivity in fine-textured soils, reducing P sorption in high P sorbing soils and increasing P sorption in sandy soils, increasing the sorption of heavy metals (thereby reducing their pollution threat) and increasing properties such as cation exchange capacity and plant-available Ca and Mg.

Notwithstanding the above, there are some aspects that require further investigation before formalised guidelines for the land disposal of WTR can be fully produced. However, the positive effects of land disposal of WTR clearly outweigh the assumed negative impacts that were the impetus behind this investigation. Thus, even without formalised guidelines, the results given in this report offer compelling evidence for DWAF to consider declassifying WTR in order that land disposal, with minimal regulatory control of the site, may be an approved option for water treatment authorities.

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