TECHNICAL SUPPORT DOCUMENT TO THE DEVELOPMENT OF THE SOUTH AFRICAN SLUDGE GUIDELINES:

VOLUME 4: REQUIREMENTS FOR THE BENEFICIAL USE OF SLUDGE

by

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EXECUTIVE SUMMARY

Dedicated beneficial use sites are areas of land where sludge is disposed of at application rates, or pollutant concentrations, higher than those permitted for land application for the purposes of agriculture. The presence of a wide variety of potentially harmful chemicals in sludge with the potential for uptake by plants and animals, together with the potential presence of human pathogens inhibit the beneficial use of sludge. The fundamental premise of this volume is that sludge can still be used beneficially provided that there are adequate management and control. These sites may be used to grow crops for specific purposes, provided that suitable management practices are adopted to protect the environment and public health and include forests, plantations, industrial crops and urban landscaping. Beneficial use of sludge should be the management option of choice for WWTP that either produce great quantities of sludge or produce sludge with too high a level of pollutants to be managed by application to privately owned agricultural fields. The beneficial use options included in Volume 4 of the Sludge Guidelines include once-off high rate sludge application to increase the organic content and nutrient status of degraded soils to sustain vegetative growth, continuous high rate applications on non-edible crops and the use of sludge as cover material on landfill.

High rate sludge application, especially practiced on a continuous base, may have negative impacts on the environment. Therefore, the negative effects on environmental resources need to be managed and effectively controlled and monitored for the protection of human and animal health, protection of water resources and land quality in general. To achieve this, the basic principles of the Minimum Requirements, as adopted for sludge handling and disposal are included in this Volume of the Sludge Guidelines to enable the wastewater industry to familiarise themselves with waste handling practices.

Cover material is used in various applications on landfills at different stages in the operation life. Landfill final covers and caps are designed to isolate waste from the environment and are used to manage water ingress into the landfill. Various cover configurations are used, and the degree to which water is excluded from the landfill impacts on the rate of degradation and the quality and volume of landfill emissions.

The Guidelines for the beneficial use of sludge at high application rates is based on the following information:

- Local and international research findings
- International guidelines and legislative trends
- The results of risk assessments
- Practical considerations

The same risk assessment protocol developed by the USEPA to develop the USEPA Part 503 Rule for the land application of wastewater sludge was followed. This was found to be the best way to develop guidelines to protect human health as well as the environment. A risk ranking matrix was developed to systematically evaluate the significance of different source-receptor pathways and identify matters that will need to be managed through the guidelines. 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 sludge land application and eliminates issues that are insignificant. The risk assessment included the following steps:

- Source characterization (characteristics of sludge including pathogens, disease causing issues, odours, vector attraction, moisture content, pH, metals, nutrients and organic pollutants)
- Receptor identification (workers, general public, surface water, groundwater, soil, animals, etc.)
- Pathway identification between source and receptor
- Population of risk ranking matrix to identify pathways with high risk to the receptors
- Identify mitigating factors. Receptors could be protected against constituents of concern in the sludge by either removing the constituents of concern from the sludge through a treatment process, or by placing a barrier between the receptor and the sludge.

The sludge classification system remains the same as in the previous Volumes, consisting of a Microbiological class (A, B or C), Stability class (1, 2 or 3; based on the odour and vector attraction properties of the sludge) and a Pollutant class (a, b or c). The compliance and classification criteria for the Microbiological class remain the same as for the other Volumes. The same vector attraction reduction options are recommended for beneficial use at high application rates as for agricultural use. The Pollutant class determination of sludge in Volumes 1 and 2 was based on the total metal content (*aqua regia* digestion) of the sludge. It is recommended that the same classification be used for beneficial use of sludge at high rates. However, the use of sludge as landfill cover material will be directed by the Minimum Requirements, the Pollutant class for this purpose will have to be based on the leachable metal fraction (TCLP fraction which predicts the quality of leachate that will originate from the waste body) in the sludge.

Beneficial use of sludge on land can be either on-site (within the boundaries of the WWTP) or off-site (outside the boundaries of the WWTP). Different authorisations/permits will be required for these sites. The site selection and site investigation requirements should be followed to ensure that the environment is adequately protected.

The following restrictions will apply to sludge intended for beneficial use at high application rates:

- Sludge quality restrictions
- Soil quality restrictions – restrictions on metal content of soils that would be allowed at sludge application sites (maximum permissible levels – MPL) need to be implemented to ensure that the soil quality does not degrade to such an extent that rehabilitation would be nearly impossible and the surface and groundwater becomes polluted. This soil quality management apply specifically for sites that receive Pollutant class b and c sludge.

- Restrictions on crop production – the cultivation of vegetables consumed raw, or grow directly above or below the soil/sludge mixture are prohibited. A specified time period should expire before crops can be harvested.
- Restrictions on grazing animals – Grazing animals will only be allowed on site after a specified time period has expired.
- Public access restrictions – should be restricted under certain conditions.

Land application sites receiving high rate sludge applications should be managed in a responsible way to protect the environment against the potential negative impact of these operations. These management practices could also serve as mitigating factors to protect the receptors against the potentially harmful substances present in the sludge and must at least include odour control, run-off interception and groundwater protection.

Monitoring requirements are only applicable to sites receiving **continuous high rate sludge applications**. It is assumed that once-off high rate sludge application will not have such a negative impact on the environment that monitoring will be required. The monitoring programme should be implemented to protect the different receptors.

Remediation will only be applicable to **existing sites receiving continuous high rate sludge** application. All new sites will be monitored and sludge application will cease before remediation of the area is necessary.

Due to the high rate of sludge application at these sites restrictions and requirements should be applied to protect the receiving environment. These restrictions and requirements become more stringent with deteriorating sludge quality and the vulnerability of the receiving environment. Especially at existing continuous application sites, where the necessary criteria for site selection are not met, the management and monitoring requirements increases substantially. The development of closure and remediation plans is introduced to ensure sustained acceptability.

TABLE OF CONTENTS

SECTION **PAGE**

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

Dedicated beneficial use sites are areas of land where sludge is disposed of at application rates, or pollutant concentrations, higher than those permitted for land application for the purposes of agriculture. Wastewater sludge has beneficial soil conditioning and fertilising properties. In fact, a wide array of elements contained in sludge are essential for plant growth and the organic content of sludge has led some agronomists to suggest that sludge is a more complete fertiliser than inorganic fertilisers. However, the presence of a wide variety of potentially harmful chemicals in sludge (albeit in trace amounts) with the potential for uptake by plants and animals, together with the potential presence of human pathogens inhibit the beneficial use of sludge. The fundamental premise of this volume is that sludge can still be used beneficially provided that there are adequate management and control. These sites may be used to grow crops for specific purposes, provided that suitable management practices are adopted to protect the environment and public health and include forests, plantations, industrial crops and urban landscaping. Beneficial use of sludge should be the management option of choice for WWTP that either produce great quantities of sludge or produce sludge with too high a level of pollutants to be managed by application to privately owned agricultural fields. The beneficial use options included in Volume 4 of the Sludge Guidelines include once-off high rate sludge application to increase the organic content and nutrient status of degraded soils to sustain vegetative growth, continuous high rate applications on non-edible crops and the use of sludge as cover material on landfill.

High rate sludge application, especially practiced on a continuous base, may have negative impacts on the environment. Therefore, the negative effects on environmental resources need to be managed and effectively controlled and monitored for the protection of human and animal health, protection of water resources and land quality in general. To achieve this, the principals of the Minimum Requirements have been adopted for all land application options. The Minimum Requirements are living documents which are updated regularly and the reader would be referred to these documents, or any future updates of the documents, when necessary. However, Volume 3 and 4 were developed recognising that the wastewater industry is not necessarily familiar with waste handling practices and legal requirements. Therefore, the basic principles of the Minimum Requirements, as adopted for sludge handling and disposal are included in these Volumes of the Sludge Guidelines to enable the wastewater industry to familiarise themselves with waste handling practices.

1.1 Purpose of Volume 4

The emphasis of the new Sludge Guidelines is on the sustainable, beneficial use of wastewater sludge. The new Sludge Guidelines comprises 5 Volumes, each addressing a different use/disposal option. Volume 1 details the characterisation, classification and selection of management options for sludge utilisation while Volume 2 addresses the use of sludge in agriculture (both these documents are available from the WRC) and Volume 3 describes the restrictions and requirements applicable to sludge disposal. The premise of Volume 4 of the Sludge Guidelines is on the beneficial use of sludge at application rates higher than the normal agronomic rate and/or higher than the maximum application rate of 10 ton/ha/y recommended for agricultural use. This high rate sludge application should be managed to ensure minimum negative environmental effects.

Volume 4 describes the requirements and restrictions related to:

- Once-off high rate sludge application to land to increase the physical and chemical properties of the soil
- Continuous high rate sludge application to land to supply plant nutrients and microelements for plant growth
- Use of sludge as landfill cover material

Volume 4 should be used for guidance on the:

- Rehabilitation/remediation of degraded/depleted soils. This soil degradation could be due to mining activities, intensive farming and industrial activities. Inorganic waste material such as mine tailings and degraded soils could benefit from the addition of organically rich material. However, due to the potentially high pathogen and metal concentration of sludge, high rate application can cause environmental problems. This application must therefore be done responsibly. This volume details the process to follow to use sludge in the treatment of organically poor material to increase the physical structure and to sustain vegetation.
- Use of sludge during the construction of golf courses, sports fields, establishment of vineyards, fruit orchards, road embankments and public parks. These application sites can either be private land (vineyards, orchards) or land where public access is probable. Due to the potentially high pathogen content of sludge, the application of sludge on public access site should be regulated and mitigated to protect the general public.
- Beneficial land application at continuous high loading rates. Some crops such as industrial crops, trees, grain crops, plants, flowers, seedlings and instant lawn can be cultivated using sludge applications much higher than the recommended agronomic rates. These practices must be managed to avoid nitrate leaching and other negative environmental effects. This volume details the requirements for the beneficial use of sludge at high loading rates.
- Use of sludge as cover material on landfill. Sludge could be used as part of the capping material for landfills or as daily or final cover. This volume gives guidance on these practices.

1.2 Extent of beneficial use of sludge in South Africa

A survey of wastewater treatment plants (WWTP) was conducted by Herselman *et al*. (2005) to determine the extent of sludge utilization and disposal in South Africa. The survey of 234 WWTP indicated that a wide variety of disposal options are used in South Africa but the beneficial use of sludge is limited. Only 6% of plants used sludge for agriculture and 3% use it for instant lawn cultivation. No other beneficial use options were identified during the survey but the use of sludge to rehabilitate mine tailings is a beneficial use option at some mines.

1.3 Description of beneficial use options

Several beneficial use options can be considered for sludge, but it can be divided into 3 main classes:

- Once-off high rate application,
- Continuous high rate application and
- Landfill cover material.

1.3.1 Once-off high rate sludge application to land

Since sludge is known to improve especially the physical characteristics of soils but also to provide essential nutrients and micro elements, it can benefit soils under the following circumstances:

- Rehabilitation of disturbed/degraded soils (nutrient depletion, erosion, acidity and salinity, poor physical properties, reduced biological activity) after mining activities, intensive farming and industrial activities
- Establishment of golf courses, race courses, vineyards, road embankments, public parks

Sludge can be added once-off to soil at high rate (higher than agronomic rates) to improve its chemical and physical characteristics to enable it to sustain vegetation. In some instances once-off application may not be enough to improve the soil's capacity to sustain vegetative growth and additional application may be required.

The negative environmental effects on the receiving environment after once-off high rate sludge application will be not as much as continuous high rate sludge application. A decision had to be made on how many applications will still classify as once-off application. It was decided that the impact of the nitrate and the metals in the sludge on the soil, groundwater and surface water have to be mitigated and managed strictly if it is applied more than 3 times on the same piece of land in a 5-year period. Therefore, if sludge is added to the same piece of land more than three times in 5 years (adopted from USEPA, forestry) at rates higher than agronomic rates and/or 10 ton/ha/y, it will classify as continuous sludge application.

Crop restrictions and public access restriction will be applicable to protect human health (especially at public access sites) and other management requirements should be implemented to protect the environment from adverse effects due to high rate sludge applications. These restrictions are detailed in Section 4.5 and the management requirements in Section 4.6 of this document.

<u>Mine rehabilitation</u>

Although mine rehabilitation with sludge application to establish vegetation can be regarded as once-off high rate sludge application there are certain specific considerations for mine rehabilitation that are different from that of other beneficial uses, including acid mine drainage and high baseline metal concentrations in the tailings or soil to be rehabilitated.

The core economy of South Africa has developed around the mining industry but the finite quantity of an ore body places a limit on the life of a mine. As the viability of mines begins to decline, mine closure becomes more and more a reality, as do the liabilities associated with mine closure. One of the liabilities is the rehabilitation of areas disturbed by mining or associated activities. Regulatory standards and guidelines for the rehabilitation of tailings dams are becoming increasingly prescriptive as regards procedural and technical requirements. Sustainability is a closure requirement, however, no guidelines for the assessment of the sustainability and/or rehabilitation success are provided by mining legislation in South Africa. When in contact with oxygen and water, the reactive sulphides in tailings and waste rock oxidize and generate an acidic leachate that can carry heavy metals and dissolved salt. Acid mine drainage (AMD) and the management of acid-generating tailings and waste rock represent the largest environmental liability with regard to mine rehabilitation. Tailings vary greatly in their physical and chemical properties and are usually difficult to stabilise and to vegetate. Therefore, there are no common standard procedures to rehabilitate them.

The best cover for tailings and waste disposal sites, if possible, is a self-sustaining vegetative cover. Due to the high probability of the presence of contaminants, most tailings will require either physical changes or chemical changes or both in order to sustain a satisfactory plant growth. The physical properties of the material to be rehabilitated have to be determined, including concentrations of contaminating plant toxins, pH and salinity. If these levels are unsuitable, no matter how much fertiliser is applied, little plant growth will occur.

The generation and management of AMD, resulting in low pH values is the single biggest concern during mine rehabilitation. There are a limited number of plants that will survive in a soil that has pH 4.5 or less. It is therefore far better to attempt to raise the pH of the soil to above 4.5 and thus enable the selection of many more species for revegetation. The most cost effective method for raising the pH is by the use of lime. The acid to base condition of the tailings will determine the amount of lime required. Another common problem is the low organic carbon content of tailings material. The addition of organic materials will improve the soil texture and the structure of the tailings, and sub-surface aeration and moisture infiltration and retention properties are also increased. With the addition of organic material, micro-organisms and bacteria are introduced too (UNEP/WHO, 1998).

Although the principal nutrients are nitrogen, phosphorous and potassium; sulphur, calcium and magnesium commonly occur with them. There is also a need for minor or trace elements in small quantities, these elements can be very toxic if applied too extensively, or if the pH is either too high or too low. Of the three major nutrients nitrogen is the most important to successful plant propagation. The most beneficial fertilisers are organic fertilisers which include sewage sludge, garden mulch, crop mulch, manure and wood chips.

The principal purpose of capping and vegetation of tailings is to prevent access of air and water, which lead to the generation of toxic leachate. It is necessary to ensure that the cap is sufficiently thick so that the root system that may develop does not reduce the impermeability of the cap, thus destroying the purpose of the capping. Although capping is site-specific, depending on the availability of materials, a common example of multiple layer impermeable capping is (UNEP/WHO, 1998):

- Reshaping of the surface to provide controlled drainage away from the centre toward the periphery of the dam. This would involve contouring and gently inclined outward dipping slopes.

- A layer of compacted clay or similar impermeable material should be laid over the tailings to provide a surface for free drainage. The thickness of this clay layer should be from 0.75 metres to 1.0 metres thick.

- Overlaying this is a free draining rock layer to provide positive drainage away from the centre of the structure. Generally this layer is composed of course grained material which has good porosity and permeability, and should be from 0.25 meters to 0.5 meters thick

- Overlying this free draining material, a filter cloth should be laid to stop the infiltration of fine material which would ultimately clog the free draining horizon

- This filter cloth is overlain by subsoil and then topsoil, if available, and vegetation.

- Ideally the whole structure should be at least 2 metres thick.

1.3.2 Continuous high rate sludge application to land

Sludge is not only applied to the soil to increase its fertility and physical soil properties, but also as fertilizer to sustain vegetation at rates higher than agronomic rates (more nutrients than is needed by the crop). Sludge can either be applied in liquid or dewatered form. This beneficial use option can include, but is not limited to:

- Continuous application of sludge in natural forests and plantations
- Use of sludge as growth medium for plants, flowers and seedlings
- Cultivation of grain and fruit trees
- Cultivation of industrial crops (cotton, tobacco)
- Instant lawn cultivation

Continuous high rate sludge application to land is essentially the same as dedicated land disposal (DLD) except that some of the nutrients in the sludge are taken up by the crop. However, the same pollution potential exists as in case of DLD and should therefore be managed. Crop restrictions and public access restriction will be applicable to protect human health and other management requirements should be implemented to protect the environment from adverse effects due to continuous high rate sludge applications. These restrictions are detailed in Section 4.5 and the management requirements in Section 4.6 of this document.

1.3.3 Use of sludge as landfill cover

Cover material is used in various applications on landfills at different stages in the operation life. Landfills operated as sanitary landfills use cover material to cover waste at the end of each working day. Once the landfill operational life is completed, a cover or capping system is placed to limit moisture coming into contact with the waste and to manage gas emissions (Crawford and Smith, 1985). At times, sections of the landfill that have reached the final waste volume are covered with an intermediate cover until the final cover is constructed.

Landfill final covers and caps are designed to isolate waste from the environment and are used to manage water ingress into the landfill. Various cover configurations are used, and the degree to which water is excluded from the landfill impacts on the rate of degradation and the quality and volume of landfill emissions (Ham and Barlaz, 1987). In addition, the effectiveness of the landfill gas extraction system depends on the extent to which air ingress is limited by the capping system (Shamrock et al., 2006).

Intermediate covers may be a thick layer (300 mm) of soil placed over sections of waste until such time as the final cover is constructed or if no further waste is to be deposited in an area for some time. An advantage of placing an intermediate capping layer and only installing the final capping system after a while is that the section of waste will undergo decay and settlement in the interim, and the final cap is then not subjected to extensive settlement. Daily cover layers are approximately 150 mm thick, help to control odours and ensure that waste is not exposed to precipitation, wind or other vectors.

Sludge has possible benefits when used as part of daily, intermediate and final covers. The properties that provide these potential benefits are the high nutrient concentrations and moisture retention capacity of dewatered and composted sewage sludge. These are, however, offset by the presence of pathogens and metals derived from wastewater treatment. Wastewater sludge, with a solids content of 50% or higher, looks and functions much like soil and will increase the water holding capacity of the final cover of the landfill facility and has high odour absorbing abilities. Where sludge quality is less acceptable, the final product may be mixed with soil for use as a daily landfill cover and as the final capping material for a landfill. The beneficial use of sludge as landfill cover must be balanced against human health and environmental limitations.

2 APPROACH AND METHODOLOGY

Part 1 gives the reader background on the reason and motivation for the development of Volume 4 as well as a short summary of the approach followed to develop Volume 4. The approach and methodology are discussed in detail in the sections that follow.

2.1 Approach

The Guidelines is based on the following information:

- Local and international research findings
- International guidelines and legislative trends
- The results of risk assessments
- Practical considerations

The US EPA followed a risk assessment protocol to develop the USEPA 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 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 that 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.

It was decided by the project team and the Reference Group that this was the best way to develop guidelines to protect human health as well as the environment. Receptors could be protected against constituents of concern in the sludge by:

- Removing the constituents of concern from the sludge through a treatment process, or
- Placing a barrier between the receptor and the sludge (see Figure 2.a).

2.2 Methodology

Data compiled by Snyman *et al*. (2004) on the pathogen and metal content of South African sludge as well as international data on the different properties of wastewater sludge were sourced to give an indication of the constituents of concern that may be present in the sludge. Receptors were identified which might be impacted by the beneficial use of sludge on land. 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. The risk assessment was used to identify possible mitigating factors (barriers) where high risks were identified.

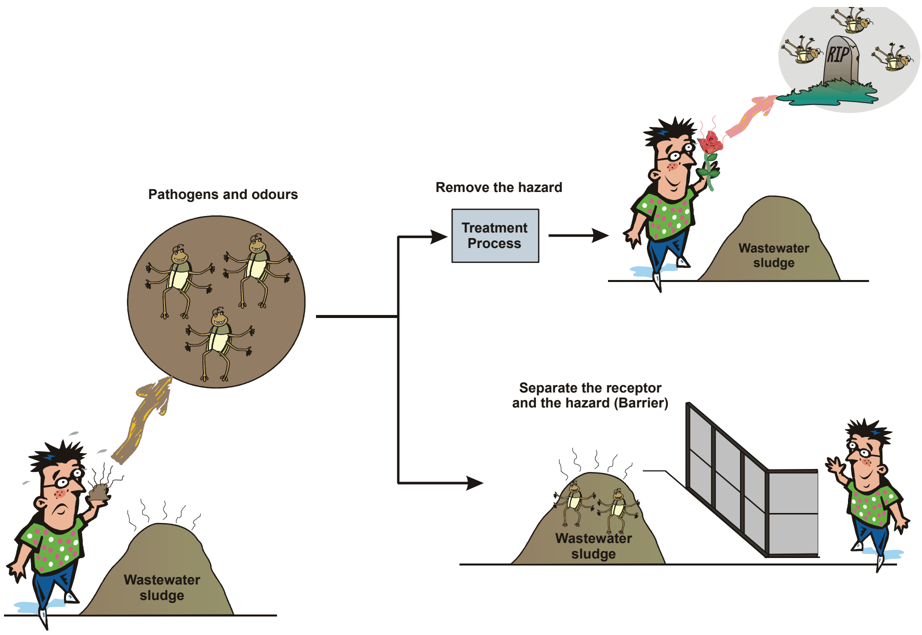

Figure 2.a: Visual representation of ways to protect receptors against potential harmful constituents in sludge

The risk assessment included the following steps:

- Source characterization
- Receptor identification
- Pathway identification between source and receptor
- Population of risk ranking matrix to identify pathways with high risk to the receptors
- Identify mitigating factors

2.3 Source characterisation

The following characteristics of the sludge were considered:

- Microbiological – Pathogens, disease causing issues
- Stability – Odours, vector attraction, moisture content, pH
- Metals – Potentially harmful metals, Cd, As, Cr, etc.
- Nutrients – N, P
- Organic pollutants – Pesticides, PAH, etc.
- Other – management issues

2.4 Receptors

The following eleven receptors were identified that could be impacted by high rate land application of sludge.

2.4.1 Workers

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

2.4.2 General public

The general public can either directly or indirectly be exposed to sludge. Direct exposure includes the members of public present at or near the land application sites where the sludge are applied. They may either be in direct contact with the sludge during application and/or inhale air-borne dust and volatile pollutants during land application.

The general public can also be indirectly exposed through:

- ingesting plants grown on application sites,
- ingesting meat of animals that grazed on application sites,
- drinking surface and/or groundwater impacted by sludge application,
- eating fish from impacted surface water and
- direct contact with surface and groundwater impacted by sludge during and after application are also included as indirect contact.

2.4.3 Soil

The effects of sludge application on soil have been studied extensively nationally and internationally. All studies indicated an increase in soil metal and P content with sludge application (Kabata-Pendias & Pendias, 2001; Adriano, 2003; Herselman *et al*., 2005). During high rate sludge application to land, the soil is the receptor which will be most severely impacted.

2.4.4 Crops

Crops grown on application sites may have elevated metal concentrations and may be impacted by the pathogens and organic pollutants in the sludge as well.

2.4.5 Vegetation

Constituents in the sludge, especially phytotoxic elements, may have negative effects on natural vegetation.

2.4.6 Air

Air quality could be affected by air-borne pollutants in the sludge as well as odours.

2.4.7 Surface water

The chemical quality of surface water bodies in close proximity to application sites may be impacted negatively as a result of run-off after sludge application or due to direct run-off from sludge.

2.4.8 Groundwater

Constituents of concern in sludge could migrate through the soil and negatively impact the groundwater resource. Research conducted by Herselman *et al*. (2005) indicated that leaching of metals after several years of application may impact on the groundwater. The N content of sludge poses a serious threat to groundwater resources due to its mobility in the soil profile.

2.4.9 Marine environment

There are possibilities, albeit relatively remote, of indirect effects on the marine environment arising from sludge application sites, or handling facilities, that are located in close proximity to the coast or within coastal river catchments. Effects might be induced through atmospheric transfer, direct surface water run-off or groundwater contamination.

2.4.10 Grazing animals

Grazing animals can be impacted directly through ingesting sludge and soil at application sites or indirectly through ingesting vegetation at these sites as well as inhalation of air-borne dust and pollutants. Grazing animals can also be affected by impacted surface and groundwater.

2.4.11 Fauna

Similarly to grazing animals, natural fauna can also be impacted through direct ingestion of sludge and soil at application sites or through ingesting vegetation grown on these sites and inhalation of air-borne dust and pollutants. The natural fauna can also be affected by impacted surface and groundwater.

2.5 Pathways

The identified receptors may be impacted by sludge application through various pathways. Table 2.a show the pathways that were considered for the risk matrix (total of 67). Some of these pathways have multiple barriers to cross (3 receptors before the final receptor) and the negative impact to the final receptors may be insignificant. An example is the ingestion of meat of animals that grazed on disposal sites by the general public: Sludge → Soil → Plant → Animal → Human. The negative effect of the sludge would be on the plant (if phytotoxic) or on the animal (zootoxic) and would most probably not reach the human receptor.

Table 2.a: Exposure pathways considered during the risk assessment

Receptors	Possible pathways
Workers	Sludge → Dermal absorption of toxic constituents
	Sludge → Air → Human (inhalation of volatile pollutants)
	Sludge → Air → Human (inhalation of incinerator emissions)
	Sludge → Ingestion of toxic constituents
	Sludge → Soil → Air → Human
	Sludge → Vector → Human
General population	Sludge → Dermal absorption of toxic constituents
	Sludge → Ingestion of toxic constituents
	Sludge → Air → Human (inhalation of volatile pollutants)
	Sludge → Air → Human (inhalation of incinerator emissions)
	Sludge → Soil → Plant → Human
	Sludge → Soil → Plant → Animal → Human

	Possible pathways
	Sludge → Soil → Surface water → Human
	Sludge → Soil → Surface water → Fish → Human
	Sludge → Marine environment → Biota → Human
	Sludge → Soil → Surface water → Human
	Sludge → Soil → Groundwater → Human (ingestion)
	Sludge → Soil → Groundwater → Human (direct contact)
	Sludge → Soil → Human
	Sludge → Soil → Air → Human
	Sludge → Animal → Human
	Sludge → Vector → Human
Soil/sediments	Sludge → Soil physical properties
	Sludge → Soil chemical and fertility
	Sludge → Soil microbiological characteristics
	Sludge → Surface water → Sediment (estuaries and rivers)
	Sludge → Water Column → Sediment
	Sludge → Surface water → Sediment (wetlands)
Crops	Sludge → Soil → Commercial crops (yield)
	Sludge → Soil → Grazing crops
	Sludge → Soil → Commercial crops (quality)
Vegetation	Sludge → Soil → Natural vegetation
Air	Sludge → Air (before application)
	Sludge → Air (during application)
	Sludge → Soil → Air
	Sludge → Air (emissions from incinerator)
Surface water	Sludge → Soil → Surface water
	Sludge → Surface water
	Sludge → Air → Surface water
	Sludge → Soil → Air → Surface water
	Sludge → Groundwater → Surface water
	Sludge → Birds → Surface water
	Sludge → Vector → Surface water
Groundwater	Sludge → Soil → Groundwater (leaching)
	Sludge → Groundwater
	Sludge → Soil → Groundwater (seepage into low lying areas)
	Sludge → Surface water → Groundwater
Marine receptor	Sludge → Water column
	Sludge → Surface water → Marine environment
	Sludge → Marine environment
	Sludge → Water column → Sea bed → Deposition centre
	Sludge → Air → Marine environment
Grazing animals	Sludge → Soil → Plant → Animal
	Sludge → Soil → Animal (ingestion of soil)
	Sludge → Soil → Surface water → Animal

	Possible pathways						
	Sludge	→	Soil	→	Groundwater	→	Animal
	Sludge	→	Soil	→	Animal (inhalation of volatile pollutants)		
	Sludge	→	Animal				
	Sludge	→	Plant	→	Animal		
	Sludge	→	Vector	→	Animal		
Fauna	Sludge	→	Soil	→	Plant	→	Animal
	Sludge	→	Soil	→	Animal (ingestion of soil)		
	Sludge	→	Soil	→	Surface water	→	Animal
	Sludge	→	Soil	→	Groundwater	→	Animal
	Sludge	→	Soil	→	Animal (inhalation of volatile pollutants)		
	Sludge	→	Animal				
	Sludge	→	Surface water	→	Aquatic fauna		

2.6 Population of risk ranking matrix

A risk ranking matrix was developed to systematically evaluate the significance of different source-receptor pathways and identify matters that will need to be managed through the guidelines. 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 sludge disposal and eliminates issues that are insignificant.

The risk ranking matrix (Figure 2.b) is based on:

- Consequence – the effect that the source may have for a given receptor. The consequence may vary from very severe (severe negative health condition to multiple parties requiring hospitalisation of the human receptor or permanent impairment of groundwater resource quality) to neutral (no impact of source on human receptor or groundwater) (Figure 2.c).
- Probability/frequency that a specific consequence will occur, varying from frequent (1:10 events) to highly unlikely (1:1 000 000 events) (Figure 2.b).

The consequence and probability should be determined for each pathway that may impact a receptor (see Table 2.a). The risk ranking matrix was populated for each of the receptors and the pathways, concentrating on the information that is available on the source (sludge). A separate matrix was developed for each of the beneficial uses considered in Volume 4 (Appendix 1). Mitigating factors have been identified for high risk situations. The outcome of the risk ranking and the mitigating factors will be discussed for each receptor and sludge disposal option in the sections that follow.

2.6.1 Once-off high rate sludge application to land

<u>Workers</u>

The impact that wastewater sludge have on workers at the WWTP is not a sludge use issue and it was decided to exclude the workers from the risk ranking matrix.

General public

Public health would be affected mainly by the microbiological and organic pollutant content of the sludge (Appendix 1). However, metals may also accumulate in crops grown on these sites and have adverse impact on public health. Most of the pathways through which the general public could be impacted have multiple barriers before the pollutant will get into contact with the human receptor. In most cases the human receptor is the fourth or fifth receptor down the line.

In general, the pathogens and organic pollutants present in the sludge are the constituents of concern to public health, especially with ingestion of crops grown on this land. Both these constituents could cause isolated negative health conditions and the probability would be low (1:10 000) after once-off high rate application with a risk rating of 12 (low to medium risk). Other pathways that may lead to negative effects on the general public are ingestion of surface and groundwater contaminated with pathogens present in the sludge. The risk ratings for these pathways are low in the case of once-off high rate sludge application and are also multiple barrier pathways. The odour and vector attraction characteristics of sludge could also impact on the general public (risk rating = 9).

The following management requirements are recommended to protect the general public against the potential negative impacts of once-off high rate sludge application:

- Access restrictions – at public access sites where Microbiological class B and C sludge is applied, access should be restricted for at least 30 days after sludge application and no access should be allowed unless sludge is incorporated into the soil and/or covered by vegetation. This management practice minimises public contact with pollutants, especially pathogens that may be present in the sludge.
- Crop restrictions are implemented to prevent food-chain contamination. The following crop restrictions apply:
    - Fruit and vegetables with harvested / edible parts that touch the soil/sludge mixture or are within the soil/sludge mixture **may not be cultivated** on beneficial use sites due to pathogens and metals that will be added with high rate sludge application
    - **No edible crops** may be cultivated on soils with metal concentrations above the total maximum threshold (TMT) due to the potential build-up of metals in the crop that can be ingested by.
    - Edible crops with harvested / edible parts that do not touch the soil/sludge mixture (grain and fruit trees) may be grown on land application sites but should not be harvested until 30 days after the last sludge application (Microbiological class B) or 90 days after the last sludge application (Microbiological class C).
    - Industrial crops include all non-edible crops that are cultivated on-site, including cotton, tobacco, trees (forestry), seedlings (flowers and trees) and grass, etc. These crops may be cultivated on land application sites but may not be harvested until 30 days after the last sludge application.

	1	2	3	4	5	6		Consequence Class
5	5	10	15	20	25	30	5	Very Severe
4	4	8	12	16	20	24	4	Severe
3	3	6	9	12	15	18	3	Moderate
2	2	4	6	8	10	12	2	Low
1	1	2	3	4	5	6	1	Neutral
	1	2	3	4	5	6		

	1	2	3	4	5	6
Frequency Class	Highly Unlikely	Rare	Low Likelihood	Possible/ Probable	Can Occur	Frequent
Probability	Not Expected to Happen	Not During Life	Could Happen	Possibly Will Happen	Could Happen Regularly	Expected to Occur
Frequency (Lifetime)	1:1 000 000	1:100 000	1:10 000	1:1 000	1:100	1:10
	Probability					

KEY

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

Figure 2.b: Risk ranking matrix and frequency class

Consequence Class	Receptors				
	Workers	General population	Soil	Vegetation	Air
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 volatile pollutants/emmisions on a regional scale
Severe	Isolated negative health conditions requiring hospitalisation	Isolated negative health conditions requiring hospitalisation	Extensive intervention and remediation required	Severe phytotoxic effects and loss of biodiversity	Toxic volatile pollutants and/or emmissions impacting on the surrounding community
Moderate	Recoverable condition	Recoverable condition	Intervention required to rehabilitate soil	Deterioration in yield or biodiversity	Volatile pollutants / emmissions and/or odour nuisance confined to the working area
Low	Self treatable conditions	Self treatable conditions	Degradation impacts are manageable	Some intervention required to maintain yield or biodiversity	Sporadic nuisance
Neutral	No impact	No impact	No impact	No impact	No impact

Consequence Class	Receptors			
	Surface water	Groundwater	Grazing animals	Fauna
Very Severe	Acute or Chronic effects at regional scale	Acute or Chronic effects at regional scale	Animal deaths	Animal deaths and loss of biodiversity
Severe	Long term impairment of fitness for use	Long term impairment of fitness for use	Severe toxic effects observed	Severe toxic effects observed
Moderate	Recoverable impacts to fitness for use	Recoverable impacts to fitness for use	Some intervention required to maintain viable animals	Biodiversity will recover after closure
Low	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

Figure 2.c: Consequences for each receptor

- Restrictions on grazing animals – The restrictions on grazing animals are implemented to protect the animals from the pathogens present in the sludge. The following restrictions apply:
    - Animals shall not be allowed to graze on land until 30 days after the last sludge application where Microbiological class B sludge is applied.
    - Animals shall not be grazed on land until 90 days after the last sludge application where Microbiological class C sludge is applied.
- Buffer zones –
    - Depth to aquifer – >5 m (to protect groundwater)
    - Distance from borehole – >200
    - Distance from surface water bodies: Above the 1:100 year flood line
    - Distance from dwellings – >500 m (to protect public from odours and vectors)

Soil and sediment

Soil would be the most vulnerable receptor during high rate sludge application since it's the first line of defence. Due to the high application rates of sludge, the metals and organic pollutants present in sludge may cause soil chemical degradation. However, due to once-off application the degradation impacts are manageable and the risk ranking is 8 (no risk).

The implementation of total maximum thresholds (TMT) and maximum permissible levels (MPL) for metals is proposed for soils receiving sludge at high application rates. These metal limits will ensure that the metal concentrations of the soils do not increase to levels where the attenuation capacity of the soil is exceeded and leaching to groundwater will increase. The microbiological, nutrient and metal contents of sludge may also have an effect on sediments in estuaries and rivers, marine sediments and on wetlands due to contaminations of the surface water which feeds into these systems but it is highly unlikely to occur after once-off high rate sludge application. However, the implementation of a buffer zone between the sludge application site and surface water bodies is recommended (>200 m) to mitigate surface water contamination which could result in sediment contamination. It is also recommended that the application site should be above the 1:100 year flood line.

Crops

The crop yield after high rate sludge application will increase due to the presence of nutrients and micro elements in the sludge, but to quality of the crop may be negatively influenced by the constituents (pathogens and metals) present in the sludge. The probability of severe negative effects after once-off high rate application is low and the risk rating is 9 (no risk).

Vegetation

The natural vegetation at application sites is vulnerable to several of the constituents present in the sludge (nutrients, trace elements, metals). Plants are in direct contact with the sludge and the sludge/soil mixture from where available elements are absorbed by the plant roots. The metal content of the sludge could have severe phytotoxic effects on natural vegetation and may cause loss of biodiversity but the probability is low after once-off high rate application 1:10 000 (risk rating 9 – no risk).

Air quality

Sludge application will affect air quality before, during and after application. The odour associated with sludge application will regularly (1:100) have a moderate influence on air quality and will impact the surrounding community (risk rating 12 – low to medium risk). The pathogens and volatile organic pollutants present in the sludge may have a moderate consequence (confined to the working area or areas down-wind from disposal site) with a 1:1000 probability (risk rating 12 – low to medium risk).

The following management requirements are recommended to mitigate the air quality problem:

- Apply vector attraction reduction options – use only stabilised sludge at public contact sites, add lime and/or cover/incorporate sludge
- Buffer zones – Distance from dwellings – >500 m (to protect public from odours, vectors and volatile pollutants)
- Areas immediately upwind of a residential area in the prevailing wind direction(s) should not be considered for sludge application except were Stability class 1 sludge is applied.

Surface water

The impact on surface water sources in close proximity to sludge application sites could be low (sludge → soil → surface water) to moderate (sludge → surface water) due to pathogens, metals, nutrients and organic pollutants present in the sludge. The probability of surface water contamination is low with a risk rating 6-9; no risk). However, to ensure surface water protection, the following mitigating factors are recommended:

- Buffer zones –

  Distance from surface water/borehole – >200
- Bund walls or cut-off trenches should be erected around/down slope of application sites where run-off may occur. Run-off should be collected, contained and treated/re-cycled/discharged depending on the water quality. If water is discharged it must comply with the water use licence conditions or the provisions of Government Notice No 339 of 26 March 2004, Schedule 3.

Groundwater

Groundwater is most vulnerable to the nutrient concentration (especially N) of the sludge. Nitrogen leaches readily through the soil profile and could have severe consequences for groundwater (long term impairment of fitness for use of the groundwater resource) but the probability after once-off high rate application is low (1:10 000). The impact of metals on groundwater may also have severe consequences but the probability is lower (1:100 000) due to the metals being immobile in the soil profile. The probability of groundwater contamination with metals will increase when:

- soil pH is lower than 6.5
- soil have low clay content (<20%)

The following management requirements are recommended to mitigate groundwater contamination:

- Buffer zone –
  - Distance from borehole – >200
  - Depth to aquifer – >5 m
  - Might not be allowed in subterranean government water control areas as set out in Table 4 of Schedule 4 of Government Notice 399 of 26 March 2004.

Marine environment

It was assumed that existing buffer zones between application sites and the marine environment would adequately protect the marine receptor, especially in case of once-off high rate sludge application.

Grazing animals

Grazing animals ingesting soil or the soil/sludge mixture on sites that received sludge with high pathogen and/or metal content could cause toxic effects to the animal, but the probability is low after once-off high rate application (low to medium risk). There is a low likelihood of adverse effects on grazing animals ingesting crops cultivated on application sites or the ingestion of natural vegetation growing on these sites due to several barriers in pathway.

The following mitigating factors are recommended for grazing animals:

- Animals shall not be allowed to graze on land until 30 days after the last sludge application where Microbiological class B sludge is applied.
- Animals shall not be grazed on land until 90 days after the last sludge application where Microbiological class C sludge is applied.
- Animals should not be allowed to graze on land where Pollutant class b sludge is applied if the sludge is not incorporated into the soil

Fauna

The pathways through which fauna are impacted by sludge have multiple barriers with fauna being the third or fourth receptor down the line. The constituents in sludge that may affect fauna include pathogens, metals and organic pollutants. The consequence of these constituents on fauna are low (some intervention required to maintain yield or biodiversity) and the risk rating is 6-8 (no risk).

2.6.2 Continuous high rate sludge application to land

General public

The general public in close proximity to sites receiving sludge continuously at high rates would be most vulnerable to the microbiological and organic pollutant content of the sludge but would also be affected by the stability of the sludge (odours and vectors). However, most of the pathways have multiple barriers with the human receptor being the fourth or fifth receptor down the line.

In general, the pathogens and organic pollutants present in the sludge are the constituents of concern to public health. Both these constituents could cause recoverable conditions but the probability would be low (1:10 000) with a risk rating of 9 (No risk). The most critical pathways are ingestion of surface and groundwater contaminated with pathogens present in the sludge. Both these pathways have a risk rating of 12 (low to medium risk) but are also multiple barrier pathways. The odour and vector attraction characteristics of sludge could also impact on the general public (risk rating = 12).

The following management requirements are recommended as to protect the general public against the potential negative impacts of sludge:

- Access restrictions – at public contact sites access should be restricted for at least 30 days after sludge application and no access should be allowed unless sludge is incorporated into the soil and/or covered by vegetation. This management practice minimises public contact with pollutants, including pathogens that may be present in the sludge.
- Crop restrictions are implemented to prevent food-chain contamination. The following crop restrictions apply:
  - Fruit and vegetables with harvested / edible parts that touch the soil/sludge mixture or are within the soil/sludge mixture **may not be cultivated** on beneficial use sites due to pathogens and metals that will be added with high rate sludge application
  - **No edible crops** may be cultivated on soils with metal concentrations above the total maximum threshold (TMT).
  - Edible crops with harvested / edible parts that do not touch the soil/sludge mixture (grain and fruit trees) may be grown on land application sites but should not be harvested until 30 days after the last sludge application (Microbiological class B) or 90 days after the last sludge application (Microbiological class C)

- Industrial crops include all non-edible crops that are cultivated on-site, including cotton, tobacco, trees (forestry), seedlings (flowers and trees) and grass, etc. These crops may be cultivated on land application sites but may not be harvested until 30 days after the last sludge application.

- Restrictions on grazing animals – The restrictions on grazing animals are implemented to protect the animals from the pathogens present in the sludge and therefore protecting the public ingesting the animal. The following restrictions apply:
  - Animals shall not be allowed to graze on land until 30 days after the last sludge application where Microbiological class B sludge is applied.
  - Animals shall not be grazed on land until 90 days after the last sludge application where Microbiological class C sludge is applied.
- Buffer zones –
  - Depth to aquifer – >5 m (to protect groundwater)
  - Distance from borehole – >200
  - Distance from surface water bodies: Above the 1:100 year flood line
  - Distance from dwellings – >500 m (to protect public from odours and vectors)

Soil and sediment

Soil would be the most vulnerable receptor during continuous high rate sludge application since it's the first line of defence. Due to the continuous high application rates of sludge, the metals and organic pollutants present in sludge will cause soil chemical degradation. Intervention would be required to remediate the soil and the risk ranking is 15 (high risk). These soils could not be considered for normal agricultural or residential use after continuous high rate application site due to the elevated concentrations of metals, pathogens and organic pollutants that may be present in the soil.

The implementation of total maximum thresholds (TMT) and maximum permissible levels (MPL) for metals is proposed for soils receiving sludge at high application rates. These limits will ensure that the metal concentrations of the soils do not increase to levels where the attenuation capacity of the soil is exceeded and leaching to groundwater will increase. Frequent soil quality monitoring is also recommended to serve as an early warning system for mobility of constituents in the soil profile. Monitoring should be more frequent for sites that receive liquid sludge (especially anaerobically digested sludge) due to the mobility of metals in these sludge types.

Areas characterised by shallow bedrock with little soil cover and areas overlying or adjacent to important or potentially important aquifers should be avoided. Dolomitic areas should also be avoided.

The microbiological, nutrient and metal contents of sludge may also have an effect on sediments in estuaries and rivers, marine sediments and on wetlands due to contamination of the surface and groundwater which feeds into these systems. The sediments may need intervention to remediate but the probability is low (1:10 000). Therefore the risk ranking is 9 (low risk). The implementation of a buffer zone between the sludge application site and surface water bodies is recommended (>200 m) to mitigate surface water contamination which could result in sediment contamination.

Crops

The crop yield after continuous high rate sludge application will increase due to the presence of nutrients and micro elements in the sludge, but to quality of the crop may be negatively influenced by the constituents (pathogens and metals) present in the sludge. The probability of severe negative effects after continuous high rate application is high (1:100) and the risk rating is 15 (high risk). The following restrictions and requirements are recommended:

- Sludge quality should be specified for sensitive crops. This will also protect the public and grazing animals consuming the crop
- The type of crop should be selected to exclude plants with a high metal uptake if the crop is destined for consumption and include hyper accumulators where ingestion by humans and animals will not occur.

Vegetation

The natural vegetation at sites with continuous high rate sludge application is vulnerable to several of the constituents present in the sludge (nutrients, trace elements, metals). Plants are in direct contact with the sludge and the sludge/soil mixture from where available elements are absorbed by the plant roots. The metal content of the sludge could have severe phytotoxic effects on natural vegetation and may cause loss of biodiversity at a probability of 1:1000 (risk rating 16 – medium to high risk). Additional vegetation could be planted in cases of severe loss of vegetation. These plants should be selected for the specific conditions. Continuous high rate sludge application is not recommended on land where it could affect endangered plant species or its critical habitat.

Air

Continuous high rate sludge application will affect air quality before, during and after application. The odour associated with sludge will regularly (1:100) have a severe influence on air quality which will affect the surrounding community (risk rating 20 – high risk). The pathogens and volatile organic pollutants present in the sludge may have moderate consequences (confined to the working area or areas down-wind from disposal site) with a 1:1000 probability (risk rating 12 – low to medium risk).

The following management requirements are recommended to mitigate the air quality problem:

- Apply vector attraction reduction options – use only stabilised sludge at public contact sites, add lime and/or cover/incorporate sludge
- Buffer zones – Distance from dwellings – >500 m (to protect public from odours, vectors and volatile pollutants)

- Areas immediately upwind of a residential area in the prevailing wind direction(s) should not be considered for sludge application except were Stability class 1 sludge is applied.

Surface water

Surface water sources in close proximity to sludge application sites could be moderately (sludge → soil → surface water) to severely (sludge → surface water) impacted by the pathogens, metals, nutrients and organic pollutants present in the sludge. The probability of surface water contamination is 1:10 000 (risk rating 9- 12; low to medium risk). The nutrient present in the sludge may also affect the surface water via groundwater contamination (sludge → groundwater → surface water). The following mitigating factors are recommended to protect surface water from contamination:

- Buffer zones –
  - Distance from surface water/borehole – >200
  - Depth to aquifer – >5 m (to protect groundwater)
- Bund walls or cut-off trenches should be erected around/down slope of application sites. Run-off should be collected, contained and treated/re-cycled/discharged depending on the water quality.

Groundwater

Groundwater is most vulnerable to the nutrient concentration (especially N) of the sludge. Nitrogen leaches readily through the soil profile and could have severe consequences for groundwater (long term impairment of fitness for use of the groundwater resource) with a high probability (1:100), especially at continuous high rate application. The probability for groundwater contamination will be even higher for liquid sludge application.

The impact of metals on groundwater may also have severe consequences but the probability is lower (1:10 000) due to the metals being immobile in the soil profile. The probability of groundwater contamination with metals will increase when:

- soil pH is lower than 6.5
- soil have low clay content (<20%)
- liquid sludge are disposed
- anaerobically digested sludge is disposed, due to the high soluble metal fraction present in this type of sludge

The following management requirements are recommended to mitigate groundwater contamination:

- Might not be allowed in subterranean government water control areas as set out in Table 4 of Schedule 4 of Government Notice 399 of 26 March 2004
- Buffer zone –
  - Distance from borehole – >400

- Depth to aquifer – >5 m

- Soil MPL should not be exceeded
- Strict and frequent groundwater monitoring requirements to serve as early warning system

Marine environment

It was assumed that these sites would not be close to the marine environment and that the recommended buffer zones will adequately protect the marine environment. Site specific investigations are recommended for sites that may have a negative impact on the marine environment.

Grazing animals

Grazing animals ingesting soil or the soil/sludge mixture on sites that received sludge with high pathogen and/or metal content could cause toxic effects to the animal, and the probability is high after once-off high rate application (medium to high risk). There is a low likelihood of adverse effects on grazing animals ingesting crops cultivated on application sites or the ingestion of natural vegetation growing on these sites due to several barriers in the pathway.

The following mitigating factors are recommended for grazing animals:

- Animals shall not be allowed to graze on land until 30 days after the last sludge application where Microbiological class B sludge is applied.
- Animals shall not be grazed on land until 90 days after the last sludge application where Microbiological class C sludge is applied.
- Animals should not be allowed to graze on land where Pollutant class b sludge is applied if the sludge is not incorporated into the soil

Fauna

The pathways through which fauna are impacted by sludge have multiple barriers with fauna being the third or fourth receptor down the line. The constituents in sludge that may affect fauna include pathogens, metals and organic pollutants. The consequence of these constituents on fauna are low (some intervention required to maintain yield or biodiversity) and, although the probability is 1:10 000, the risk rating is 8-10 (low risk). However, endangered species would have to be protected and therefore an EIA would be needed where sludge is applied at high rates.

2.6.3 Co-disposal on landfill

General public

The general public in close proximity to landfill sites would be most vulnerable to the microbiological and organic pollutant content of the sludge but would also be affected by the stability of the sludge (odours and vectors). However, most of the pathways have multiple barriers with the human receptor being the fourth or fifth receptor down the line.

In general, the pathogens and organic pollutants present in the sludge are the constituents of concern to public health. Both these constituents could cause recoverable conditions but the probability would be low (1:10 000) with a risk rating of 9 (No risk). The most critical pathways for the other disposal options are ingestion of surface and groundwater contaminated with pathogens present in the sludge. At landfill sites these pathways will be protected by adhering to the Minimum Requirements (Latest edition) and therefore would not be a critical pathway for the human receptor. The odour and vector attraction characteristics of sludge could also impact on the general public (risk rating = 12; low to medium risk).

The following management requirements are recommended as to protect the general public against the potential negative impacts of sludge:

- Access restrictions – Public access to landfill sites are restricted by the Minimum Requirements (Latest edition) and should be adhered to while the site is in operation and 3 years after closure. This management practice minimises public contact with pollutants, including pathogens that may be present in the sludge. It also keeps the public away from areas where there is the potential for methane gas explosions.
- Restrictions on crop production – the owner/operator should ensure that no edible, wild crops grow on the site that could serve as a food source to the general public.
- Buffer zones –
    - Depth to aquifer – >5 m (to protect groundwater)
    - Distance from surface water/borehole – >400 (to protect surface water)
    - Distance from dwellings – >500 m (to protect public from odours and vectors). Refer to the Minimum Requirements (Latest edition), because the buffer zones could be site specific depending on the class of landfill being considered.

<u>Soil and sediment</u>

It is assumed that the landfill owner/operator comply with the Minimum Requirements (Latest edition). Soil would be contaminated by constituents present in the sludge, but would not impact on other receptors in the receiving environment (i.e. surface and groundwater) due to management practices that should be implemented (liners and leachate collection).

The sediments in estuaries and rivers, marine sediments and wetlands are also protected by the Minimum Requirements (Latest edition) by the implementation of management systems to protect surface and groundwater.

Crops

It is assumed that the cultivation of agricultural crops is not allowed at landfill sites and therefore was not included for landfill sites. Preventative measures should be adopted if the land use after closure will include agricultural use or residential use. The quality of the material used as final cover should be evaluated to ensure no food chain contamination and that children ingesting the soil will not be adversely affected.

Vegetation

The natural vegetation at landfill sites is vulnerable to several of the constituents present in the sludge (nutrients, trace elements, metals) as well as constituents present in other disposed waste. Landfill sites should be considered as "sacrificial" land where biodiversity would be compromised. Landfill sites should not be situated near areas where it could affect endangered plant species or its critical habitat.

Air quality

The odour associated with sludge disposal will regularly (1:100) have a severe influence on air quality with will affect the surrounding community (risk rating 20 – high risk). The pathogens and volatile organic pollutants present in the sludge may have a moderate consequence (confined to the working area or areas down-wind from disposal site) with a 1:1000 probability (risk rating 12 – low to medium risk).

The following management requirements are recommended to mitigate the air quality problem:

- Apply vector attraction reduction options – add lime and composting of sludge before use
- Buffer zones – Distance from dwellings – >500 m (to protect public from odours, vectors and volatile pollutants). Although 500 m should be sufficient, the new Minimum Requirements (Latest edition) require that air quality modelling be conducted and based on the outcome of this, the buffer zone for the various impacts is determined.
- Areas immediately upwind of a residential area in the prevailing wind direction(s) should not be considered for landfill.

Surface water

It is assumed that the landfill owner/operator complies with the Minimum Requirements (Latest edition) and that all the necessary management systems to protect surface water are intact.

Groundwater

It is assumed that the landfill owner/operator complies with the Minimum Requirements (Latest edition) and that all the necessary management systems to protect groundwater are intact.

Marine environment

It was assumed that existing buffer zones between landfill sites and the marine environment would protect the marine receptor.

Grazing animals

It is assumed that no grazing animals will be allowed at landfill sites during operation. However, the end land use may include agricultural land or residential areas and it should be ensured that the quality of the final cover material should not have adverse effects on the environment and in this case, grazing animals. There is a low likelihood of adverse effects on grazing animals ingesting crops cultivated on application sites or the ingestion of natural vegetation growing on these sites due to several barriers in pathway.

The following mitigating factors are recommended for grazing animals after site closure:

- Animals shall not be allowed to graze on land until 30 days after the last sludge application where Microbiological class B sludge is applied.
- Animals shall not be grazed on land until 90 days after the last sludge application where Microbiological class C sludge is applied.
- Animals should not be allowed to graze on land where Pollutant class b sludge is applied if the sludge is not incorporated into the soil
- Animals should not be allowed to graze on land where the soil quality exceeds the MPL

Fauna

The pathways through which fauna are impacted by sludge have multiple barriers with fauna being the third or fourth receptor down the line. The constituents in sludge that may affect fauna include pathogens, metals and organic pollutants. The consequence of these constituents on fauna are low (some intervention required to maintain yield or biodiversity) and, although the probability is 1:1000, the risk rating is 6-8 (no risk). The EIA that would be necessary for landfill sites should include investigation on the impact of the use of sludge as final cover on natural fauna.

3 SLUDGE CLASSIFICATION FOR LAND APPLICATION

The sludge classification system remains the same as in the previous Volumes, consisting of a Microbiological class (A, B or C), Stability class (1, 2 or 3; based on the odour and vector attraction properties of the sludge) and a Pollutant class (a, b or c).

3.1 Microbiological class

The Microbiological class classification system of Volumes 1 and 2 were adopted for beneficial use of sludge as well (Table 3.a). Sludge producers should however be encouraged to increase the microbiological classification of their sludge.

3.2 Stability class

The same vector attraction reduction options apply as discussed in Volume 1 (Table 3.b). These vector attraction reduction criteria were adopted from the US EPA 503 Sludge rule (US EPA, 1993; US EPA 1994). These criteria (or very similar) have been adopted by many other countries including Australia.

3.3 Pollutant class

The Pollutant class determination of sludge in Volumes 1 and 2 was based on the total metal content (*aqua regia* digestion) of the sludge. Since the total metal content of sludge does not give an indication of the potential leachability of the metals in the sludge, it was recommended that the Pollutant class for disposal purposes (Volume 3) be based on the leachable metal fraction in the sludge as recommended by the Minimum Requirements (Latest edition). The Toxicity Characteristic Leaching Procedure (TCLP) was developed in the USA by the Environmental Protection Agency to measure a waste's leachability (quality of the leachate generated by the waste body) and hence the risk it poses to groundwater. It plays a major part in determining the Concentration Based Exemption Criteria used in the USA for the classification of wastes. In preference to this, South Africa has adopted the Expected Environmental Concentration (EEC), which is a method whereby the exposure of fauna to constituents of concern in the waste is estimated and quantified. The TCLP test can be used to support/affirm the EEC.

The procedure simulates the dissolving action of the organic acid leachate formed in a landfill where Hazardous Waste has been co-disposed with General Waste. It can be used to determine the mobility of organics and inorganics in liquid, solid and multiphase wastes including volatile and semi-volatile organic compounds. The procedure is based on the fact that different hazardous elements or compounds exhibit different solubility. It is important to note that that the mobility of a specific element will depend on its nature and composition. The procedure is therefore also particularly useful for evaluating the residues or products of wastes (Minimum Requirements, Latest edition).

For the beneficial use of sludge at high rate and continuous high rate application, it is recommended that the Pollutant class classification be based on the total metal content (*aqua regia*) of the sludge. The recommended Pollutant class classification for sludge destined for landfill cover should be based on the TCLP extraction. Table 3.c and Table 3.d indicate the recommended Pollutant class classification limits for sludge.

Table 3.a: Compliance and classification criteria for the Microbiological class

Microbiological class	Unrestricted use quality		General use quality		Limited use quality
	A		B		C
	Target value	Maximum permissible value	Target value	Maximum permissible value	
Faecal coliform (CFU/g_{dry})	< 1 000 (5 log reduction)	10 000 (4 log reduction)	< $1x10^6$ (2 log reduction)	$1x10^7$ (1 log reduction)	> $1x10^7$ (no reduction)
Helminth ova (Viable ova/g_{dry})	< 0.25 (or one ova/4g)	1	< 1	4	> 4
Compliance requirements					
Requirements for classification purposes (Minimum 3 samples)	All the samples submitted for classification purposes must comply with these requirements	Not applicable	Two of the three samples submitted for classification purposes must comply with these requirements	The sample that failed may not exceed the Minimum Permissible Value	Not applicable
Requirements for monitoring purposes	90% compliance	The 10% (maximum) of samples that exceed the Target Value, may not exceed the Maximum Permissible Value	90% compliance	The 10% (maximum) of samples that exceed the Target Value, may not exceed the Maximum Permissible Value	Not applicable

Table 3.b: Determination of the Stability class

Stability class	1	2	3
	Plan/design to comply with one of the options listed below on a 90 percentile basis.	Plan/design to comply with one of the options listed below on a 75 percentile basis.	No stabilisation or vector attraction reduction options required.
Vector attraction reduction options (Applicable to Stability class 1 and 2 only)			
Option 1	Reduce the mass of volatile solids by a minimum of 38 percent		
Option 2	Demonstrate vector attraction reduction with additional anaerobic digestion in a bench-scale unit		
Option 3	Demonstrate vector attraction reduction with additional aerobic digestion in a bench-scale unit		
Option 4	Meet a specific oxygen uptake rate for aerobically treated sludge		
Option 5	Use aerobic processes at a temperature greater than 40°C (average temperature 45°C) for 14 days or longer (eg during sludge composting)		
Option 6	Add alkaline material to raise the pH under specific conditions		
Option 7	Reduce moisture content of sludge that do not contain unstabilised solids (from treatment processes other than primary treatment) to at least 75 percent solids		
Option 8	Reduce moisture content of sludge with unstabilised solids to at least 90 percent solids		
Option 9	Inject sludge beneath the soil surface within a specified time, depending on the level of pathogen treatment		
Option 10	Incorporate sludge applied to or placed on the surface of the land within specified time periods after application to or placement on the surface of the land		

Sludge producers are encouraged to increase the sludge quality to protect the receiving environment during application. Sludge classified as Pollutant class a could be used beneficially on land and as cover material on landfill with minimal restrictions. Pollutant class b sludge could also be used beneficially, although the restrictions and requirements (especially for monitoring) will be more onerous. Where Pollutant class b sludge is considered for landfill cover the same restrictions will apply as for sludge co-disposal on landfill. This includes liming of the sludge (CaO) at a recommended dosage of 25 kg_{lime}/ton_{sludge}. The TCLP test should be repeated on the sludge after liming. If the new results indicate Pollutant class a sludge, the sludge could be used as landfill cover as normal Pollutant class a sludge. In cases where the analytical results after liming still indicate Pollutant class b sludge, the load principle should be applied where the maximum load for the application area is calculated based on the TCLP concentration of the constituents of concern and more stringent management requirements would apply. DWAF/DEAT need to be informed of the situation and the application site owner/operator should provide the authority with the analytical results.

Land application of Pollutant class c sludge would only be allowed with very strict restrictions and monitoring requirements. For the application of sludge as landfill cover specific liming tests are recommended to achieve at least a Pollutant class b classification before application will be allowed.

Table 3.c: Pollutant class classification for sludge destined for beneficial use on land

Aqua regia extractable metals (mg/kg)	Pollutant class		
	a	b	c
Arsenic (As)	<40	40 - 75	>75
Cadmium (Cd)	<40	40 - 85	>85
Chromium (Cr)	<1 200	1 200 - 3 000	>3 000
Copper (Cu)	<1 500	1 500 - 4 300	>4 300
Lead (Pb)	<300	300 - 840	>840
Mercury (Hg)	<15	15 - 55	>55
Nickel (Ni)	<420	420	>420
Zinc (Zn)	<2 800	2 800 - 7 500	>7 500

Note : A 90% compliance is required to comply with the requirements of a pollutant class. The compliance will therefore only be evident once 10 sample results are available.

Table 3.d: Pollutant class classification for sludge destined for landfill cover

TCLP extractable metals (mg/l)	Pollutant class		
	a	b	c
	<AE	≥AE and ≤ 10*AE	>10*AE
Arsenic (As)	<0.43	0.43 - 4.3	>4.3
Cadmium (Cd)	<0.031	0.031 - 0.31	>0.31
Chromium (Cr III))	<4.7	4.7 - 47	>47
Chromium (Cr VI)	<0.02	0.02 - 0.2	>0.2
Copper (Cu)	<0.1	0.1 - 1	>1
Lead (Pb)	<0.1	0.1 - 1	>1
Mercury (Hg)	<0.022	0.022 - 0.22	>0.22
Nickel (Ni)	<1.14	1.14 - 11.4	>11.4
Zinc (Zn)	<0.7	0.7 - 7	>7

4 RESTRICTIONS AND REQUIREMENTS FOR BENEFICIAL USE / LAND APPLICATION OF SLUDGE AT HIGH APPLICATION RATES

Several general restrictions and requirements are applicable to all beneficial use options considered in Volume 4 of the Sludge Guidelines. These restrictions and requirements will be discussed in the sections that follow.

4.1 Legal requirements

Beneficial use of sludge on land can be either on-site (within the boundaries of the WWTP) or off-site (outside the boundaries of the WWTP). The authorisation/s required for the beneficial use of sludge is/are as follows:

- **On-site land application of sludge** – Water Use Authorisation in terms of Section 40 of the National Water Act (Act No. 36 of 1998). On site land application of sludge is usually included in the water use authorisation for the WWTP, and does not necessarily require a separate authorisation. The authorisation may be in the form of a water use licence, general authorisation or an existing lawful use.

- **Off-site land application of liquid sludge** – Disposal site Permit in terms of Section 20 of the Environment Conservation Act (Act No. 73 of 1989) (Exception: Water Use Authorisation in terms of Section 40 of the National Water Act (Act No. 36 of 1998) for irrigation of liquid sludge). Application of sludge on land will require a disposal site permit, however where liquid sludge is **irrigated** onto land a water use authorisation is required.

- **Off-site land application of dewatered sludge** – Disposal site Permit in terms of Section 20 of the Environment Conservation Act (Act No. 73 of 1989)

- **Use as landfill cover** – Disposal site Permit in terms of Section 20 of the Environment Conservation Act (Act No. 73 of 1989). Authorisation for use of sludge as landfill cover material is included in the permit for the landfill site and does not require a separate authorisation.

A summary of the relevant regulatory requirements applicable to the on-site and off-site land application of sludge are listed in Table 4.a. While the regulatory instrument may be either a waste permit or water use authorisation, DWAF or DEAT as the supporting authority to the lead authority will however still have to approve the activity and/or impacts before either authorisation is issued. For example, DWAF may require a positive Record of Decision (RoD) for an EIA from DEAT in order to issue a water use licence. Similarly DEAT will require a RoD from DWAF to approve water use impact aspects before a waste permit is issued. The different departments have committed to co-operative governance and to improve inter-departmental communication, which should simplify the regulatory process. Similarly, the lead authority will also consult with the other national and provincial departments that could have regulatory requirements that must be taken into consideration.

4.2 Integrated Environmental Management

For all new sites receiving high rate sludge applications on continuous bases an Environmental Impact Assessment (EIA) **may be requested** by the permitting authority (DWAF/DEAT) before a Record of Decision (RoD) will be granted. With regard to the issuing and enforcement of a site permit and the conditions contained therein, the Minister of Water Affairs and Forestry will be responsible for the protection of the water resource as defined in the National Water Act (Act 36 of 1998) whereas the Minister of Environmental Affairs and Tourism is responsible for the protection of the environment and matters connected therewith (Minimum Requirements, Latest edition). Once a candidate site has been found feasible for development by DWAF/DEAT, further detailed investigation and reporting are required and will include the assessment of the environmental impact of such a site.

The objectives of the assessment of potential environmental impacts are:

- To identify the various ways in which an existing, proposed or closed site will affect its receiving environment

- To ensure that the identified impacts can be eliminated or mitigated (minimised) by means of proper design and operation, combined with ongoing monitoring.

Table 4.a: Regulatory requirements applicable for the beneficial use of sludge

Disposal Option	On-site land application of sludge	Continuous off-site land application of liquid sludge	Continuous off-site land application dewatered sludge	Once-off high rate sludge application	Use as landfill cover
Applicable Act Governing Practice	National Water Act (Act No. 36 of 1998)	Environment Conservation Act (Act No. 73 of 1989) National Environmental Management: Waste Management Act (*for irrigation of sludge* National Water Act (Act No. 36 of 1998))	Environment Conservation Act (Act No. 73 of 1989) National Environmental Management: Waste Management Act	Environment Conservation Act (Act No. 73 of 1989) National Water Act (Act No. 36 of 1998)	Environment Conservation Act (Act No. 73 of 1989) National Environmental Management: Waste Management Act
Authorisation Required	**Water Use Authorisation**	**Disposal site Permit** (*for irrigation of sludge* Water Use Authorisation)	**Disposal site Permit**	**None** However permission may be required from DWAF and/or DEAT and the onus is upon the sludge user/producer to consult the regulators	**Disposal site Permit**
Lead Authority	**DWAF**	**DEAT** (*for irrigation of sludge* **DWAF***)*	**DEAT**	**DEAT** (*for irrigation of sludge* **DWAF***)*	**DEAT**
Regulatory Instrument	**Water Use licence** (or general authorisation or existing lawful water use)	**Disposal site Permit** (or **Water use licence**, general authorisation or existing lawful water use if sludge is irrigated)	**Disposal site Permit**	**None**	**Disposal site Permit**
Regulatory Guidelines	**Sludge Guidelines (Volume 4)** and/or **Minimum Requirements (latest edition)** and if applicable, **Regulation 1048** in terms of section 29 of the Conservation of Agricultural Resources Act (Act No. 43 of 1983) related to the control measures for the restoration and reclamation o eroded land and of disturbed or denuded land.				

The Environmental Impact Assessment involves the process of assessing the impacts of a site, determining the significance of each impact on the environment and formulating mitigatory measures that are relevant to the consideration of an application for such an activity. Based on this, the design, operation and monitoring of the site are optimised, while taking economic considerations into account. This is to ensure that the surrounding environment and affected communities suffer the least possible adverse impacts. As a minimum, any adverse impact must comply with environmental standards. The preparation of EIAs is stipulated in the Environmental Impact Assessment Regulations (EIAR) as promulgated by the Department of Environmental Affairs and Tourism (Government Gazette, No.18261, 5 September 1997, No. R1182 and R1183]. The EIA must comply with the EIAR and be approved by the Competent Authority (Minimum Requirements, Latest edition).

The EIA Report must explain what steps will be taken to ensure that the disposal site will not have an adverse effect on any component of the receiving environment. The Report will therefore, *inter alia*, encompass the outcomes of the EIA process (issues, alternatives, impacts and significance of impacts), as well as the Design, the Operating Plan, the Monitoring Plan and the Closure Plan. Detailed documents on Integrated Environmental Management including the processes to be followed are available on the DEAT website: www.deat.gov.za.

4.3 Site selection

According to Section 24 of the Constitution 'Everyone has the right to an environment that is not harmful to their health or well-being'. The establishment and operation of a land application site that will continuously receive sludge at high rates must therefore not violate the constitutional right of the communities living in the vicinity of the site (Minimum Requirements, Latest edition).

The objectives of site selection are as follows:

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

The following approach to site selection is recommended in the Minimum Requirements (Latest edition):

- **Size of the site**. When the site is classified, the size of the waste stream is calculated. This calculation gives a good indication of the physical size of the site and hence the area of land required. In addition the cumulative effect of the areas potentially impacted by the site must be considered and adequate land area must be available beyond the site boundaries to accommodate the buffer zone

- **General site location**. It is economically sound practice to establish the proposed land application facility as close to the WWTP(s) as possible, with a view to minimising transport costs. Thus, the initial area of investigation is defined by the economic radius, which will vary depending on the existing or proposed mode of waste transport. Existing and future land uses will influence site location considerations, as incompatible land uses could prove to be a fatal flaw in the site selection process

For existing sludge application sites the following site selection procedure is recommended:

- Ensure that the site is not located in an area where sludge application could not be allowed (see Section 4.4.1)
- Ensure that the site is located as far as possible from the area where the final effluent is discharged to limit possible contamination of the final effluent
- Ensure that all buffer zones are adhered to (see Section 4.4.2)

For new sites that will receive continuous high rate sludge application the selection procedures described in the Minimum Requirements (Latest edition) need to be followed. For sites that will receive once-off high rate sludge application site investigations is not required, but certain aspects should be considered to mitigate possible negative effects.

4.3.1 Areas where high rate sludge application is not allowed

According to the Minimum Requirements (Latest edition) the following areas are classified as areas with fatal flaws with regard to disposal. In essence, continuous high rate sludge application can be seen as disposal since the same piece of land are receiving sludge in high concentrations on a continuous bases. Therefore, continuous high rate sludge application should also not be permitted at these sites.

- Areas below the 1 in 100 year flood line (wetlands, vleis, pans and flood plains) to minimize water pollution
- Areas in close proximity to significant surface water bodies, e.g. water courses or dams and catchment areas for important water resources. Although all sites ultimately fall within a catchment area, the size and sensitivity of the catchment may represent a Fatal Flaw, especially if it feeds a water resource
- Unstable areas (fault zones, seismic zones and dolomitic or karst areas where sinkholes and subsidence are likely)
- Areas characterised by steep gradients where slope stability could be a problem and soil erosion would be prevalent
- Areas of ground water recharges on account of topography and/or highly permeable soils to minimise groundwater pollution
- Areas immediately upwind of a residential area in the prevailing wind direction(s)
- An additional fatal flaw area was added for continuous high rate sludge application to land, i.e. areas where the soil clay content <20%. This recommendation is based on local research conducted by Herselman (2006) on the influence of soil properties on the baseline concentration of trace elements in South African soils. Research results from this study indicated that the attenuation capacity of soils with clay content >15-20% are significantly better than that of sandy soils, resulting in lower mobility of trace elements in these soils.
- It is recommended that run-off interception mechanisms be applied at land disposal sites. These could include properly constructed bund-walls or cut-off trenches or the cultivation of trees to intercept run-off.

Once-off high rate application is not considered in the same way since it is unlikely to cause pollution. Therefore, the above mentioned areas should be considered when an application site is selected, to minimise potential environmental impacts. The only area where once-off high rate application will not be permissible is within the 1:100 year floodline.

4.3.2 Buffer zones

Buffer zones are areas of land separating the registered surveyed boundaries of sludge application sites from the registered surveyed boundaries of identified sensitive land use categories. The establishment and maintenance of buffer zones are enforceable in terms of the Health Act, 1977 (Act 63 of 1977), which makes provision for measures to prevent any nuisance, unhygienic or offensive condition that may be harmful to health.

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

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

The following buffer zones are suggested for beneficial use sites and were adopted from the Minimum Requirements (Latest edition):

- Depth to aquifer –
  - Once-off high rate application – >2 m for dewatered sludge application and >5 m for liquid sludge application
  - Continuous high rate application and landfill cover – >5 m for dewatered sludge application and >10 m for continuous irrigation with sludge (same as for sludge disposal, Volume 3)
- Distance from surface water/borehole –
  - Once-off high rate application – >200
  - Continuous high rate application and landfill cover – >400 m (same as for sludge disposal, Volume 3)

These buffer zones may be relaxed on condition that proof is provided by the sludge producer or site manager that the groundwater and surface water is adequately protected.

4.4 Initial site investigation

Initial site investigation is necessary to collect background/baseline data which could be used to assess the impact of continuous high rate sludge application on the environment. This investigation is not necessary for once-off high rate application but the topography and soil properties should be considered during site selection. The initial investigation should as a minimum include:

4.4.1 Topography

The selection of the application site needs to include an evaluation of landscape topography along with the soil and underlying geologic layers. The landscape can be looked upon as a surface transport system for the applied sewage sludge, while the soil can be looked upon as an internal transport system for sludge constituents. An important component of topography for site selection is the slope since it is an important factor in determining the run-off that is likely to occur. Most soils on a 0-6% slope will have a slow to very slow run-off, soils on a 6-12% slope have medium run-off and soil on steeper slopes generally have a rapid run-off. The length and shape of slopes also influence the rate of runoff from a site (Figure 4.a). Rapid surface runoff can readily erode sludge-soil mixtures and transport them to surface waters. Specific guidance on maximum slopes allowable for sludge disposal sites under various conditions, such as sludge physical characteristics, application techniques, and application rates, should be obtained from the designated regulatory agency (Metcalf & Eddy, 1989; Lue-Hing *et al*., 1992).

4.4.2 Soil properties

Sludge application sites are often located on lands that are largely composed of disturbed or naturally unproductive soils. This lessens the public perception that productive lands will be spoiled or polluted. In selecting a site, soil surveys are an important source of information in making preliminary judgement on the suitability of potential sites for sludge application. An important component of the soil survey is the land capability or suitability classification where land is classified according to the most suitable sustained use that can be made of it while providing adequate protection from erosion or other means of deterioration (Lue-Hing *et al*., 1992).

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

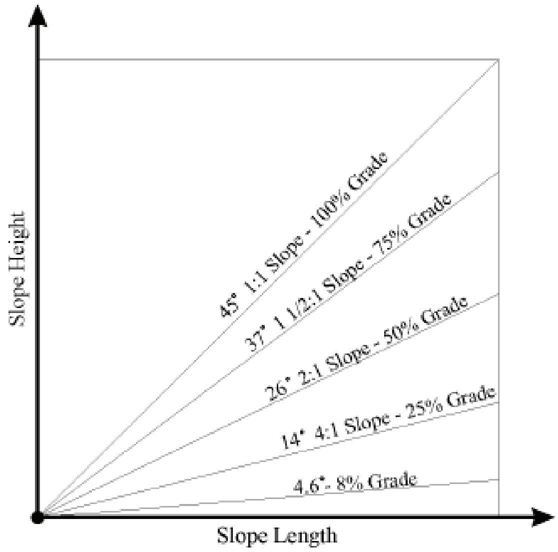

Figure 4.a: Indication of different slope grades

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

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

Cation exchange capacity (CEC) is another soil chemical property that needs to be determined in soils that receive sewage sludge. This property is simply the sum total of the exchangeable cations that a soil can absorb. Fine textured soils tend to have higher cation exchange capacities, while coarse textured soils tend to have low cation exchange capacities. Many researchers recognize cation exchange capacity as one of the soil properties that is related to soil retention of metals. Because of this, cation exchange capacity is used by the US EPA and many state agencies to determine cumulative loading limits for sludge-applied metals.

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

4.4.3 Surface water

The number, size, and nature of surface water bodies on or near a potential sludge application site are significant factors that need to be evaluated in site selection. These surface water bodies have the potential to be contaminated by site runoff or flooding. In general, areas subject to frequent flooding have severe limitations for sewage sludge application.

Background water quality sampling is required to determine potential future impact of sludge application on surface water

4.4.4 Groundwater

The depth to **groundwater**, the yield and the importance of the groundwater as a resource is important. The vulnerability of the aquifer and the risk of its possible pollution should be assessed to determine whether the site is suitable for sludge application. Generally, the greater the depth to the water table, the more desirable the site. Sludge should not be placed where there is potential for direct contact with groundwater (Metcalf & Eddy, 1989). A minimum depth of 5 m to the aquifer is recommended for sludge application sites. DWAF will not issue licenses in terms of Section 20 of the Environment Conservation Act unless land has been zoned appropriately. For the purposes of licensing, the Department will base its regulatory response upon the importance and vulnerability of the aquifer (Table 4.b) which is threatened by waste disposal activities.

Table 4.b. Types of aquifers differentiated for groundwater quality management

AQUIFER TYPE	DESCRIPTION
Sole-source aquifer	An aquifer used to supply 50% or more of urban domestic water for a given area and for which there are no reasonably available alternative sources of water.
Major aquifer	A high-yield aquifer system of good quality water.
Minor aquifer	A moderate-yield aquifer system of variable water quality.
Poor aquifer	A low- to negligible-yield aquifer system of moderate to poor water quality.
Special aquifer	An aquifer system designated as such by the Minister of Water Affairs and Forestry, after due process.

Major aquifers and vulnerable sole-source aquifers: The Department will place a general ban on waste application and other polluting activities within 200 metres of the recharge zone for major aquifers and sole-source aquifers.

Minor aquifers**:** The Department will generally not object to licensing or authorisation of waste application within the recharge zone of minor aquifers provided that adequate pollution control measures will be implemented. Such measures as may be necessary for the most commonly practiced methods may be published by the Department in the form of Best Practice guidelines from time to time or may be published in regulations.

Poor aquifers**:** The Department will not normally object to waste application activities on areas which are underlain by poor aquifers. Minimum standards of Best Practice will nevertheless be a pre-requisite in these cases (DWAF, 2000).

Monitoring and auditing: Monitoring of performance of waste application facilities and their associated pollution prevention measures will be mandatory. Monitoring systems shall generally form part of the management systems which the waste facility operator must implement. Routine auditing may be prescribed as a license condition.

The hydraulic gradient should be determined to assess the direction of groundwater flow and the position of the monitoring boreholes. Groundwater quality (up gradient and down gradient) will give baseline information to assess future impact of sludge application on groundwater. Initial groundwater sampling should be done at a frequency high enough to obtain statistically valid background information. For any long-term facility, three initial sampling exercises, all within 90 days and not less than 14 days apart, are suggested (Minimum Requirements, Latest edition).

4.5 Restrictions for beneficial use at high loading rates

4.5.1 Sludge quality restrictions

There are certain restrictions for different sludge classes for high rate land application. These restrictions will be detailed in the sections that follow.

<u>Restrictions based on Microbiological class</u>

According to research conducted by the USEPA (1995), bacterial pathogens generally die-off to negligible numbers (99 percent die-off) in 12 days (Salmonella sp.) or 18 days (feacal coliform) at a temperature of 15°C following land application. Viruses commonly survive a maximum of 19 days (surface application) at 15°C. Viable helminth ova densities in sludge applied to the surface of grassed plots are reduced by more than 90 percent within 3 to 4 months; viable helminth ova survive longer if sewage sludge is tilled into the soil. Generally, none of these microorganisms will leach through the soil system to pollute the receiving ground waters, but instead will remain in the surface soils for the duration of their survival period (US EPA, 1995). Therefore, the following restriction and requirements is recommended in terms of the microbiological content of sludge:

Microbiological class A

No restrictions apply for land application. This product is of high quality and the microbiological content will not pose a risk to the environment.

Microbiological class B

The following restrictions apply for Microbiological class B sludge and were adopted from the US EPA Rule 503 (same as for agricultural use):

- No public access for 30 days after sludge application
- No grazing animals shall be allowed on land until 30 days after the last sludge application
- Edible crops with harvested / edible parts that do not touch the soil/sludge mixture (grain and fruit trees) may be grown on land application sites but may not be harvested until 30 days after the last sludge application
- Industrial crops (including all non-edible crops that are cultivated on-site, including cotton, tobacco, trees (forestry), seedlings (flowers and trees) and grass, etc.) may be cultivated on land application sites but may not be harvested until 30 days after the last sludge application.
- Additional monitoring (at sites receiving continuous high rate applications) of faecal coliforms is recommended in surface and groundwater due to the sludge quality.

Note: These restrictions can be relaxed if sufficient proof is provided the negative effects of the pathogens present in the sludge will be negligible before the required 30 days resting period has expired.

Microbiological class C

The following restrictions apply for Microbiological class C sludge were adopted from the US EPA Rule 503 (same as for agricultural use):

- Not permissible on public access sites
- No public access for 90 days after sludge application on private land
- No grazing animals shall be allowed on land until 90 days after the last sludge application
- Edible crops with harvested / edible parts that do not touch the soil/sludge mixture (grain and fruit trees) may be grown on land application sites but may not be harvested until 90 days after the last sludge application
- Industrial crops
    - All non-edible crops that are cultivated on-site, including cotton, tobacco, trees (forestry) may be cultivated on land application sites but may not be harvested until 90 days after the last sludge application (USEPA Rule 503)

  - Non-edible crops destined for use by general public including seedlings (flowers and trees) and grass are not permissible.
- Additional monitoring of faecal coliforms and *E. coli* is recommended (at sites receiving continuous high rate applications) in surface and groundwater due to the sludge quality

Note: These restrictions can be relaxed if sufficient proof is provided the negative effects of the pathogens present in the sludge will be negligible before the required 90 days resting period has expired.

Restrictions based on Stability class

Stability class 1

No restrictions apply. This product is stable and will not pose any vector attraction problems.

Stability class 2

Depending on the reliability of the vector attraction reduction measures implemented, additional management systems may be required.

Stability class 3

Beneficial use of unstable sludge **will not be allowed**. At least one vector attraction reduction option should be implemented.

Restrictions based on Pollutant class

Pollutant class a

No restrictions apply for land application. The metal concentration in this sludge is within acceptable levels and the impact on the environment will be limited. However, at sites continuously receiving high rate applications the metals may build-up in the soil and soil monitoring will be necessary (see Section 4.7.4).

Pollutant class b

The following restriction will apply for Pollutant class b sludge:

- To protect the general public (especially children that can ingest soil/sludge), public access should be restricted when:
  - Sludge is not incorporated into the soil (if it is incorporated, there will be dilution effect);
  - Soil surface is not covered with vegetation (if covered with plants the risk for ingesting soil/sludge is reduced).

- Grazing animals should be restricted unless the sludge is incorporated into the soil. This will reduce the risk of grazing animals ingesting sludge.
- Soil quality restrictions will apply (see Section 4.6.4 for an explanation of soil quality management and how it will protect the environment). High rate sludge application will only be permissible in the following cases:
  - Public access sites – until the soil reaches the TMT;
  - Private land –
    - Edible crops – until the soil reaches the TMT;
    - Industrial crops – until the soil reaches the MPL.
- Where sludge is intended for use as landfill cover material, it is recommended that the sludge is treated with lime (CaO) at an application rate of 25 kg lime/t sludge to reduce the mobility of the metals. The sludge should then be re-analysed with the TCLP test to determine whether the lime application has immobilised the metals. If the sludge can still not be delisted (Pollutant class b), the load principle will apply.

Pollutant class c

The following restriction will apply for Pollutant class c sludge:

- Application not permissible on public access sites;
- Public access on private land should be restricted when:
  - Sludge is not incorporated into the soil;
  - Soil surface is not covered with vegetation.
- No grazing animals should be allowed;
- Soil quality restrictions on private land will apply. High rate sludge application will only be permissible until the soil reaches the MPL;
- The maximum load principle will apply for use as landfill cover material;
- Continuous high rate application of Pollutant class c sludge is not permissible.

4.5.2 Restrictions on crop production

To protect human health, no edible crops with harvested/edible parts touching the soil/sludge mixture or below the soil/sludge mixture may be grown on sludge application sites (US EPA, 1994). For cultivation of these types of crops see Volume 2 of the Sludge Guidelines dealing with agricultural use at agronomic rates with a maximum application rate of 10 ton/ha/year.

Edible crops with harvested / edible parts that do not touch the soil/sludge mixture (grain and fruit trees) may be grown on land application sites with the following restrictions (adopted from USEPA Rule 503):

- shall not be harvested until 30 days after the last sludge application (Microbiological class B)
- shall not be harvested until 90 days after the last sludge application (Microbiological class C).

Industrial crops include all non-edible crops that are cultivated on-site, including cotton, tobacco, trees (forestry), seedlings (flowers and trees) and grass, etc. Since these crops will not be consumed by humans, they may be cultivated on land application sites. However, if it is destined for public access sites (parks, sports fields, etc.) certain restrictions would apply, i.e. crops may not be harvested (instant lawn) until 30 days after the last sludge application. This requirement is to protect the public against high pathogen content in sludge.

Note: For instant lawn cultivation the following requirements apply:

- Microbiological class B – Sludge application must stop 30 days before harvest and must be irrigated with clean water during this stage
- Microbiological class C – Not permissible

4.5.3 Restrictions on grazing animals

- Animals shall not be allowed to graze on land until 30 days after the last sludge application (Microbiological class B) (USEPA Rule 503).
- Animals shall not be grazed on land until 90 days after the last sludge application (Microbiological class C).
- Grazing animals should be restricted on sites receiving Pollutant class b sludge, unless the sludge is incorporated into the soil (sludge incorporation into the soil serve as dilution to protect animals from ingesting high metal loads with sludge)
- No grazing animals should be allowed on sites receiving Pollutant class c sludge (metal content of sludge too high)
- No grazing animals should be allowed on sites where the soil metal concentration exceed the MPL (metal content of the soil are high and may pose risk to animals ingesting soil and plants)

4.5.4 Public access restrictions

Public access must be restricted at land application sites to minimise public contact with pollutants, including pathogens that may be present in the sludge.

- Access to land with public exposure is restricted for 30 days after the last sludge application (Microbiological class B) (USEPA Rule 503).
- Access to land with public exposure is restricted for 90 days after the last sludge application (Microbiological class C).
- Public access to land receiving Pollutant class b sludge should be restricted when:
    - Sludge is not incorporated into the soil (reduce risk through dilution factor as well as pathogens incorporated into the soil)

- Soil surface is not covered with vegetation (vegetation serve as a barrier)

- No public access should be allowed on sites receiving Pollutant class c sludge (metal content of the sludge may pose risk to public)

4.6 Management requirements for high rate sludge application to land

Land application sites receiving high rate sludge applications should be managed in a responsible way to protect the environment against the potential negative impact of these operations. More management requirements are applicable to continuous high rate sludge application practices than to once-off high rate sludge application sites due to the higher environmental risk posed by continuous high rate sludge application to land. These management practices could also serve as mitigating factors to protect the receptors against the potentially harmful substances present in the sludge.

4.6.1 Odour control

Vectors attracted by odours pose a high risk to livestock and the public at land application sites. The compliance criteria for the different stability classes adopted in the New Sludge Guidelines are based on the USEPA Part 503 Sludge rule (USEPA, 1993). The potential of sludge to generate odours and attract vectors are the aspect that influences public perception most. Therefore, odours must be combated by good cover application and maintenance. Furthermore, the prompt covering of malodorous waste to reduce odour problems is a Minimum Requirement (Minimum Requirements, Latest edition) if the site is permitted in terms of Section 20(1) of ECA as a disposal facility. This may also become the case for sites receiving high sludge applications on continuous bases. In extreme cases, odour suppressants such as spray curtains may be required. The application of soil or other suitable cover can eliminate odour and generally improves aesthetics. At least one of the vector attraction reduction options must be applied to minimise the production of odours.

4.6.2 Run-off interception

Run-off includes rainwater and other liquids that drain over the land and run off the land surface. Run-off may be contaminated by sludge and must be collected and disposed of according to the water use authorisation requirements. According to the USEPA Part 503 Rule on Surface Disposal of Sludge (1994), the run-off collection system must have the capacity to handle run-off from a 25 year, 24-hour storm event. In SA the 1:100 year rule applies. This requirement ensures that run-off which may contain pollutants is not released into the environment, especially into nearby surface water bodies. Surface water resources near the continuous high rate application sites need to be protected against contamination by constituents from the sludge. This could be achieved by:

- Constructing cut-off trenches or bund walls down-gradient of the application site to intercept run-off

- Increasing the buffer zone between the sludge application site and the water body to ensure no run-off will reach the water body

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

4.6.3 Groundwater protection

Groundwater is a key component of the water resources of South Africa. As such it will provide much of the water required for basic needs, especially since the country's surface water resources are unevenly distributed and cannot cope with the growing demand for water. Groundwater is especially important because:

- it occurs widely, even in the drier two-thirds of the country where there is little or no surface water;
- almost two-thirds of South Africa's population depends on groundwater for their domestic water needs; and
- essential domestic needs can be met cost-effectively from groundwater sources.

Groundwater, in many parts of the country, provides the only means of satisfying basic human needs. Present coverage of water supply is estimated at around 68%. The target is full coverage to satisfy basic needs by 2007. As the country's people start depending more and more on groundwater, so the need grows to provide for the security of its supply. Protection of groundwater has, therefore, now become a national priority. It is common for groundwater to be poorly managed. This is because of its invisible nature – it takes a long time to notice when it has become polluted and, unlike surface water, it has limited ability to purify itself. It is difficult, and often impossible, to restore polluted groundwater, and certainly very expensive (DWAF, 2000). Therefore, sludge placed on land should not contaminate the aquifer. Aquifer contamination means introducing a substance that can cause the concentrations of constituents of concern in groundwater to increase above regulated limits. Due to the potential negative impact on groundwater, continuous high rate sludge application might not be allowed in subterranean government water control areas as set out in Table 4 of Schedule 4 of Government Notice 399 of 26 March 2004. The impact of once-off high rate sludge application on groundwater is considered to be minimal, therefore no management requirements will be necessary if all the consideration for site selection have been met.

In water-unsaturated sub-soil, the water content only slightly exceeds the field capacity, therefore the volume of transport is also low. The rate of water percolation through fine and medium-sized pores is low. Long-lasting, heavy precipitation results in soil water content that greatly exceeds the field capacity. This surplus water can pass freely through an increasing number of coarse pores until reaching groundwater in the water-saturated zone. Water transport down to deeper regions occurs at a greater rate in solid rock areas, because percolating water is able to pass through joints and gaps in the rock. In the water-saturated groundwater zone, water predominantly moves horizontally in the direction of the hydraulic gradient. This allows the stratification of the water by age and concentration to be maintained. In pore aquifers the rate of flow is between less than 1 m per day and a few metres per day. In karst and jointed aquifers flow rates are much higher, up to a few kilometres per day. With increasing depth groundwater becomes ever older and originates from percolation areas progressively farther upstream (US EPA, 1998).

Soil water infiltration is controlled by the rate and duration of water application, soil physical properties, slope, vegetation, and surface roughness. Generally, whenever water is ponded over the soil surface, the rate of infiltration exceeds the soil infiltrability. On the other hand, if water is applied slowly, the infiltration rate may be smaller than the soil infiltrability, and the supply rate becomes a determining factor for the infiltration rate. This type of infiltration process is termed *supply controlled* (Hillel, 1982). However, once the infiltration rate exceeds the soil infiltrability it is the latter which determines the actual infiltration rate, and thus the process becomes *profile controlled*. Generally, soil water infiltration has a high rate in the beginning, decreasing rapidly, and then slowly decreasing until it approaches a constant rate. The metal and nutrient concentrations of the transition zone will give an indication of the concentrations of these elements that are en-route to the aquifer.

Groundwater is most vulnerable to nitrate present in sludge that leach through the soil profile into the aquifer. Organic N represents 95% or more of total N in the soil. So the process by which unavailable organic forms are converted to available forms is important to plant growth. This process is called mineralization. It occurs as micro-organisms decompose organic materials for their energy supply. As the organic matter is decomposed, the organisms use some of the energy released plus part of the essential nutrients in the organic matter. Nitrogen can also be converted from inorganic to organic forms. This process is called immobilization. Immobilization occurs when crop residues high in carbon (C) and low in N content are incorporated into the soil. In general, when the carbon vs. nitrogen ratio of organic material is greater than 20-30, the immobilization occurs. The addition of sludge increases the soils inorganic nitrogen content. Sewage sludge application produces an immediate increase of the inorganic N, mainly in ammonium form. With higher dosages of sludge, immobilization of N occurs due to the addition of a large quantity of organic matter, of which 45% consists of fractions resistant to degradation over a short period. The rapidness of nitrogen mineralization from organic compounds is a function of the carbon nitrogen ratio (C:N) of the material. In substances with low C:N ratio, less than 15:1, the nitrogen content is relatively high and the microorganisms rapidly release nitrogen when they decompose the material. On the other hand, if the C:N ratio of the material is high (greater than 30:1), indicating a low nitrogen content, then mineralization is slow. In order for the organisms to break down a high C:N material inorganic nitrogen is removed from the soil solution. This process is called immobilization and occurs frequently when high C:N substances (for example: sawdust, some compost, types of sludge) are added to soil. If the material has a high enough C:N ratio all of the inorganic nitrogen can be removed from the soil for a considerable amount of time.

Liquid sludge application generally results in more leaching than dewatered sludge. Enhancing volatilization of NH_3 from sewage sludge by aging, dewatering, and applying to the soil surface will minimize conversion to NO_3 and reduce the potential for leaching to groundwater. Excessive production of NO_3 from nitrification of land-applied sludge may be managed by addition of organic carbon. Maintenance of higher soil water contents through increased irrigation water results in greater potential for leaching. The potential for groundwater contamination increases when conditions maximizing vertical water movement through the soil profile are coupled with the presence of a mobile chemical such as NO_3. Irrigation water management appears to be the most important factor in reducing potential for N leaching. The method of irrigation water application influences the leaching process. Irrigation should not fill the soil to field capacity and the soil profile should never be used to store irrigation water.

Because of the delay in the response of groundwater to changes in soil, some endangered aquifers have not yet shown the increase expected from the increased use of nitrogen fertiliser or manure.

Once the nitrate reaches these aquifers, they will remain contaminated for decades, even if there is a substantial reduction in the nitrate loading at the surface. It is recommended that sludge irrigation be scheduled to prevent the soil profile from getting saturated.

The maximum permissible level for **NO_3-N** in water for domestic use is presented in Table 4.c (DWAF South Africa Water Quality Guidelines, 1998). The maximum contaminant level for N in the USA is 10 mg/l (US EPA, 1994) and the WHO maximum limit for nitrate concentration in drinking waters is 50 mg l^{-1} NO_3 , equivalent to 11.3 mg l^{-1}as NO_3-N.

The application site owner/operator should provide proof that groundwater is not contaminated by:

- Groundwater monitoring programme developed by a qualified person
- Certification by a qualified person the groundwater would not be contaminated either because of the depth of the water table or the amount of sludge applied. This certification is generally infeasible for sites without liners unless the depth to groundwater is considerable and there is a natural clay layer under the soil (US EPA, 1994)

It is recommended that the groundwater quality should not deteriorate more than 1 class (acceptable to tolerable) due to sludge disposal with a **maximum permissible NO_3-N of 20 mg/l**. If there is any possibility that the groundwater may be used for **drinking purposes**, the acceptable level of **10 mg/l NO3-N** may not be exceeded.

Table 4.c: South Africa water quality guideline for nitrate (domestic use)

	Target Water Quality Guideline	Acceptable	Tolerable	Unacceptable
NO_3-N (mg/l N)	6	10	20	> 20

A groundwater monitoring programme at a site continuously receiving sludge at high application rates will serve as an early warning system to indicate potential contamination of the aquifer/s at the disposal site. The number of monitoring wells and their proper placement will depend on the location of the water table and direction of groundwater flow. The depth of the monitoring wells will depend on the depth of the water table. The monitoring network should include the integration of unsaturated and saturated zone sampling. The chemical quality of the groundwater should be compared to the baseline groundwater quality prior to sludge application to determine if any contamination occurred.

4.6.4 Soil quality

The major impact of pollutants during high rate sludge application is on surface and groundwater and the receiving soil. This impact is due to nutrients, present in the sludge, that will leach in the soil profile and not the metal content of the sludge. Research results by Herselman *et al*. (2005) indicated that, even after long periods of high rate sludge application to land, the metals remain in top 500 mm of the soil profile and are not mobile. However, certain restrictions on metal content of soils that would be allowed at sludge application sites (maximum permissible levels – MPL) need to be implemented to ensure that the soil quality does not degrade to such an extent that rehabilitation would be nearly impossible and the surface and groundwater becomes polluted. This soil quality management apply specifically for sites that receive Pollutant class b and c sludge.

In Australia, guidelines for reuse of sludge on soils are published for NSW (NSW EPA, 1997) and for Southern Australia (SA EPA, 1996). These guidelines contain maximum permitted concentrations for metals in soils receiving sludge (Table 4.d). In the NSW document there is a differentiation between these concentrations for agricultural soil and non-agricultural soil. These levels are risk-based levels intended to protect the food chain and the human receptor.

Maximum permitted soil concentrations for soil receiving sludge have also been published for New Zealand by the NZ Department of Health (NZ DoH, 1992) and by the New Zealand Water and Wastes Association (NZWWA, 1999). There is some consistency between these documents and in general the regulations for metals in soils are largely based on the European guidelines (CEC, 1986) (Table 4.d). All these guidelines are intended to protect public health and are aimed to prevent metal accumulation in the food chain.

The US EPA developed soil screening levels (SSL) above which further study or investigation is warranted (US EPA, 1996). These levels were developed for all kinds of contamination and not only for sludge disposal sites and are also aimed at human health protection. The generic SSLs for industrial soil and groundwater protection are presented in Table 4.d.

Table 4.d: Metal limits for soils in different countries (mg kg^{-1})

Metals	Australia non-agric soil MPC[1]	Australia soil MPC[2]	New Zealand Arable Soil MPC[3]	New Zealand Soil MPC[4]	Europe Environ investigation level[5]	Dutch Reference values[6]	USA Industrial soil[7]	USA Groundwater protection level[7]
As	20	20	10	-	-	40	260	29
Cd	5	3	3	1	3	12	450	8
Cr	250	-	600	600	-	230	450	38
Cu	375	200	140	100	140	190	400	-
Pb	150	200	300	300	300	290	800	-
Hg	9	1	1	1	1.5	10	310	2
Ni	125	60	35	60	75	210	200	130
Zn	700	250	300	300	300	720	3100	1200

[1] NSW EPA, 1997 [2] SA EPA, 1996 [3] NZ DoH, 1992 [4] NZWWA, 1999
[5] CEC, 1986 [6] Smit, 1998 [7] US EPA, 1996

In Volume 2 of the Sludge guidelines a total maximum threshold (TMT) was implemented for South African soils. This TMT value was derived from the upper limit of the baseline concentrations of metals in South African soils. Essentially this means that 97.5% of natural soils in South Africa will have metal concentrations below this value. Once the metal concentration in the soil reaches this value, Pollutant class b sludge could no longer be applied if the soil is used for agricultural purposes. However, in Volume 3 it was assumed that sludge disposal sites (on-site and off-site) will not be used for agricultural purposes after closure and will remain as an industrial land-use, provided it is zoned as such. Therefore, the MPC values of Australia for non-agricultural land receiving sludge were adopted as maximum permissible levels (MPL) for South African soils at these sites. Since the Australian values for Cr and Ni are much lower than the total maximum threshold (TMT) for South African soils, the US EPA values for industrial soils were adopted for these two variables which are 50 and 100 mg kg^{-1} higher than the TMT for Ni and Cr respectively. Table 4.e show the metal limits proposed for South African soils.

The land use of the beneficial use site and the accessibility to the general public will determine applicable soil limit that should be applied. When the total metal content (*aqua regia* digestion) of the soil is below the TMT, sludge application may continue with regular monitoring of the soil. If the total metal content of the soil exceeds the TMT, sludge application at public access sites should be terminated and no edible crops may be cultivated on these soils. On private land sludge application may continue and industrial crops may still be cultivated while the soil is strictly monitored on regular intervals to ensure that the metals stay immobile in the soil profile, especially at existing application sites where the soil pH<6.5 and the soil clay content <20%. The metal content of the soil should be re-evaluated after every monitoring event to determine whether sludge disposal should cease. Once the total metal content of the soil reaches the MPL, sludge application should stop. At this point remediation of soils would not be necessary. However, at existing sites the metal concentrations in the soil might be significantly higher than the MPL in which case a remediation program must be developed and implemented.

Table 4.e: Total metal limits for soil at sludge application sites (mg kg^{-1})

Metals	Total maximum threshold (TMT)	Maximum permissible level (MPL)
As	2	20
Cd	3	5
Cr	350	350
Cu	120	375
Pb	100	150
Hg	1	9
Ni	150	150
Zn	200	700

The TMT and MPL were used as input into the RISC Workbench model ($RISC_4$ Workbench, 2001) as was done with the limits set in Volume 2 of the sludge guidelines. The risk to human health via vegetable ingestion, dermal contact as well as direct ingestion of soil was determined. The input parameters of the model are detailed in Table 4.f. It was assumed that all the metals are present in the soil at either the TMT or MPL concentrations.

Table 4.f: Human health risk input parameters

Parameter	Adult	Child
Body weight (kg)	70	15
Lifetime (y)	70	70
Vegetable Ingestion rate (g/day)	214.5	104
Soil ingestion rate (mg/day)	40	90
Ingestion frequency (events/y)	350	350
Duration of ingestion (y)	9	6

The results of the simulation (Table 4.g) indicated that the TMT level for soil will protect human health as intended with a carcinogenic risk < 1:300 000 and a hazard quotient <1. The results also show that edible crops must not be cultivated on soil if the soil metal level due to the hazard to children ingesting the vegetables (hazard quotient >1) as well as the carcinogenic risk to children (1:100 000). The crop restrictions introduced will therefore protect human health (see Section 4.5.6).

Table 4.g: Risk analyses of the TMT and MPL of metals in soils

		Child			Adult		
Soil limit	**Risk type**	**Vegetable ingestion**	**Ingestion of soil**	**Dermal contact**	**Vegetable ingestion**	**Ingestion of soil**	**Dermal contact**
TMT	**Carcinogenic risk (As)**	$1:10^6$	$5.5:10^7$	$3.2:10^8$	$6.8:10^7$	$2.4:10^8$	$7.3:10^9$
	Hazard Quotients	0.5	0.1	0.003	0.2	0.003	0.0004
MPL	**Carcinogenic risk (As)**	$1:10^5$	$5.5:10^6$	$3.2:10^7$	$6.8:10^6$	$2.4:10^7$	$7.3:10^8$
	Hazard Quotients	1.2	0.3	0.01	0.5	0.008	0.002

4.6.5 Sludge application rate

There are some important issues that need to be understood when considering high rate sludge application to land:

Liquid sludge application

Saturated soils have fewer pore spaces occupied by oxygen, thus creating anaerobic conditions that favor the growth of denitrifying microorganisms. The texture of soil, coarse (sandy) to fine (clay), affects the porosity and capacity to store water and oxygen, thus influencing the prevalence of anaerobic conditions even when soil is not saturated. When liquid sludge is applied to soil at high loads on continuous bases, anaerobic conditions in the soil may occur. The volume of sludge needed to cause anaerobic conditions in the soil will depend on soil properties as well as sludge characteristics and no research results could be found to indicate the volume of sludge that will cause anaerobic conditions.

The plant nutrient requirements

Any excess nutrients (especially nitrate) may leach through the soil profile into the groundwater. At the time this document was developed, research at the University of Pretoria was conducted to determine the nutrient uptake of maize and oats from sludge applied soils (personal communication with Prof John Annandale and Eyob Tesfamariam, May 2007). Sludge was applied at 4, 8 and 16 ton/ha/year under dry land as well as irrigated conditions. Preliminary research results indicated that, under dry land agricultural practices, maize crops take up less nitrogen than applied with the sludge, even at an application rate of 8 ton/ha/year. However, when maize is irrigated, the nitrogen uptake exceeds the amount of N supplied with sludge application, even at an application rate of 16 ton/ha/year. In the case of the oats trials, more than the supplied nitrogen is taken up under dry land as well as irrigated conditions.

During the same trials the uptake of P by maize and oats were also determined. Under dry land conditions the oats took up more P than the supplied amount and under the irrigated conditions the uptake and supply was equal. However, under both dry land and irrigated conditions the P uptake of maize was significantly lower than the supply with all the application rates. These preliminary results indicate that P build-up in the soil with high rate sludge application may be a reason for concern although the mobility of P is low and it is unlikely that groundwater will be contaminated. The types of crops cultivated should be selected in such a way that crops requiring high P should be cultivated to decrease the P in the soil were problem are expected.

Pasture was also cultivated under dry land conditions needed more than the N supplied with the 4 and 8 ton/ha/year treatments, but the N supplied with the 16 ton/ha/year treatment was more than the pasture needed. With all the treatments the P supplied was far more than the P needed by the plants.

With these results in mind, the sludge user must ensure that the nutrients applied with sludge must be in line with the nutrient requirements of the crop to ensure minimal leaching and build-up of nutrients in the soil. Excessively high sludge application rates will shorten the lifespan of the application site.

Metal uptake by crops and build-up in the soil

Small concentrations of metals and micronutrients applied with sludge will be taken up by the cultivated crop. High rate application will cause metal build-up in the soil and the soil quality will deteriorate. Excessively high sludge application rate will rapidly increase the metal build-up in the soil, decreasing the lifespan of the beneficial use site.

Permissible application rate (PAR) for high rate application sites

The soil metal content measured before sludge application can be used to calculate the sludge load that can be accommodated by the soil before the TMT or MPL will be reached, assuming no metal attenuation by the soil. This will enable the user to ensure that the TMT and MPL soil limits will not be exceeded after a single sludge application. It is recommended that the permissible application rate (PAR) or load should be calculated before each sludge application but this may be impractical at continuous high rate application sites. Therefore it is recommended the PAR be calculated after each soil monitoring event or, in the case of once-off high rate application, before the first application. The following equation can be used for this purpose:

$$PAR = \frac{TMT - Soil_{conc}}{Sludge_{conc}} * 3900$$

Where:

PAR = permissible application rate (ton/ha)

TMT = total maximum threshold (Table 4e) in mg/kg. The MPL can be used where applicable for private land (rehabilitation sites), sites where industrial crops are grown and where public access is restricted.

$Soil_{conc}$ = the actual metal content of the soil (mg/kg) analysed before sludge application

$Sludge_{conc}$ = metal concentration in the sludge that will be applied (mg/kg)

3900 = conversion factor to account for soil density (1.3 g/cm^3) and sludge incorporation depth of 300 mm

<u>Example</u>

A land developer wants to use sludge at high application rate to establish a golf course. The sludge classification is B1b. The analytical results of the soil samples indicate that the metal content of the soil is well below the TMT except for the Cu concentration of 140 mg/kg which is close to the TMT for soil. The Cu concentration of the sludge is 1800 mg/kg. To ensure that the soil metal content do not increase to a level above the TMT the Developer must not add too much sludge to the soil.

Therefore: $$PAR = \frac{TMT - Soil_{conc}}{Sludge_{conc}} * 3900$$

$$PAR = \frac{120 mg/kg - 110 mg/kg}{1800 mg/kg_{conc}} * 3900$$

= 21 $ton_{dry\ sludge}/ha$

At an application rate of 21 ton_{sludge}/ha the Cu application will be 10 mg_{Cu}/kg_{soil} and the TMT of the soil will not be exceeded.

If this site was situated on private land with limited public access where industrial crops (i.e. instant lawn) were grown, the MPL rather than the TMT could be used in the equation. The PAR would then increase to 574 ton/ha. However, such a high application rate would increase the Cu content of the soil to such a level that further sludge application would not be permissible.

Maximum annual sludge application rate (MAR)

The USEPA Rule 503 states that sludge should be applied to land at agronomic rates to prevent nitrate leaching. However, agronomic rates might not be enough for certain sites where higher application rates will be needed to sustain vegetation. Based on site specific evidence the sludge application rates at these sites might be increased, provided that enough mitigation measures are implemented to adequately protect the receiving environment. However, the US EPA recommends a **maximum sludge application rate** of 120-200 ton/ha/year (60-100 ton/acre/year) for reclamation sites, 10-200 ton/ha in a 2 to 5 year period for forests and 4-120 ton/ha in a 2 year period for rangelands (risk based).

With this information in mind and to prevent users from using beneficial use sites as disposal sites, it was decided to adopt these maximum application rates (MAR) for South Africa as well. Therefore the MAR for South Africa is as follows:

- Animal feed = 60 ton/ha during a 2 year period
- Industrial sites/crops = 120 ton/ha/year

The Lead Authority can decrease or increase the MAR for once-off and continuous high rate application sites based on site specific data (soil properties, depth to aquifer, type of aquifer, distance from surface water resource, etc.). It must be noted that the PAR will still be the preferable application rate and that the user have to proof that higher application rates will not cause negative environmental impacts.

4.6.6 Transportation of sludge

South Africa accepts the United Nations Recommendations for the transport of Dangerous Goods as incorporated in the International Maritime Organisation's Dangerous Goods Code IMDG and the International Civil Aviation Organisation's Regulations as given in their Technical Notes. These are both implemented as legislation through the Department of Transport's Merchant Shipping Act (Act 57 of 1951) and Aviation Act (Act 72 of 1962). They are the basis of a series of SA Bureau of Standards on the Transportation of Dangerous Goods by Road currently nearing completion, as well as of forthcoming Standards on Handling and Storage (Minimum Requirements, Latest edition).

Another requirement of the transportation of Hazardous Waste relates to the "duty of care" principle. This places responsibility for a waste on the producer and is supported by the "cradle-to-grave" principle, according to which a "manifest" accompanies each load of Hazardous Waste until it is responsibly and legally disposed of. This manifest is transferred from one transporter to the next along with the load, should more than one transporter be involved (Minimum Requirements, Latest edition).

To minimise uncontrolled dumping of Hazardous Wastes, producers and transporters must comply with the SANS 10406 on Transportation of Dangerous Goods. *Inter alia*, these require an adequate level of training of all personnel involved in the handling and transportation, by both parties. The producer must satisfy himself of the competence of the transporter who in turn needs to satisfy himself of the *bona fides* of the producer to ensure that materials offered for transport are honestly described and suitably contained and labeled (Minimum Requirements, Latest edition).

Due to the potential high microbiological contaminant content of sludge, it should be handled as a hazardous waste (containing infectious substances) during transportation. The following aspects should receive attention during the transportation of sludge from the WWTP to the landfill site:

- Identification of waste – the transporters must be provided with accurate information about the nature and properties of the load.
- Documentation – the transport operator must be provided with the relevant transportation documentation.
- Hazchem placard – the transport operator must be supplied with the appropriate Hazchem placards which should be properly fitted to the vehicle.
- Protection against effect of accident – the Generator – or his representative, i.e., transporter – must ensure that adequate steps are taken to minimise the effect an accident or incident may have on the public and on the environment.

Notification – all road accidents must be reported to the Department of Transport on the prescribed documentation and a full report should be sent to the Local Authorities, the Competent Authority and the DEAT.

4.6.7 Storage of sludge before application

A producer who stores waste for a period exceeding 90 days is subject to section 20(1) of the Environmental Conservation Act and must apply for a permit for a disposal site from the Competent Authority (similar to on-site disposal) (Minimum Requirements, Latest edition).

The migration of leachate into the soil and groundwater at all storage areas must be prevented. A storage site therefore requires a firm waterproof base that is protected from the ingress of storm water from surrounding areas. It must also have an effective drainage system to a water-proof spillage collection area, where any spillage can be recovered and suitably treated. This area must be clearly demarcated and should not be accessible to unauthorised persons (Minimum Requirements, Latest edition).

According to the Minimum Requirements a producer may accumulate 100-1000 kg of Hazardous Waste (sludge; HR 2 or 3) on site for 90 days or less **without a permit** for a waste disposal site provided that:

- the waste is stored in such a manner that no pollution of the environment occurs at any time;
- the date upon which accumulation begins is clearly marked and visible for inspection on each container;
- while being stored on site, each container and tank is labeled or marked clearly;

- the producer fences off the storage area to prevent unauthorized access and erects a weatherproof, durable and clearly legible notice-board in official languages at every entrance of the storage area with the words "Unauthorized entry prohibited".

The producer / user who accumulates more than the above specified quantities or who intends to accumulate Hazardous Wastes (sludge) for more than 90 days (non-continuous) is subject to the requirements of Section 20(1) of the Environmental Conservation Act unless he has been exempted from obtaining a permit by the Minister.

4.7 Monitoring requirements for beneficial use sites

These monitoring requirements are only applicable to sites receiving **continuous high rate sludge applications**. It is assumed that once-off high rate sludge application will not have such a negative impact on the environment that monitoring will be required.

The monitoring programme should be implemented to protect the different receptors. The amount of monitoring samples and the frequency of monitoring would be influenced by the sludge class that is applied, the type of sludge applied (dewatered or irrigated), site specific conditions and the vulnerability of the receptors. These requirements will be discussed in the sections that follow.

4.7.1 Sludge monitoring

Sludge monitoring is recommended to ensure that sludge quality do not deteriorate to such an extent that it cannot be used beneficially or to determine whether sludge quality did not improve to such an extent that less strict management and monitoring requirements will apply. The sludge monitoring programme detailed in the EPA 503 Rule was adopted for these Sludge Guidelines. Table 4.h indicates the frequency of sampling and analyses needed for the sludge monitoring purposes.

4.7.2 Groundwater monitoring

According to the Minimum Requirements (Latest edition), groundwater should be monitored to ensure that no aquifer contamination occurs due to sludge disposal. The same monitoring is recommended for continuous high rate sludge application sites. Groundwater is a slow-moving medium and drastic changes in the groundwater composition are not normally encountered within days. The frequency with which water samples are to be taken from groundwater access points is therefore a function of the sampling objectives. Monitoring boreholes should be located to intersect groundwater moving away from the site. Consult the *Minimum Requirements for Water monitoring at waste management facilities* (Latest edition) for descriptions on borehole design, type, diameter, depth and protection. The following requirements apply for groundwater monitoring at continuous high rate sludge application sites:

- Boreholes should be located on either side of the application site in the direction of the groundwater gradient (upstream and downstream). A geotechnical investigation is required in order to identify sub-surface geological structures, etc. The boreholes are then sited according to the results – otherwise we might miss the water migration pathways and hence the pollution. If very little is known about the groundwater gradient, then at least one monitoring borehole should be placed at the lowest topographical point.

Table 4.h: Sludge monitoring frequency and sampling recommendations

What should be monitored?	▫ Microbiological quality ▫ Physical characteristics ▫ Chemical characteristics		
How often should samples be taken?	Amount of sludge produced ($t_{dry\ weight}$)		Monitoring frequency
	Daily average	Yearly average	
	<1	<365	Once per year
	1-5	365-1 825	4 times per year
	5-45	1 825-16 500	6 times per year
	>45	>16 500	Monthly
Type of samples	Grab samples for pathogens and composite samples for metals.		
How many samples should be taken?	At least 3 samples of each sludge stream disposed each time		
When to sample?	Before application		
Where to collect samples?	Anaerobic digested	Collect from sampling valves on the discharge side of sludge pumps	
	Aerobic digested	Collect from sampling valves on the discharge side of sludge pumps	
	Thickened	Collect from valves on the discharge side of sludge pumps	
	Heat treated	Collect from valves on the discharge side of sludge pumps after decanting	
	Mechanical dewatered	Collect from discharge point	
	Dewatered in drying beds	Divide bed into quarters, sample from each quarter and combine samples	
Sample sizes	At least 500g $_{dry\ mass}$		
Analytical methods	See Volume 1 – Appendix 2 (Faecal coliforms) and Volume 4 – Appendix 3 for recommended new helminths ova method and TCLP test for metals		

- Monitoring boreholes must be such that the section of the groundwater most likely to be polluted first is suitably penetrated to ensure realistic monitoring results. This implies that monitoring holes will at least extend through the weathered zone, the aquifer below and 5 m into the non-water-yielding formation deeper down. The latter is intended to act as a sump, where material that falls down the borehole will accumulate, without affecting the performance of the monitoring system.

- Groundwater levels must be recorded on a regular basis to detect any changes or trends. Regional groundwater levels are indicative of the direction of groundwater movement. A change in the natural water-table gradient indicates that external forces are acting upon the aquifer. Such forces may be groundwater abstraction through nearby boreholes, or recharge from impoundments.

- The frequency of sampling will depend on the type of sludge (liquid or dewatered). Research results by Herselman *et al*. (2005) indicated that liquid sludge pose a bigger threat on groundwater that dewatered sludge. It can be explained by the metals and nutrients in the liquid sludge being soluble and mobile in the soil profile while these constituents in dewatered sludge are adsorbed by the soil particles during ploughing, rendering it less soluble and immobile.

- Water sampling, preservation and analyses should be done according to described procedures described in *Minimum Requirements for Water monitoring at waste management facilities* (Latest edition) (Table 4.i)
- A closure and rehabilitation plan will be needed once groundwater contamination is observed.

Table 4.i: Groundwater sampling and analyses for monitoring

<table>
<tr><td>What should be monitored?</td><td colspan="2">pH, EC, PO_4, NH_4, NO_3, COD
Faecal coliforms and E. coli depending on sludge quality</td></tr>
<tr><td>What sampling equipment should be used?</td><td colspan="2">Plastic bottles with a plastic cap and no liner within the cap are required for most sampling exercises. Glass bottles are required if organic constituents are to be tested.</td></tr>
<tr><td>How should samples be taken?</td><td colspan="2">Appendix (Sampling procedures)</td></tr>
<tr><td rowspan="4">Should samples be preserved?</td><td>For pH, EC, PO_4 analyses</td><td>For NH_4, NO_3, COD analyses</td></tr>
<tr><td>No additives, refrigerate and analyse as soon as possible</td><td>Add H_2SO_4 to pH<2</td></tr>
<tr><td colspan="2">Microbiological analyses</td></tr>
<tr><td colspan="2">No additives, keep in cooler box with ice and analyse within 24 hours</td></tr>
<tr><td>How many samples should be taken?</td><td colspan="2">At least 2 samples from each borehole, 1 sample for pH, EC and PO_4 analyses and 1 sample for NH_4, NO_3 and COD analyses. An additional sample needed for microbiological analyses (if applicable).</td></tr>
<tr><td>Sample sizes</td><td colspan="2">At least 100 mℓ of each sample will be needed</td></tr>
<tr><td>Analytical methods</td><td colspan="2">Standard analytical methods – see relevant Volume</td></tr>
</table>

- **Sampling frequency**:
  - Dewatered sludge application – due to limited leaching potential of N and metals in dewatered sludge, biannual monitoring of groundwater chemistry and microbiology (for Microbiological class B or C) is recommended.
  - Liquid sludge application – due to increased leaching potential of N and metals in liquid sludge, quarterly monitoring of groundwater chemistry and microbiology (for Microbiological class B or C) is recommended.
  - At existing sites where the water table <5 m the monitoring frequency should increase to quarterly monitoring for dewatered sludge application or monthly monitoring for liquid sludge application due to an increase in the probability for groundwater contamination.
  - The monitoring frequency for groundwater monitoring could be relaxed for land application sites under the following circumstances:
    - Water table >10 m (dewatered sludge application) or >20 m (liquid sludge application). The increase in the thickness of the vadose zone serves as groundwater protection measure.

- Soil clay content >35%. Soils with higher clay content have a bigger attenuation capacity for metals, lower infiltration rate and higher water retention characteristics which all will protect the groundwater.
- When monitoring results over a 5 year period indicate no significant impact on the groundwater resource, the regulating authority may relax the monitoring frequency. However, it is recommended that samples must be taken at least once a year for dewatered sludge application and twice a year for liquid sludge applications.

- The monitoring frequency can be increased at the discretion of the regulating authority when monitoring results indicate that the groundwater is at risk (slight increases in the concentrations of elements in the groundwater samples).

4.7.3 Surface water monitoring

Surface water should be monitored to ensure that surface water bodies are not contaminated by sludge application. Surface water chemistry may change within minutes, depending on controlled or uncontrolled discharges (Minimum Requirements, Latest edition). Flow from fountains and in streams must be monitored. If pollution occurs as a result of sludge application, these practices must be stopped immediately. Surface water monitoring includes run-off monitoring. The following surface water monitoring is required for all land application sites (Table 4.j):

- **Sampling frequency:**
  - Sample **monthly** from streams above and below application site (20-50 m downstream). It is important that thorough in-stream mixing have occurred before samples are taken.
  - Water sampling, preservation and analyses should be done according to the described procedures in the *Minimum Requirements for Water monitoring at waste management facilities* (Latest edition)
  - Surface water microbiology should be monitored when Microbiological class B and C sludge is disposed. Faecal streptococci, faecal coliforms and *E. coli* are the traditional variables that seem the most appropriate bacterial indicators for monitoring of faecal pollution in groundwater and surface water. There is an international trend towards using *E. coli* instead of the more traditional faecal coliforms partly because of the availability of improved analytical techniques. If a single variable was to be chosen it would be *E. coli* (Murray *et al*., 2004).
  - Run-off should be collected and analysed before discharge
  - No analyses are needed when run-off is re-cycled into the wastewater treatment system
  - The frequency for surface water monitoring could be **relaxed if**:
    - The distance to the nearest surface water resource or borehole is > 1 km;
    - The user can prove that the surface water resource is adequately protected through run-off interception

- ◘ When monitoring results over a 5 year period indicate no significant impact on the surface water resource, the regulating authority may relax the monitoring frequency. However, it is recommended that samples must be taken at least twice a year for monitoring.

- The monitoring frequency may be **increased** at the discretion of the regulating authority when the concentration of elements in the surface water samples is reason for concern.

Table 4.j: Surface water sampling and analyses for monitoring

What should be monitored?	pH, EC, PO_4, NH_4, NO_3, COD Faecal coliforms and *E. coli* depending on sludge quality	
How often should samples be taken?	Monthly from streams above and below the disposal site (20-50 m downstream)	
What sampling equipment should be used?	Plastic bottles with a plastic cap and no liner within the cap are required for most sampling exercises. Glass bottles are required if organic constituents are to be tested.	
How should samples be taken?	Appendix (Sampling procedures)	
Should samples be preserved?	**For pH, EC, PO_4 analyses**	**For NH_4, NO_3, COD analyses**
	No additives, refrigerate and analyse as soon as possible	Add H_2SO_4 to pH<2
	Microbiological analyses	
	No additives, keep in cooler box with ice and analyse within 24 hours	
How many samples should be taken?	At least 2 samples from each stream, 1 sample for pH, EC and PO_4 analyses and 1 sample for NH_4, NO_3 and COD analyses. An additional sample needed for microbiological analyses (if applicable).	
Sample sizes	At least 100 mℓ of each sample will be needed	
Analytical methods	Appendix (Standard analytical methods)	

4.7.4 Soil monitoring

Soil monitoring will serve as an early warning system on the mobility of constituents of concern in the soil profile and the potential for groundwater contamination.

- Frequency of monitoring will depend on:
  - The sludge type applied (liquid or dewatered). Research results by Herselman *et al.* (2005) indicated that metals added to soil with liquid sludge pose a bigger threat to the environment than metals added with dewatered sludge. It can be explained by the metals in the liquid sludge being soluble and mobile in the soil profile while the metals in dewatered sludge are adsorbed by the soil particles during ploughing, rendering it less soluble and immobile.

Metals added with liquid, anaerobically digested are the worst case scenario for metal mobility in the soil profile.

Sites receiving liquid sludge also have the additional water added to the infiltrate into the soil and transport pollutants to the groundwater. Consider the following scenario as an example: The site is 4 ha and situated in an area receiving 700 mm/year rainfall. The WWTP produce 100 m^3 sludge with 2% solids per day ($2t_{dry\ sludge}$/day) and 36 500 m^3 per year which they apply on the 4ha site, cultivating instant lawn. Therefore each hectare (10000 m^2) receives 9125 m^3 sludge/year = 0.9 m (900 mm) water/year in addition to the 700 mm rainfall.

- Soil pH – metals are generally more mobile at soil pH<6.5. Therefore more frequent monitoring intervals are recommended for these soils.
- Soil clay content – metals leach faster in sandy soils, therefore more frequent monitoring intervals are recommended for soils with clay content <20%.

- Analyses will depend on the constituents of concern in the sludge but must at least include nutrients and the 8 metals specified in the classification of sludge (Table 4.k). Soils should be analysed for total metal content with the *aqua regia* method (described in Volume 1)

Table 4.k: Soil sampling and analyses for monitoring

What should be monitored?	pH, nutrients and 8 metals (total) specified in classification
How often should samples be taken?	See below
How to sample?	Sample at 100 mm intervals to at least 500 mm Appendix (Sampling procedures)
How many samples?	At least 4 composite samples of each disposal area
Sample sizes	At least 1 kg
Analytical methods	Appendix (Standard analytical methods)

- **Sampling:**
  - Sample the land application site area according to different soil types (if applicable)
  - Increase the sample frequency when the soil pH<6.5 and/or soil clay content <20%
  - Sample at 100 mm depth increments up to 500 mm
  - Collect numerous samples, mix well and submit at least three composite samples for each depth increment for every hectare of the land where sludge is added
  - Analyse samples for nutrients and metals and determine soil pH

4.8 Closure and remediation plans for continuous high rate land application sites

Closure design should account for site-specific considerations. The DWAF is in a process of formulating a remediation strategy, which will provide further guidance on site- specific remediation once completed. In order to close a site properly, closure must be preceded by remediation, to ensure that the site is environmentally acceptable. The site must also be rendered suitable for its proposed end-use (Minimum Requirements, Latest edition). Once the operation has ceased, aftercare is necessary to ensure sustained acceptability. A rehabilitation and closure plan for continuous high rate application sites may be required if contamination of the soil or water resources has occurred to levels above the prescribed limits.

If the site is authorised, it must be remediated in accordance with the Permit conditions and the relevant Minimum Requirements for closure. If, however, the site does not have a Permit, it must be authorised with a view to closure. In this event, the emphasis of the Permit Application is on closure design and remediation. Regardless of whether an application site is authorised or not, it must be investigated before remediation and closure can commence, so as to identify any closure requirements that must be implemented (Minimum Requirements, Latest edition).

Remediation will only be applicable to **existing sites receiving continuous high rate sludge** application. All new sites will be monitored and sludge application will cease before remediation of the area is necessary. A site remediation/rehabilitation plan should be developed by a responsible person when:

- Groundwater quality deteriorates due to sludge application; or
- Surface water quality is affected due to sludge application; or
- The total soil metal content exceed the MPL; or
- Mobility of metals and nutrients in the soil profile is observed.

The remediation of a site will ensure that the final condition of the site is environmentally acceptable and that there will be no adverse long term effects on the environment. It should include final cover/capping and vegetating. Any long-term leachate, storm water and erosion control systems required should be in place before closure (Minimum Requirements, Latest edition). The extent of the remediation plan will depend on several factors including:

- Size of the site
- Extent of pollution – sites where metals in the soil profile has moved slightly deeper than 500 mm will require a less complicated rehabilitation plan than sites where groundwater contamination already occurred
- Future land-use

4.9 Record keeping for land disposal

Once the applicable permits and licences have been granted, sludge application essentially become self-regulatory. This implies that certain records must be kept by the sludge producer and application site owner/operator. Table 4.l summarises the general record keeping requirements for the producer and user (irrespective of the class of sludge produced). It is the responsibility of the producer to get data from the disposal site owner/operator as per their contract/agreement. These data could be used to obtain insight into the environmental degradation due to sludge application and to determine whether the mitigating factors implemented in this Guideline were sufficient to protect all receptors.

Table 4.l: Record keeping requirements for the Sludge Producer

Description of records to be kept by sludge producer	Applicable to:	
Sludge records	**Once-off**	**Continuous**
Classification of sludge applied to land	✓	✓
Results supporting classification in terms of the: • Microbiological class • Stability class • Pollutant class	✓	✓
The original or certified copy of the contract / agreement between the sludge producer and the sludge user (if applicable)	✓	✓
A copy of the applicable permits and licenses		✓
Description of records to be kept by the sludge user		
General information		
Sludge application rate (ton/ha)	✓	✓
Frequency of sludge application (Dates)	✓	
Location of site (map or co-ordinates)	✓	✓
Initial site investigation and site selection records		
Proof that application site is not located in a sensitive area	✓	✓
Groundwater data including: • Aquifer classification (yield, depth, strategic value) • Hydraulic gradient • Groundwater quality (up gradient and down gradient)		✓
Surface water quality data		✓
Soil data including: • Soil structure, pH, clay content, permeability and cation exchange capacity (CEC) • Soil classification and soil map of the area • Concentration of nutrients, trace elements and metals (total)	✓ (metals only)	✓
Monitoring records		
Groundwater data including: • Groundwater levels • Groundwater monitoring data (chemistry and microbiology if applicable)		✓
Surface water data including: • Run-off volumes and quality (if applicable) • Water quality from nearby stream		✓
Soil data including: • Nutrient status with depth • Metal content of the soil with depth (total)		✓
Crop information: • Type of crop cultivated • Where it was sold / used / replanted		✓

5 SPECIFIC RESTRICTIONS AND REQUIREMENTS FOR USING SLUDGE AS DAILY OR FINAL COVER ON LANDFILL

For Volume 4 of the sludge guidelines the use of sludge with other cover material on landfill is considered as a beneficial use option although this option is not specifically mentioned in the Minimum Requirements. However, the restrictions and recommendation presented in the Minimum Requirements (Latest edition) should be adhered to whenever waste is placed on landfill and therefore it is applicable to this part of Volume 4 as well. There are certain requirements than should be fulfilled before sludge could be used as landfill cover material. These requirements will be discussed in the sections that follow.

5.1 Advantages and disadvantages of using sludge as landfill cover material

Using sludge as cover material, either in its dried or composted form, or when mixed with soils, has certain advantages and disadvantages. Unless the sludge is dried, composed or mixed with soils it is too wet and odorous to apply as daily or final cover material. The high moisture content makes surfaces unstable for traffic and a potential source of pests such as flies (Dollar, 2006).

Ideally landfills are sited where the soils provide a barrier between the landfill liner and any surface or groundwater. Generally, the material excavated during construction of the landfill is used to cover the waste at the end of each working day to isolate it from the environment. At sites where the natural soils have low permeability, the daily cover forms layers of low permeability and these act as barriers to the downward percolation of moisture or leachate in the landfill. This leads to the formation of perched leachate which then flows along the upper boundary of the low permeability layer and seeps out at the landfill side wall. This build up of leachate can cause instability of the side slopes. A potential advantage of using dried or composted sludge or sludge mixed with soil as daily cover is that it retains moisture, but once its storage capacity is exceeded, additional moisture is able to percolate through and ultimately reach the landfill liner and leachate management system. The moisture retention is valuable because waste decay requires moisture. In addition to the moisture retention, the sludge contains nutrients that are present in the landfill at sub-optimal levels decay and are distributed into the waste by percolation of water. Although these benefits (moisture retention and nutrient supply) are limited to waste directly adjacent to the cover layers, it does aid in the distribution of moisture and nutrients within the landfill. Even after the sludge dries out, it is able to retain moisture when next in contact with percolating moisture. In parts of South Africa where potential evaporation exceeds rainfall, this would provide a limited means of promoting waste decay and thus reduce the time required for the landfill to become stabilised (Dollar, 2006).

Sludge contains metals from the wastewater. If the waste or leachate is acidic (as is the case during the initial phases of decay), these metals can be mobilised and contribute to the pollution load of the leachate. However, sludge has some buffering capacity (Röhrs, 2002) and aids the precipitation of metals from the leachate. The extent to which this occurs is dependent on the sludge and leachate quality. The landfill cap or final cover is designed to isolate the landfill from the environment and controls the amount of precipitation that enters the landfill. This in turn impacts on the rate of decay and the quality and quantity of both gas and leachate emissions. For some time landfill caps were designed with layers of flexible membranes or low permeability clays in order to limit the amount of moisture entering the waste body (Lee and Jones-Lee, 1993). However, in many temperate areas, this led to the slowing down or ceasing of the decay processes. The problem with this is that if any cracks occur in the capping, decay starts again due to moisture ingress, but this may be at a time when there is no longer active aftercare of the landfill. Current practice is to allow small amounts of moisture to pass through the landfill cap so that decay can occur and lead to the stabilisation of the landfill (Dollar, 2006).

In areas where the climatic water balance is such that the site moisture content is low, benefits may be derived from mixing sludge with soil to form a bio-cover (Bogner et al., 2006) or evaporative cover. Dewatered sludge could be used directly from the wastewater treatment works or in its dried or composted form. The use of sludge in covers of this nature has not been done in South Africa and further research is required to determine its feasibility.

Landfill final covers in South Africa are designed with a vegetative layer overlying layers of low permeability (but of higher permeability than the liner system). There is potential to use sludge beneficially in it various forms as a soil conditioner in the vegetative layer. The advantages are derived from the addition of nutrients and the moisture retention capacity of the sludge. Disadvantages include the potential for nutrients and metals from the sludge to be leached from the cover during rainfall events before the vegetation is fully established. This would lead to a pollution load entering the surface water resources downstream of the landfill. However, this is likely to be of limited duration. Another disadvantage is that odours are produced when the sludge is wet during irrigation or precipitation. Again, this is occurs only for a short while after the material is placed.

Intermediate covers combine some of the aspects of daily and final covers. They are often constructed of the same material as the daily cover, but are thicker and provide a foundation layer for the final capping elements. The same advantages of moisture retention and nutrient supply derived from sewage sludge discussed for the daily and final covers apply; and the same disadvantages are evident (Dollar, 2006).

5.2 Minimum solids content

Sludge with solids content of 50% looks and functions much like soil. It will increase the water holding capacity of the final cover of the landfill facility and has high odour absorbing abilities. Unless the sludge is dried, composted or mixed with soil it is too wet and odorous to apply as daily or final cover material. The high moisture content makes surfaces unstable for traffic and has vector attraction properties. Landfill operators may be prepared to take sludge with lower solids content and then dry it on the landfill site before use. This can be negotiated between the sludge producer and the landfill operator / owner.

5.3 Delisting

Sludge is defined as a hazardous waste, and before it can be used as a soil conditioner in the vegetative layer of the final cover, it would have to meet the requirements for delisting. It is important to note that using sewage sludge as cover material is not considered co-disposal, and therefore the requirements pertaining to co-disposal of sewage sludge do not apply. However, the specifications given for cover materials and disposal of hazardous waste must be met (Dollar, 2006).

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

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

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

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

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

5.4 Total load / maximum mixing ratio

Sludge is defined as a hazardous waste and it would have to meet the requirements for delisting before it can be used as a soil conditioner in the vegetative layer of the final cover. Since it would be a once-off application in the form of sludge mixed with soil (liquid or dewatered sludge), it would not require prior composting, although this may be done to achieve desirable properties of the sludge-soil mixture. The mixing ratio is determined by the nutrient requirements for the vegetation and the desirable soil properties, but is limited by the concentration of metals. The total load of a hazardous substance is the amount of the specific substance that may be accepted at a certain landfill site. The maximum mixing ratio is the total load of sludge that may be mixed with other cover material before application. The mixing ratio is calculated based on the EEC (see Appendix 1 for a sample calculation). In calculating the Total Load, the factor of 100 given in Section 8.6 of the Minimum Requirements may not be used as it is a factor derived by assuming that leachate within the landfill is retained by the liner. In the case of any runoff from the cover there would be no impact from the landfill liner.

Even though the sludge might meet the delisting criteria, it is important to consider the process to be followed during the mixing of the sludge with soil and the placing of the vegetative layer to ensure that no adverse environmental impacts occur. During the establishment of vegetation there may be some leaching of pollutants from the sludge-amended soil, but this is not considered contaminated water requiring treatment (which would be the case for water coming into contact with the waste) as the EEC requirement has already been met (Dollar, 2006). An example for the calculation of the maximum mixing ration is presented in Appendix 2.

5.5 Compaction properties of the soil/sludge mixture

The moisture of the sludge and its rheological properties are very important in terms of the final properties of the soil-sludge mixture. The optimal compaction density and moisture content for the mixture will be different to that of the soil used in the mixture and this needs to be considered for operational purposes. Regardless of any maximum sludge loads calculated, the mixed material must conform to construction criteria, and it is a requirement that the compaction properties of all soils or modified soils used in the capping layers be established according to the Standard Proctor Compaction Test (*Minimum Requirements for Waste Disposal by Landfill*. 3rd edition, Section 8.3.2). In addition, the shear interface friction between the compacted mixture and the layer below must be considered to ensure that the layer will not slip at the final landfill profile slopes (*Minimum Requirements for Waste Disposal by Landfill*. 3rd edition, Section 8.3.3).

5.6 Management requirements for using sludge as landfill cover

All the management requirements as specified in the *Minimum Requirements (Latest edition) Section 10: Landfill Operation* should be adhered to by the landfill operator.

5.7 Monitoring requirements for using sludge as landfill cover material

All the monitoring requirements as specified in the *Minimum Requirements (Latest edition) Section 11: Operation Monitoring* should be adhered to by the landfill operator. Additional monitoring requirements pertaining to using sludge as cover material include:

- Sludge monitoring to ensure that the quality stays within the limits required for application to landfill. The sampling frequency for monitoring purposes depends on the amount of sludge produced and can be summarised as follows:

  <1 t $_{\text{dry weight}}$/day – yearly

  1-5 t $_{\text{dry weight}}$/day – quarterly

  5-45 t $_{\text{dry weight}}$/day – biannually

  >45 t $_{\text{dry weight}}$/day – monthly

- However, the landfill operator may require additional monitoring, especially in the case of Pollutant class b sludge that needed to be treated before it could be delisted and used as cover material.

6 CONCLUSIONS

The new Sludge Guidelines have been developed with sustainable, beneficial use of sludge in mind. Although agricultural use of sludge (as described in Volume 2) is the beneficial use option with the least environmental impact, it is not always the most feasible option. In some cases the WWTP is in an urban area, some distance away from agricultural land with transport cost implications and in other cases the sludge quality is not good enough for agricultural use. In these cases other beneficial use options have been identified where the risks to the environment and public health is mitigated although sludge is added to land at high rates.

Volume 4 of the Sludge Guidelines informs the reader regarding the legal requirements for high rate sludge application on land (both once-off and continuous) and the use of sludge as landfill cover material. This document informs the reader in the scientific and technical foundations that Volume 4 was build upon.

Due to the high rate of sludge application at these sites restrictions and requirements should be applied to protect the receiving environment. These restrictions and requirements become more stringent with deteriorating sludge quality and the vulnerability of the receiving environment. Especially at existing continuous application sites, where the necessary criteria for site selection are not met, the management and monitoring requirements increases substantially. The development of closure and remediation plans is introduced to ensure sustained acceptability.

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Appendix 1: Risk assessments

Rehabilitation/Remediation of: Mine tailings/dumps, degraded and contaminated soils		
	Microbiological	Pathogens, disease causing issues
	Stability	Odours, vector attraction, moisture content, pH
	Metal	Potentially harmful metals, Cd, As, Cr, etc.
	Nutrient	N, P
	Organic pollutants	Pesticides, PAH, etc.
	Other	Management issues

Receptor	Pathway no	Issue	Risk to receptor			Notes	Mitigating factors
			Conse-quence	Proba-bility	Risk rating		
Workers @ application site	1.1	Microbiological	4	4	16	Workers @ application sites could be severely impacted by direct contact with sludge with high pathogens	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	2	3	6	Vectors and odours may cause self treatable conditions	Workers to be equipped with proper PPE
		Metal	1	3	3	Metals have no impact via dermal contact	None required
		Nutrient	1	3	3	Nutrients have no impact via dermal contact	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and thus could occur (1:10 000)	Workers to be equipped with proper PPE
		Other			0		
	1.2	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	3	3	9	Odours and volatile pollutants from unstabilised sludge may have moderate consequences for workers	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Other			0		
	1.3	Microbiological	1	1	1	Inhalation of incinerator emissions not applicable at application sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	1.4	Microbiological	3	4	12	Ingestion of pathogens may cause recoverable conditions and thus could occur (1:10 000)	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	2	3	6	Vectors may cause self treatable conditions	Workers should be informed of health risk, how to decrease risk and

							be equipped with proper PPE
		Metal	2	4	8	Metal ingestion may cause self treatable conditions but probability is 1:1 000	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Nutrient	1	3	3	Nutrients have no impact via ingestion	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and thus could occur (1:10 000)	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Other			0		
	1.5	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	1	1	1	NA	
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Other			0		
	1.6	Microbiological	3	3	9	Pathogens carried by vectors could cause recoverable conditions and thus could occur (1:10 000)	Apply vector attraction reduction measures, beneficial use of unstable sludge should not be allowed
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures, beneficial use of unstable sludge should not be allowed
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	1	1	1	NA	NA
		Other			0		
General population	2.1	Microbiological	3	3	9	Pathogens will cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites
		Stability	2	3	6	Vectors and odours may cause self treatable conditions	Access restrictions for general public at application sites
		Metal	1	3	3	Metals have no impact via dermal contact	None required
		Nutrient	1	3	3	Nutrients have no impact via dermal contact	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites
		Other			0		
	2.2	Microbiological	3	3	9	Ingestion of pathogens may cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites
		Stability	2	3	6	Vectors may cause self treatable conditions	Access restrictions for general public at application sites

		Metal	2	2	4	Metal ingestion may cause self treatable conditions but probability is very low (1:100 000)	Access restrictions for general public at application sites
		Nutrient	1	3	3	Nutrients have no impact via ingestion	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites
		Other			0		
	2.3	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for general public at application sites, buffer zones between application sites and dwellings
		Stability	3	3	9	Odours and volatile pollutants from unstabilised sludge may have moderate consequences for general public	Access restrictions for general public at application sites, buffer zones between application sites and dwellings
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for general public at application sites, buffer zones between application sites and dwellings
		Other			0		
	2.4	Microbiological	1	1	1	Inhalation of incinerator emissions not applicable to remediation/rehabilitation sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	2.5	Microbiological	4	4	16	Ingestion of crops grown on soil amended with sludge with high pathogen content could possibly have severe consequences	Crop restriction should apply if the rehabilitated site is to be used for crop production. Crops for human consumption should rather be prohibited.
		Stability	1	1	1	NA	None required
		Metal	4	4	16	Ingestion of crops grown on soil amended with sludge with high metal content could possibly have severe consequences	Crop restriction should apply if the rehabilitated site is to be used for crop production. Crops for human consumption should rather be prohibited.
		Nutrient	1	1	1	Ingestion of nutrients don't have negative effects	None required
		Organic pollutants	1	1	1	Organic pollutants are not taken up by plants	None required
		Other	1	1	1		
	2.6	Microbiological	3	3	9	Ingesting meat from animals grazing on sludge amended soils with high pathogen content could have moderate consequences for humans. Pathway has several barriers, reducing the risk.	Crop restriction and management requirements should apply if the rehabilitated site is to be used for animal grazing.
		Stability	1	1	1		None required

		Metal	3	3	9	Ingesting meat from animals grazing on sludge amended soils with high metal content could have moderate consequences for humans. Pathway has several barriers, reducing the risk.	Crop restriction and management requirements should apply if the rehabilitated site is to be used for animal grazing.
		Nutrient	1	1	1		None required
		Organic pollutants	3	3	9	Ingesting meat from animals grazing on sludge amended soils with high organic pollutant content could have moderate consequences for humans. Pathway has several barriers, reducing the risk.	Crop restriction and management requirements should apply if the rehabilitated site is to be used for animal grazing.
		Other	1	1	1		None required
	2.7	Microbiological	3	4	12	Drinking surface water contaminated with pathogens may cause recoverable conditions, probability is possible (1:1 000)	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	2	2	4	Drinking surface water impacted by vectors may cause self treatable conditions, probability is rare (1:100 000)	None required
		Metal	3	2	6	Solubility of metals in sludge is very low and the impact to general public through drinking metal polluted surface water is assumed to be very low	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Nutrient	2	3	6	The impact of nutrients on human health via drinking of impacted surface water is assumed to be very low. Nitrate in drinking water can be as high as 20 mg/l N before any risk occur	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Organic pollutants	1	3	3	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on the general public drinking surface water is low	None required
		Other			0		
	2.8	Microbiological	1	1	1	Pathway too many barriers, no impact	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	2.9	Microbiological	2	1	2	Vaguely possible under conditions of catastrophic flooding. However under these circumstances dilutions will be high and the threat of bioaccumulation low	None required
		Stability	1	1	1	NA	
		Metal	2	1	2	Vaguely possible under conditions of catastrophic flooding. However under these circumstances dilutions will be high and the threat of bioaccumulation low	None required
		Nutrient	1	1	1	NA	
		Organic pollutants	2	1	2	Organic pollutants are insoluble	None required

		Other			0		
	2.10	Microbiological	2	3	6	Impact on general public bathing in surface water impacted by high microbiological sludge after application to remediation/rehabilitation sites is low, the probability is also low 1: 10 000	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	1	1	1	No impact	None required
		Metal	1	1	1	No impact	None required
		Nutrient	1	1	1	No impact	None required
		Organic pollutants	1	1	1	Organic pollutants are insoluble	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Other			0		
	2.11	Microbiological	3	4	12	Drinking groundwater impacted by pathogens may cause recoverable conditions, probability is 1:1 000	Buffer zones between application sites and groundwater (depth to aquifer)
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	None required
		Nutrient	2	4	8	Leaching of nitrate to groundwater at sites after high sludge application rate is probable (1:1 000; dewatered sludge) but the consequence to humans consuming groundwater is self treatable. N in groundwater can be as high as 20 mg/l before any risk to babies	Buffer zones between application sites and groundwater (depth to aquifer)
		Organic pollutants	2	2	4	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000)	Buffer zones between application sites and groundwater (depth to aquifer)
		Other			0		
	2.12	Microbiological	3	3	9	Bathing in groundwater impacted by pathogens may cause self treatable conditions, probability is 1:10 000	Buffer zones between application sites and groundwater (depth to aquifer)
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low, bathing in groundwater will have no impact	None required
		Nutrient	1	1	1	Leaching of nitrate to groundwater at remediation/rehabilitation sites is probable (1:1 000; dewatered sludge) but the consequence to humans bathing in groundwater is low.	None required
		Organic pollutants	1	1	1	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000) and the impact to humans bathing in groundwater is low	None required
		Other			0		
	2.13	Microbiological	3	3	9	Ingestion of pathogens may cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at remedial/rehabilitation sites
		Stability	2	3	6	Vectors may cause self treatable conditions	Access restrictions for general public at remedial/rehabilitation sites

		Metal	2	2	4	Metal ingestion via soil may cause self treatable conditions but probability is very low (1:100 000)	Access restrictions for general public at remedial/rehabilitation sites
		Nutrient	1	3	3	Nutrients have no impact via ingestion of soil	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and could occur (1:10 000)	Access restrictions for general public at remedial/rehabilitation sites
		Other			0		
	2.14	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for general public at remedial/rehabilitation sites
		Stability	1	1	1	NA	None required
		Metal	1	1	1	NA	None required
		Nutrient	1	1	1	NA	None required
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for general public at remedial/rehabilitation sites
		Other			0		
	2.15	Microbiological	3	3	9	Ingesting meat from animals eating sludge amended soils with high pathogen content could have moderate consequences for humans.	Management requirements should apply if the rehabilitated site is to be used for animal grazing to reduce the risk of animals ingesting sludge.
		Stability	1	1	1		None required
		Metal	3	3	9	Ingesting meat from animals eating sludge amended soils with high pathogen content could have moderate consequences for humans.	Management requirements should apply if the rehabilitated site is to be used for animal grazing to reduce the risk of animals ingesting sludge.
		Nutrient	1	1	1		None required
		Organic pollutants	3	3	9	Ingesting meat from animals eating sludge amended soils with high organic pollutant content could have moderate consequences for humans.	Management requirements should apply if the rehabilitated site is to be used for animal grazing to reduce the risk of animals ingesting sludge.
		Other	1	1	1		None required
	2.16	Microbiological	3	3	9	Pathogens carried by vectors could cause recoverable conditions and thus could occur (1:10 000)	Apply vector attraction reduction measures
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures, site remediation with unstable sludge should not be allowed
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	1	1	1	NA	NA
		Other			0		
Soil	3.1	Microbiological	1	1	1	No impact on soil physical properties	NA
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		

		Other			0	The organic material in sludge will have positive impacts on soil physical properties at remediation/rehabilitation sites.	None required
	3.2	Microbiological	1	1	1	No impact on soil fertility and chemical properties	NA
		Stability	1	1	1		
		Metal	2	4	8	If sludge with high metal content is applied to remediation/rehabilitation sites, the metal content of the soils will increase.	Management requirements should be implemented to protect the soil, i.e. maximum permissible levels for metals in soils should not be exceeded.
		Nutrient	1	4	4	Increase in soil fertility due to sludge application	None required
		Organic pollutants	2	4	8	If sludge with high organic pollutant content is applied to remediation/rehabilitation sites, it will influence soil quality.	Management requirements should be implemented to protect the soil.
		Other			0		
	3.3	Microbiological	1	1	1	Minimal threat of pathogenic effects	None required
		Stability			0	NA	NA
		Metal	2	1	2	Mortality highly unlikely. Effects, if any, likely to be localized and transitory.	None required
		Nutrient	2	1	2	Very low risk of oxygen depletion and localized mortality	None required
		Organic pollutants	2	1	2	Mortality highly unlikely. Effects, if any, likely to be localized and transitory.	None required
		Other			0		
	3.4	Microbiological	3	3	9	Impact of pathogens on sediments may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	1	1	1	NA	
		Metal	3	3	9	Impact of metals on sediments may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Nutrient	3	3	9	Impact of nutrients on sediments may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
	3.5	Microbiological	1	1	1	Very low pathogenic risk	None required
		Stability			0	NA	
		Metal	1	1	1	Very low risk of contamination. If any then likely to be localized and transitory	None required
		Nutrient	1	1	1	Very low risk of enrichment. If any then likely to be localized and transitory	None required
		Organic pollutants	1	1	1	Very low risk of contamination. If any then likely to be localized and transitory	None required
		Other			0	NA	

	3.6	Microbiological	2	3	6	Impact of pathogens on wetlands may need intervention to rehabilitate, probability is low (1: 10 000). Wetland could act as a sterilization step to remove pathogens	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	1	1	1	NA	
		Metal	3	3	9	Impact of metals on wetlands may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Nutrient	3	3	9	Impact of nutrients on wetlands may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
Crops	4.1	Microbiological	1	1	1	Pathogens will not affect yield but will affect quality	None required
		Stability	1	1	1	NA	
		Metal	4	2	8	Metals may affect crop yield at high application rates (phytotoxicity)	Sludge quality should be specified for certain crops
		Nutrient	1	1	1	NA	
		Organic pollutants	1	1	1	Not taken up by plants	
		Other	1	1	1	NA	
	4.2	Microbiological	3	3	9	The pathogen content of sludge will influence the quality of grazing crops, but not the yield.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability			0	NA	
		Metal	3	3	9	The metal content of sludge will influence the quality of grazing crops, and could also affect the yield if the type of crop is sensitive too metal concentrations or metals are phytotoxic.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Nutrient			0	Nutrients will have positive effects on crops	None required
		Organic pollutants	1	1	1	The organic pollutant content of sludge will not influence the quality of grazing crops.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Other			0		
	4.3	Microbiological	3	3	9	The pathogen content of sludge will influence the quality of crops, but not the yield.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability			0	NA	

		Metal	3	3	9	The metal content of sludge will influence the quality of crops, and could also affect the yield if the type of crop is sensitive too metal concentrations or metals are phytotoxic.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Nutrient			0	Nutrients will have positive effects on crops	None required
		Organic pollutants	3	3	9	The organic pollutant content of sludge will influence the quality of crops, but not the yield.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Other			0		
Vegetation	5.1	Microbiological	1	3	3	Pathogens will not affect vegetation (yield, biodiversity, etc.)	None required
		Stability	1	3	3	Odours and vectors will not affect vegetation (yield, biodiversity, etc.)	None required
		Metal	3	3	9	Metals could be phytotoxic to plants and result in deterioration of biodiversity. However, sites that need remediation/ rehabilitation already have biodiversity problems and sludge application would not further deteriorate biodiversity.	Remediation/rehabilitation sites would typically need revegetation. The selection of the appropriate type of vegetation should include metal tolerant plant or plants that could be used for phyto remediation.
		Nutrient	1	3	3	Nutrients will have no negative impact on natural vegetation	None required
		Organic pollutants	1	3	3	Organic pollutants will not affect vegetation (yield, biodiversity, etc.)	None required
		Other			0		
Air	6.1	Microbiological	2	4	8	Pathogens in sludge influence air quality confined to working area, 1:1 000	Supply workers with PPE
		Stability	2	5	10	Odour nuisance to surrounding community	Vector attraction reduction options, unstable sludge should not be used for rehabilitation purposes
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	4	8	Volatile pollutants confined to working area, 1:1 000	Supply workers with PPE
		Other			0		
	6.2	Microbiological	3	4	12	Pathogens in sludge influence air quality confined to working area, 1:1 000	Supply workers with PPE
		Stability	3	5	15	Odour nuisance to surrounding community	Vector attraction reduction options, unstable sludge should not be used for rehabilitation purposes
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	4	12	Volatile pollutants confined to working area, 1:1 000	Supply workers with PPE
		Other			0		
	6.3	Microbiological	2	3	6	Pathogens in sludge influence air quality confined to working area, 1:1 000	Supply workers with PPE

		Stability	2	5	10	Odour nuisance to surrounding community	Vector attraction reduction options, unstable sludge should not be used for rehabilitation purposes
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	3	6	Volatile pollutants confined to working area, 1:10 000	Supply workers with PPE
		Other			0		
	6.4	Microbiological	1	1	1	No incinerator emissions at rehabilitation sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
Surface water	7.1	Microbiological	3	3	9	Recoverable impact due to pathogens via soil, low probability	Buffer zone between remediation/rehabilitation sites and surface water bodies, implementation of run-off interception measures.
		Stability	1	1	1	NA	
		Metal	2	3	6	Temporary impact on fitness for use of surface water due to metals via soil, low probability	Buffer zone between remediation/rehabilitation sites and surface water bodies, implementation of run-off interception measures.
		Nutrient	3	3	9	Recoverable impact due to nutrients via soil, low probability	Buffer zone between remediation/rehabilitation sites and surface water bodies, implementation of run-off interception measures.
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	7.2	Microbiological	4	3	12	Long-term impairment of fitness of use due to pathogens, low probability	Buffer zone between remediation/rehabilitation sites and surface water bodies, implementation of run-off interception measures.
		Stability	1	1	1	NA	
		Metal	3	3	9	Recoverable impact on fitness for use of surface water due to metals, low probability	Buffer zone between remediation/rehabilitation sites and surface water bodies, implementation of run-off interception measures.
		Nutrient	4	3	12	Long-term impairment of fitness of use due to nutrients, low probability	Buffer zone between remediation/rehabilitation sites and surface water bodies, implementation of run-off interception measures.
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	7.3	Microbiological	3	2	6	Recoverable impact due to airborne pathogens, rare probability	Buffer zone between remediation/rehabilitation sites and surface water bodies.
		Stability	1	1	1	NA	
		Metal	2	2	4	Temporary impact on fitness for use of surface water due to airborne metals, rare probability	Buffer zone between remediation/rehabilitation sites and surface water bodies.

		Nutrient	2	2	4	Temporary impact on fitness for use of surface water due to airborne nutrients, rare probability	Buffer zone between remediation/rehabilitation sites and surface water bodies.
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	7.4	Microbiological	3	1	3	Recoverable impact due to airborne pathogens via soil, highly unlikely probability	None required
		Stability	1	1	1	NA	
		Metal	2	1	2	Temporary impact on fitness for use of surface water due to airborne metals via soil, highly unlikely probability	None required
		Nutrient	2	1	2	Temporary impact on fitness for use of surface water due to airborne nutrients, highly unlikely probability	None required
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	7.5	Microbiological	3	3	9	Pathogens may leach through soil to groundwater and impact on surface water. Moderate consequence and low probability	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer) will protect surface water as well
		Stability	1	1	1	NA	NA
		Metal	4	2	8	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a rare probability that groundwater will be impacted	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer) will protect surface water as well
		Nutrient	4	5	20	Nutrients may cause long-term impairment of fitness for use, and due to the mobility of especially N, it could happen regularly	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer) will protect surface water as well
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	7.6	Microbiological	2	3	6	Low intensity impact, low likelihood	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	2	2	4	Low intensity impact, rare probability	None required
		Other			0		
	7.7	Microbiological	2	2	4	Low intensity impact, rare probability	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	2	1	2	Low intensity impact, highly unlikely	None required
		Other			0		
Groundwater	8.1	Microbiological	3	3	9	Pathogens in sludge may migrate through the soil into groundwater.	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)

	Stability	4	2	8	Low pH mobilize metals, may cause long-term impairment of fitness for use, rare probability	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)
	Metal	4	2	8	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a rare probability	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)
	Nutrient	4	5	20	Nutrients may cause long-term impairment of fitness for use, and due to the mobility of especially N, it could happen regularly	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)
	Organic pollutants	2	1	2	Low intensity impact, highly unlikely	None required
	Other			0		
	Microbiological	3	3	9	Pathogens in sludge may migrate through preferential pathways directly into groundwater, causing recoverable impacts.	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)
	Stability	1	1	1	NA	NA
8.2	Metal	4	3	12	Metals may cause long-term impairment of fitness for use, low likelihood of direct groundwater contamination	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)
	Nutrient	4	4	16	Nutrients may cause long-term impairment of fitness for use, direct contamination is possible	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)
	Organic pollutants	1	1	1	NA (low solubility)	
	Other			0		
	Microbiological	3	3	9	Pathogens in sludge may migrate through the soil into groundwater.	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)
	Stability	4	2	8	Low pH mobilize metals, may cause long-term impairment of fitness for use, rare probability	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)
8.3	Metal	4	2	8	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a rare probability	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)
	Nutrient	4	5	20	Nutrients may cause long-term impairment of fitness for use, and due to the mobility of especially N, it could happen regularly	Buffer zone between remediation/rehabilitation sites and groundwater (depth to aquifer)
	Organic pollutants	2	1	2	Low intensity impact, highly unlikely	None required
	Other			0		
	Microbiological	4	2	8	Long-term impairment of fitness of use due to pathogens, rare probability	Buffer zone between remediation/rehabilitation sites and surface water bodies will also protect groundwater
	Stability	1	1	1	NA	
8.4	Metal	3	2	6	Recoverable impact on fitness for use of surface water due to metals, rare probability	Buffer zone between remediation/rehabilitation sites and surface water bodies will also protect groundwater
	Nutrient	4	4	16	Long-term impairment of fitness of use due to nutrients, probable	Buffer zone between remediation/rehabilitation sites and surface water bodies will also protect groundwater

		Organic pollutants	2	1	2	Low intensity impact, highly unlikely (low solubility)	None required
		Other			0		
Marine environment	9.1	Microbiological	1	1	1	NA to remediation/rehabilitation sites	None required
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	9.2	Microbiological	3	3	9	Recoverable impact due to pathogens via surface water, low probability	Buffer zone between remediation/rehabilitation sites and surface water bodies, implementation of run-off interception measures.
		Stability	1	1	1	NA	
		Metal	2	3	6	Temporary impact on fitness for use of surface water, low probability	Buffer zone between remediation/rehabilitation sites and surface water bodies, implementation of run-off interception measures.
		Nutrient	3	3	9	Recoverable impact due to nutrients via surface water, low probability	Buffer zone between remediation/rehabilitation sites and surface water bodies, implementation of run-off interception measures.
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	9.3	Microbiological	3	1	3	Pathogens in sludge could impact on marine environment if the remediation/rehabilitation site is close enough to the surf zone, highly unlikely	None required
		Stability			0	NA	
		Metal	3	1	3	Metals in sludge could impact on marine environment if the remediation/rehabilitation site is close enough to the surf zone, highly unlikely	None required
		Nutrient	3	1	3	Nutrients in sludge could impact on marine environment if the remediation/rehabilitation site is close enough to the surf zone, highly unlikely	None required
		Organic pollutants	3	1	3	Organic pollutants in sludge could impact on marine environment if the remediation/rehabilitation site is close enough to the surf zone, highly unlikely and insolubility of organic pollutants	None required
		Other			0	NA	
	9.4	Microbiological	1	1	1	NA to remediation/rehabilitation sites	None required
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		

	9.5	Microbiological	3	1	3	Air borne pathogens in sludge could impact on marine environment if the remediation/rehabilitation site is close enough to the surf zone, highly unlikely	None required
		Stability	1		0	NA	
		Metal	3	1	3	Metals in air borne sludge could impact on marine environment if the remediation/rehabilitation site is close enough to the surf zone, highly unlikely	None required
		Nutrient	3	1	3	Nutrients in air borne sludge could impact on marine environment if the remediation/rehabilitation site is close enough to the surf zone, highly unlikely	None required
		Organic pollutants	3	1	3	Organic pollutants in air borne sludge could impact on marine environment if the remediation/rehabilitation site is close enough to the surf zone, highly unlikely and insolubility of organic pollutants	None required
		Other			0	NA	
Grazing animals	10.1	Microbiological	3	4	12	Grazing animals on sites that were rehabilitated with sludge with high pathogen content could cause moderate effects to the animal, and it can possibly happen.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability	1	1	1	NA	
		Metal	4	3	12	Grazing animals on sites that were rehabilitated with sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen due to several barriers in pathway.	Restrictions on sludge quality used for rehabilitation of sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented.
		Nutrient	1	1	1	NA	
		Organic pollutants	3	1	3	Organic pollutants in the sludge may pose a risk to animals but the probability is highly unlikely due to the insolubility of the constituents	None required
		Other			0		
	10.2	Microbiological	4	4	16	Grazing animals on sites that were rehabilitated with sludge with high pathogen content could cause moderate effects to the animal, and it can possibly happen.	Access restrictions for a certain period after sludge application and management requirements (incorporate sludge into the soil) should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability	1	1	1	NA	

		Metal	4	3	12	Grazing animals on sites that were rehabilitated with sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen.	Restrictions on sludge quality used for rehabilitation of sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented. Sludge should be incorporated into the soil.
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	10.3	Microbiological	3	4	12	Drinking surface water contaminated with pathogens may cause recoverable conditions, probability is possible (1:1 000)	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	2	2	4	Drinking surface water impacted by vectors may cause recoverable effects, probability is rare (1:100 000)	None required
		Metal	3	2	6	Solubility of metals in sludge is very low and the impact on animals through drinking metal polluted surface water is assumed to be very low	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Nutrient	2	2	4	The impact of nutrients on animal health via drinking of impacted surface water is assumed to be very low. Nitrate in water used for animal drinking water can be as high as 100 mg/l NO3 before any risk occur	None required
		Organic pollutants	1	3	3	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on the general public drinking surface water is low	None required
		Other			0		
	10.4	Microbiological	3	4	12	Drinking groundwater impacted by pathogens may cause recoverable conditions, probability is 1:1 000	Buffer zones between application sites and groundwater (depth to aquifer)
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	None required
		Nutrient	2	4	8	Leaching of nitrate to groundwater at sites after high sludge application rate is probable (1:1 000; dewatered sludge) but the consequence to animals consuming groundwater is recoverable. Nitrate in groundwater can be as high as 100 mg/l without negative effects on grazing animals	Buffer zones between application sites and groundwater (depth to aquifer)
		Organic pollutants	2	2	4	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000)	Buffer zones between application sites and groundwater (depth to aquifer)
		Other			0		

	10.5	Microbiological	2	3	6	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for certain time periods after application for grazing animals
		Stability	2	2	4	Odours and volatile pollutants from unstabilised sludge may have recoverable effects for animals	None required
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	3	6	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for certain time periods after application for grazing animals
		Other			0		
	10.6	Microbiological	4	4	16	Grazing animals ingesting sludge with high pathogen content on rehabilitated sites could cause moderate effects to the animal, and it can possibly happen.	Access restrictions for a certain period after sludge application and management requirements (incorporate sludge into the soil) should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability	1	1	1	NA	
		Metal	4	3	12	Grazing animals on sites that were rehabilitated with sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen.	Restrictions on sludge quality used for rehabilitation of sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented. Sludge should be incorporated into the soil.
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	10.7	Microbiological	4	3	12	Grazing animals ingesting sludge on plants with high pathogen content on rehabilitated sites could cause moderate effects to the animal, and it can possibly happen.	Access restrictions for a certain period after sludge application and management requirements (incorporate sludge into the soil) should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability	1	1	1	NA	
		Metal	4	3	12	Grazing animals on sites that were rehabilitated with sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen.	Restrictions on sludge quality used for rehabilitation of sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented. Sludge should be incorporated into the soil.
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required

		Other			0		
	10.8	Microbiological	2	3	6	Pathogens carried by vectors could cause recoverable conditions and thus could occur (1:10 000)	Apply vector attraction reduction measures
	10.8	Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures, site remediation with unstable sludge should not be allowed
	10.8	Metal	1	1	1	NA	NA
	10.8	Nutrient	1	1	1	NA	NA
	10.8	Organic pollutants	1	1	1	NA	NA
	10.8	Other			0		
Fauna	11.1	Microbiological	3	4	12	Natural fauna on sites that were rehabilitated with sludge with high pathogen content could cause moderate effects to the animal, and it can possibly happen.	Restrictions on type of crop cultivated for animal feed.
Fauna	11.1	Stability	1	1	1	NA	
Fauna	11.1	Metal	4	3	12	Fauna on sites that were rehabilitated with sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen due to several barriers in pathway.	Restrictions on sludge quality used for rehabilitation of sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented.
Fauna	11.1	Nutrient	1	1	1	NA	
Fauna	11.1	Organic pollutants	3	1	3	Organic pollutants in the sludge may pose a risk to animals but the probability is highly unlikely due to the insolubility of the constituents	None required
Fauna	11.1	Other			0		
Fauna	11.2	Microbiological	4	4	16	Fauna ingesting soil on sites that were rehabilitated with sludge with high pathogen content could cause moderate effects to the animal, and it can possibly happen.	Management requirements (incorporate sludge into the soil) should be implemented
Fauna	11.2	Stability	1	1	1	NA	
Fauna	11.2	Metal	4	3	12	Fauna ingesting soil on sites that were rehabilitated with sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen.	Maximum permissible levels for metals in the receiving soil should be implemented. Sludge should be incorporated into the soil.
Fauna	11.2	Nutrient	1	1	1	NA	
Fauna	11.2	Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
Fauna	11.2	Other			0		
Fauna	11.3	Microbiological	3	4	12	Drinking surface water contaminated with pathogens may cause recoverable conditions, probability is possible (1:1 000)	Buffer zones between application sites and surface water bodies. Run-off interception measures
Fauna	11.3	Stability	2	2	4	Drinking surface water impacted by vectors may cause recoverable effects, probability is rare (1:100 000)	None required

		Metal	3	2	6	Solubility of metals in sludge is very low and the impact on animals through drinking metal polluted surface water is assumed to be very low	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Nutrient	2	2	4	The impact of nutrients on animal health via drinking of impacted surface water is assumed to be very low. Nitrate in water used for animal drinking water can be as high as 100 mg/l NO3 before any risk occur	None required
		Organic pollutants	1	3	3	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on animals drinking surface water is low	None required
		Other			0		
	11.4	Microbiological	3	4	12	Drinking groundwater impacted by pathogens may cause recoverable conditions, probability is 1:1 000	Buffer zones between application sites and groundwater (depth to aquifer)
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	None required
		Nutrient	2	4	8	Leaching of nitrate to groundwater at sites after high sludge application rate is probable (1:1 000; dewatered sludge) but the consequence to animals consuming groundwater is recoverable. Nitrate in groundwater can be as high as 100 mg/l without negative effects on grazing animals	Buffer zones between application sites and groundwater (depth to aquifer)
		Organic pollutants	2	2	4	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000)	Buffer zones between application sites and groundwater (depth to aquifer)
		Other			0		
	11.5	Microbiological	2	3	6	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for certain time periods after application
		Stability	2	2	4	Odours and volatile pollutants from unstabilised sludge may have recoverable effects for animals	None required
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	3	6	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for certain time periods after application
		Other			0		
	11.6	Microbiological	4	4	16	Fauna ingesting sludge with high pathogen content on rehabilitated sites could cause moderate effects to the animal, and it can possibly happen.	Management requirements (incorporate sludge into the soil) should be implemented, sludge should not be stored on site.
		Stability	1	1	1	NA	
		Metal	4	3	12	Fauna ingesting sludge on sites that were rehabilitated with sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen.	Sludge should be incorporated into the soil. No on-site storage allowed.

		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	11.7	Microbiological	3	4	12	Surface water contaminated with pathogens may cause deterioration in biodiversity of aquatic animals, probability is possible (1:1 000)	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	2	2	4	Drinking surface water impacted by vectors may need intervention to maintain aquatic biodiversity, probability is rare (1:100 000)	None required
		Metal	4	2	8	Solubility of metals in sludge is very low but the impact on aquatic animals in polluted surface water may be severe	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Nutrient	3	5	15	The impact of nutrients on aquatic live in impacted surface water may be moderate but the probability is regular. N as high as 2.5 mg/l N can cause decrease in biodiversity.	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Organic pollutants	3	1	3	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on the aquatic animals is low	None required
		Other			0		

Once off high rate application: **Golf course, vineyards, orchards, road-side cuttings, urban landscaping**	
Microbiological	Pathogens, disease causing issues
Stability	Odours, vector attraction, moisture content, pH
Metal	Potentially harmful metals, Cd, As, Cr, etc.
Nutrient	N, P
Organic pollutants	Pesticides, PAH, etc.
Other	Management issues

Receptor	Pathway no	Issue	Risk to receptor			Notes	Mitigating factors
			Consequence	Probability	Risk rating		
Workers @ application site	1.1	Microbiological	4	2	8	Workers @ application sites could be severely impacted by direct contact with sludge with high pathogens, however the probability is low since it is once off.	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	2	3	6	Vectors and odours may cause self treatable conditions	Workers to be equipped with proper PPE
		Metal	1	3	3	Metals have no impact via dermal contact	None required
		Nutrient	1	3	3	Nutrients have no impact via dermal contact	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and thus could occur (1:10 000)	Workers to be equipped with proper PPE
		Other			0		
	1.2	Microbiological	3	2	6	Inhalation of airborne pathogens may cause recoverable conditions however the probability is low since it is once off	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	3	3	9	Odours and volatile pollutants from unstabilised sludge may have moderate consequences for workers	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Inhalation of airborne organic pollutants may cause recoverable conditions	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Other			0		
	1.3	Microbiological	1	1	1	Inhalation of incinerator emissions not applicable at application sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	1.4	Microbiological	3	3	9	Ingestion of pathogens may cause recoverable conditions and thus could occur (1:10 000)	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	2	3	6	Vectors may cause self treatable conditions	Workers should be informed of health risk, how to decrease risk and be equipped with proper

							PPE
		Metal	2	3	6	Metal ingestion may cause self treatable conditions but probability is 1:10 000	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Nutrient	1	3	3	Nutrients have no impact via ingestion	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and thus could occur (1:10 000)	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Other			0		
	1.5	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	1	1	1	NA	
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Other			0		
	1.6	Microbiological	3	3	9	Pathogens carried by vectors could cause recoverable conditions and thus could occur (1:10 000)	Apply vector attraction reduction measures, beneficial use of unstable sludge should not be allowed
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures, beneficial use of unstable sludge should not be allowed
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	1	1	1	NA	NA
		Other			0		
General population	2.1	Microbiological	3	3	9	Pathogens will cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites for a specified period during and after sludge application
		Stability	2	3	6	Vectors and odours may cause self treatable conditions	Access restrictions for general public at application sites for a specified period during and after sludge application
		Metal	1	3	3	Metals have no impact via dermal contact	None required
		Nutrient	1	3	3	Nutrients have no impact via dermal contact	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites for a specified period during and after sludge application
		Other			0		

	2.2	Microbiological	3	3	9	Ingestion of pathogens may cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites for a specified period during and after sludge application
		Stability	2	3	6	Vectors may cause self treatable conditions	Access restrictions for general public at application sites for a specified period during and after sludge application
		Metal	2	2	4	Metal ingestion may cause self treatable conditions but probability is very low (1:100 000)	Access restrictions for general public at application sites for a specified period during and after sludge application
		Nutrient	1	3	3	Nutrients have no impact via ingestion	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites for a specified period during and after sludge application
		Other			0		
	2.3	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions in general public	Access restrictions for general public at application sites for a specified period during and after sludge application, buffer zones between application sites and dwellings
		Stability	3	3	9	Odours and volatile pollutants from unstabilised sludge may have moderate consequences for general public	Access restrictions for general public at application sites for a specified period during and after sludge application, buffer zones between application sites and dwellings
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for general public at application sites for a specified period during and after sludge application, buffer zones between application sites and dwellings
		Other			0		
	2.4	Microbiological	1	1	1	Inhalation of incinerator emissions not applicable to land application sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	2.5	Microbiological	4	3	12	Ingestion of crops grown on soil amended with sludge with high pathogen content could possibly have severe consequences	Crop restrictions should apply if the application site is to be used for crop production. Crops for human consumption should rather be prohibited.
		Stability	1	1	1	NA	None required

		Metal	4	3	12	Ingestion of crops grown on soil amended with sludge with high metal content could possibly have severe consequences	Crop restrictions should apply if the application site is to be used for crop production. Crops for human consumption should rather be prohibited.
		Nutrient	1	1	1	Ingestion of nutrients don't have negative effects	None required
		Organic pollutants	1	1	1	Organic pollutants are not taken up by plants	None required
		Other	1	1	1		
	2.6	Microbiological	3	3	9	Ingesting meat from animals grazing on sludge amended soils with high pathogen content could have moderate consequences for humans. Pathway has several barriers, reducing the risk.	Crop restriction and management requirements should apply if the application site is to be used for animal grazing.
		Stability	1	1	1		None required
		Metal	3	3	9	Ingesting meat from animals grazing on sludge amended soils with high metal content could have moderate consequences for humans. Pathway has several barriers, reducing the risk.	Crop restriction and management requirements should apply if the application site is to be used for animal grazing.
		Nutrient	1	1	1		None required
		Organic pollutants	3	3	9	Ingesting meat from animals grazing on sludge amended soils with high organic pollutant content could have moderate consequences for humans. Pathway has several barriers, reducing the risk.	Crop restriction and management requirements should apply if the application site is to be used for animal grazing.
		Other	1	1	1		None required
	2.7	Microbiological	3	3	9	Drinking surface water contaminated with pathogens may cause recoverable conditions but since its once-off application the probability for surface water to become contaminated due to sludge application is low (1:10 000)	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	2	2	4	Drinking surface water impacted by vectors may cause self treatable conditions, probability is rare (1:100 000)	None required
		Metal	3	2	6	Solubility of metals in sludge is very low and the impact to general public through drinking metal polluted surface water is assumed to be very low	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Nutrient	2	3	6	The impact of nutrients on human health via drinking of impacted surface water is assumed to be very low. Nitrate in drinking water can be as high as 20 mg/l N before any risk occur	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Organic pollutants	1	3	3	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on the general public drinking surface water is low	None required
		Other			0		
	2.8	Microbiological	1	1	1	Pathway too many barriers, since it is once-off application of sludge the probability of surface water to be contaminated is highly unlikely	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		

		Organic pollutants	1	1	1		
		Other			0		
	2.9	Microbiological	2	1	2	Vaguely possible under conditions of catastrophic flooding. However under these circumstances dilutions will be high and the threat of bioaccumulation low	None required
		Stability	1	1	1	NA	
		Metal	2	1	2	Vaguely possible under conditions of catastrophic flooding. However under these circumstances dilutions will be high and the threat of bioaccumulation low	None required
		Nutrient	1	1	1	NA	
		Organic pollutants	2	1	2	Organic pollutants are insoluble	None required
		Other			0		
	2.10	Microbiological	2	2	4	Impact on general public bathing in surface water impacted by high microbiological sludge after once-off application is low, and would only occur on rare occasions (1: 100 000)	None required
		Stability	1	1	1	No impact	None required
		Metal	1	1	1	No impact	None required
		Nutrient	1	1	1	No impact	None required
		Organic pollutants	1	1	1	Organic pollutants are insoluble	None required
		Other			0		
	2.11	Microbiological	3	2	6	Drinking groundwater impacted by pathogens may cause recoverable conditions, but the probability is 1:100 000 since it is once-off sludge application	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	None required
		Nutrient	2	2	4	Leaching of nitrate to groundwater at sites after once-off high sludge application rate is rare (1:100 000; dewatered sludge) but the consequence to humans consuming groundwater is self treatable. N in groundwater can be as high as 20 mg/l before any risk to babies	None required
		Organic pollutants	2	1	2	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000)	None required
		Other			0		
	2.12	Microbiological	2	2	4	Bathing in groundwater impacted by pathogens may cause self treatable conditions, the probability is 1:100 000 since groundwater contamination with pathogens after once-off sludge application is rare	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low, bathing in groundwater will have no impact	None required

		Nutrient	1	2	2	Leaching of nitrate to groundwater will be rare after once-off sludge application (1:100 000; dewatered sludge) and the consequence to humans bathing in groundwater is low.	None required
		Organic pollutants	1	1	1	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000) and the impact to humans bathing in groundwater is low	None required
		Other			0		
	2.13	Microbiological	3	2	6	Ingestion of pathogens may cause recoverable conditions but it would be rare (1:100 000)	None required
		Stability	2	2	4	Vectors may cause self treatable conditions	None required
		Metal	2	2	4	Metal ingestion via soil may cause self treatable conditions but probability is very low (1:100 000)	None required
		Nutrient	1	2	2	Nutrients have no impact via ingestion of soil	None required
		Organic pollutants	3	2	6	Organic pollutants may cause recoverable conditions but would be rare (1:100 000)	None required
		Other			0		
	2.14	Microbiological	3	2	6	Inhalation of airborne pathogens may cause recoverable conditions but it would be only on rare occasions that the general population would be affected during once-off application	None required
		Stability	1	1	1	NA	None required
		Metal	1	1	1	NA	None required
		Nutrient	1	1	1	NA	None required
		Organic pollutants	3	2	6	Inhalation of airborne organic pollutants may cause recoverable conditions but it would be only on rare occasions that the general population would be affected during once-off application	None required
		Other			0		
	2.15	Microbiological	3	3	9	Ingesting meat from animals eating sludge amended soils with high pathogen content could have moderate consequences for humans and would happen on rare occasions after once-off application.	Management requirements should apply if the rehabilitated site is to be used for animal grazing to reduce the risk of animals ingesting sludge. Access restrictions for grazing animals for a certain time period after sludge application
		Stability	1	1	1		None required
		Metal	3	2	6	Ingesting meat from animals eating sludge amended soils with high metal content could have moderate consequences for humans.	None required
		Nutrient	1	1	1		None required
		Organic pollutants	3	2	6	Ingesting meat from animals eating sludge amended soils with high organic pollutant content could have moderate consequences for humans.	None required
		Other	1	1	1		None required

	2.16	Microbiological	3	2	6	Pathogens carried by vectors could cause recoverable conditions and could occur on rare occasions (1:100 000)	Apply vector attraction reduction measures
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures, land application of unstable sludge should not be allowed
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	1	1	1	NA	NA
		Other			0		
Soil	3.1	Microbiological	1	1	1	No impact on soil physical properties	NA
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0	The organic material in sludge will have positive impacts on soil physical properties at application sites.	None required
	3.2	Microbiological	1	1	1	No impact on soil fertility and chemical properties	NA
		Stability	1	1	1		
		Metal	2	4	8	If sludge with high metal content is applied to soil, the metal content of the soils will increase.	Management requirements should be implemented to protect the soil, i.e. maximum permissible levels for metals in soils should not be exceeded.
		Nutrient	1	4	4	Increase in soil fertility due to sludge application	None required
		Organic pollutants	2	4	8	If sludge with high organic pollutant content is applied, it will influence soil quality.	Management requirements should be implemented to protect the soil.
		Other			0		
	3.3	Microbiological	1	1	1	Minimal threat of pathogenic effects	None required
		Stability			0	NA	NA
		Metal	2	1	2	Mortality highly unlikely. Effects, if any, likely to be localized and transitory.	None required
		Nutrient	2	1	2	Very low risk of oxygen depletion and localized mortality	None required
		Organic pollutants	2	1	2	Mortality highly unlikely. Effects, if any, likely to be localized and transitory.	None required
		Other			0		
	3.4	Microbiological	2	2	4	Impact of pathogens on sediments will be low since once-off high rate application will only on rare occasions contaminate surface water	None required
		Stability	1	1	1	NA	
		Metal	2	2	4	Impact of metals on sediments will be low since once-off high rate application will only on rare occasions contaminate surface water	None required

		Nutrient	2	2	4	Impact of nutrients on sediments will be low since once-off high rate application will only on rare occasions contaminate surface water	None required
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
	3.5	Microbiological	1	1	1	Very low pathogenic risk	None required
		Stability			0	NA	
		Metal	1	1	1	Very low risk of contamination. If any then likely to be localized and transitory	None required
		Nutrient	1	1	1	Very low risk of enrichment. If any then likely to be localized and transitory	None required
		Organic pollutants	1	1	1	Very low risk of contamination. If any then likely to be localized and transitory	None required
		Other			0	NA	
	3.6	Microbiological	2	2	4	Impact of pathogens on wetlands may need intervention to rehabilitate, probability is rare (1: 100 000). Wetland could act as a sterilization step to remove pathogens	None required
		Stability	1	1	1	NA	
		Metal	3	2	6	Impact of metals on wetlands may need intervention to rehabilitate, probability is rare (1: 100 000)	Buffer zones between application sites and wetlands. Run-off interception measures
		Nutrient	3	2	6	Impact of nutrients on wetlands may need intervention to rehabilitate, probability is rare (1: 100 000)	Buffer zones between application sites and wetlands. Run-off interception measures
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
Crops	4.1	Microbiological	1	1	1	Pathogens will not affect yield but will affect quality	None required
		Stability	1	1	1	NA	
		Metal	4	2	8	Metals may affect crop yield at high application rates (phytotoxicity)	Sludge quality should be specified for certain crops
		Nutrient	1	1	1	NA	
		Organic pollutants	1	1	1	Not taken up by plants	
		Other	1	1	1	NA	
	4.2	Microbiological	3	3	9	The pathogen content of sludge will influence the quality of grazing crops. However it will only happen on rare occasions with once-off application when pathogen content is extremely high or application rate is extremely high.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability			0	NA	
		Metal	3	3	9	The metal content of sludge will influence the quality of grazing crops.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.

		Nutrient			0	Nutrients will have positive effects on crops	None required
		Organic pollutants	1	1	1	The organic pollutant content of sludge will not influence the quality of grazing crops.	None required
		Other			0		
	4.3	Microbiological	3	3	9	The pathogen content of sludge will influence the quality of crops.	Restrictions on type of crop cultivated. Management requirements should be implemented, i.e. certain time should elapse after application before planting/harvesting.
		Stability			0	NA	
		Metal	3	3	9	The metal content of sludge will influence the quality of crops especially if the type of crop is sensitive too metal concentrations or metals are phytotoxic.	Restrictions on type of crop cultivated. Management requirements should be implemented, i.e. certain time should elapse after application before planting/harvesting is allowed.
		Nutrient			0	Nutrients will have positive effects on crops	None required
		Organic pollutants	1	1	1	The organic pollutant content of sludge will not influence the quality of crops.	None required
		Other			0		
Vegetation	5.1	Microbiological	1	3	3	Pathogens will not affect vegetation (yield, biodiversity, etc.)	None required
		Stability	1	3	3	Odours and vectors will not affect vegetation (yield, biodiversity, etc.)	None required
		Metal	3	3	9	Metals could be phytotoxic to plants and result in deterioration of biodiversity. However, the probability would be rare during once-off sludge application.	The selection of the appropriate type of vegetation should include metal tolerant plant or plants that could be used for phyto remediation.
		Nutrient	1	3	3	Nutrients will have no negative impact on natural vegetation	None required
		Organic pollutants	1	3	3	Organic pollutants will not affect vegetation (yield, biodiversity, etc.)	None required
		Other			0		
Air	6.1	Microbiological	2	4	8	Pathogens in sludge influence air quality confined to working area, 1:1 000	Supply workers with PPE
		Stability	2	4	8	Odour nuisance to surrounding community	Vector attraction reduction options, unstable sludge should not be used for land application
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	4	8	Volatile organic pollutants confined to working area, 1:1 000	Supply workers with PPE
		Other			0		
	6.2	Microbiological	3	4	12	Pathogens in sludge influence air quality confined to working area, 1:1 000	Supply workers with PPE
		Stability	3	4	12	Odour nuisance to surrounding community	Vector attraction reduction options, unstable sludge should not be used for rehabilitation purposes
		Metal	1	1	1	NA	

		Nutrient	1	1	1	NA	
		Organic pollutants	3	4	12	Volatile pollutants confined to working area, 1:1 000	Supply workers with PPE
		Other			0		
	6.3	Microbiological	2	3	6	Pathogens in sludge influence air quality confined to working area, 1:1 000	Supply workers with PPE
		Stability	2	4	8	Odour nuisance to surrounding community	Vector attraction reduction options, unstable sludge should not be used for rehabilitation purposes
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	3	6	Volatile pollutants confined to working area, 1:10 000	Supply workers with PPE
		Other			0		
	6.4	Microbiological	1	1	1	No incinerator emissions at land application sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
Surface water	7.1	Microbiological	3	3	9	Recoverable impact due to pathogens via soil, could happen due to run-off after heavy rains (once-off application)	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Stability	1	1	1	NA	
		Metal	2	3	6	Temporary impact on fitness for use of surface water due to metals via soil, low probability	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Nutrient	3	3	9	Recoverable impact due to nutrients via soil, low probability	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	7.2	Microbiological	4	3	12	Long-term impairment of fitness of use due to pathogens, could happen due to run-off after a rainstorm	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Stability	1	1	1	NA	
		Metal	3	3	9	Recoverable impact on fitness for use of surface water due to metals, low probability	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Nutrient	4	3	12	Long-term impairment of fitness of use due to nutrients, low probability	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		

7.3	Microbiological	3	2	6	Recoverable impact due to airborne pathogens, rare probability	None required
	Stability	1	1	1	NA	
	Metal	2	2	4	Temporary impact on fitness for use of surface water due to airborne metals, rare probability	None required
	Nutrient	2	2	4	Temporary impact on fitness for use of surface water due to airborne nutrients, rare probability	None required
	Organic pollutants	1	1	1	NA (low solubility)	None required
	Other			0		
7.4	Microbiological	3	1	3	Recoverable impact due to airborne pathogens via soil, highly unlikely probability	None required
	Stability	1	1	1	NA	
	Metal	2	1	2	Temporary impact on fitness for use of surface water due to airborne metals via soil, highly unlikely probability	None required
	Nutrient	2	1	2	Temporary impact on fitness for use of surface water due to airborne nutrients, highly unlikely probability	None required
	Organic pollutants	1	1	1	NA (low solubility)	None required
	Other			0		
7.5	Microbiological	3	2	6	Pathogens may leach through soil to groundwater and impact on surface water. Moderate consequence but rare probability	None required
	Stability	1	1	1	NA	NA
	Metal	4	2	8	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a rare probability that groundwater will be impacted	Buffer zone between application sites and groundwater (depth to aquifer) will protect surface water as well
	Nutrient	4	3	12	Nutrients may cause long-term impairment of fitness for use due to the mobility of especially N, the probability is low after once-off high application	Buffer zone between application sites and groundwater (depth to aquifer) will protect surface water as well
	Organic pollutants	1	1	1	NA (low solubility)	None required
	Other			0		
7.6	Microbiological	2	3	6	Low intensity impact, low likelihood	None required
	Stability	1	1	1	NA	NA
	Metal	1	1	1		
	Nutrient	1	1	1		
	Organic pollutants	2	2	4	Low intensity impact, rare probability	None required
	Other			0		
7.7	Microbiological	2	2	4	Low intensity impact, rare probability	None required
	Stability	1	1	1	NA	NA
	Metal	1	1	1		
	Nutrient	1	1	1		
	Organic pollutants	2	1	2	Low intensity impact, highly unlikely	None required
	Other			0		

Groundwater	8.1	Microbiological	3	2	6	Pathogens in sludge may migrate through the soil into groundwater. Due to once-off application the probability would be rare	None required
		Stability	3	2	6	Low pH mobilize metals, may cause long-term impairment of fitness for use, rare probability	None required
		Metal	3	2	6	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a rare probability	None required
		Nutrient	4	3	12	Nutrients may cause long-term impairment of fitness for use due to the mobility of especially N. This will happen on rare occasions when the once-off application rate is extremely high	Management requirements including application rate to protect groundwater.
		Organic pollutants	2	1	2	Low intensity impact, highly unlikely	None required
		Other			0		
	8.2	Microbiological	3	2	6	Pathogens in sludge may migrate through preferential pathways directly into groundwater, causing recoverable impacts, but the probability is rare.	None required
		Stability	3	2	6	Low pH mobilize metals, may cause long-term impairment of fitness for use, rare probability	None required
		Metal	4	2	8	Metals may cause long-term impairment of fitness for use, low likelihood of direct groundwater contamination	None required
		Nutrient	4	3	12	Nutrients may cause long-term impairment of fitness for use, direct contamination is possible	Management requirements including application rate to protect groundwater.
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
	8.3	Microbiological	3	1	3	Pathogens in sludge may migrate through the soil into groundwater and into low lying areas, highly unlikely after once-off application.	None required
		Stability	4	1	4	Low pH mobilize metals, may cause long-term impairment of fitness for use of low lying areas, highly unlikely	None required
		Metal	4	1	4	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a rare probability	None required
		Nutrient	4	2	8	Nutrients may cause long-term impairment of fitness for use due to the mobility of especially N, it could happen on rare occasions after once-off application	Management requirements including application rate to protect groundwater.
		Organic pollutants	2	1	2	Low intensity impact, highly unlikely	None required
		Other			0		
	8.4	Microbiological	3	1	3	Long-term impairment of fitness of use due to pathogens, highly unlikely	None required
		Stability	1	1	1	NA	

		Metal	3	1	3	Recoverable impact on fitness for use of surface water due to metals, highly unlikely	None required
		Nutrient	4	2	8	Long-term impairment of fitness of use due to nutrients, probable on rare occasions	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Organic pollutants	2	1	2	Low intensity impact, highly unlikely (low solubility)	None required
		Other			0		
Marine environment	9.1	Microbiological	1	1	1	NA to land application sites	None required
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	9.2	Microbiological	3	2	6	Recoverable impact due to pathogens via surface water, rare probability after once-off high application	None required
		Stability	1	1	1	NA	
		Metal	2	2	4	Temporary impact on fitness for use of surface water due to metals, rare probability after once-off application	None required
		Nutrient	3	2	6	Recoverable impact due to nutrients via surface water, low probability	None required
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	9.3	Microbiological	3	1	3	Pathogens in sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Stability			0	NA	
		Metal	3	1	3	Metals in sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Nutrient	3	1	3	Nutrients in sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Organic pollutants	3	1	3	Organic pollutants in sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely and insolubility of organic pollutants	None required
		Other			0	NA	
	9.4	Microbiological	1	1	1	NA to land application sites	None required
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		

	9.5	Microbiological	3	1	3	Air borne pathogens in sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Stability	1		0	NA	
		Metal	3	1	3	Metals in air borne sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Nutrient	3	1	3	Nutrients in air borne sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Organic pollutants	3	1	3	Organic pollutants in air borne sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely and insolubility of organic pollutants	None required
		Other			0	NA	
Grazing animals	10.1	Microbiological	3	3	9	Grazing animals on sites that received sludge with high pathogen content could cause moderate effects to the animal, but the likelihood is low.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability	1	1	1	NA	
		Metal	4	3	12	Grazing animals on sites that received sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen due to several barriers in pathway.	Restrictions on sludge quality used for rehabilitation of sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented.
		Nutrient	1	1	1	NA	
		Organic pollutants	3	1	3	Organic pollutants in the sludge may pose a risk to animals but the probability is highly unlikely due to the insolubility of the constituents	None required
		Other			0		
	10.2	Microbiological	4	3	12	Grazing animals on sites that received sludge with high pathogen content could cause moderate effects to the animal, but the probability is low after once-off application.	Access restrictions for a certain period after sludge application and management requirements (incorporate sludge into the soil) should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability	1	1	1	NA	
		Metal	4	3	12	Grazing animals on sites that received sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen after once-off application.	Restrictions on sludge quality used for rehabilitation of sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented. Sludge should be incorporated into the soil.
		Nutrient	1	1	1	NA	

		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	10.3	Microbiological	3	3	9	Drinking surface water contaminated with pathogens may cause recoverable conditions, probability is low (1:10 000) after once-off application	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	2	2	4	Drinking surface water impacted by vectors may cause recoverable effects, probability is rare (1:100 000)	None required
		Metal	3	2	6	Solubility of metals in sludge is very low and the impact on animals through drinking metal polluted surface water is assumed to be very low	None required
		Nutrient	2	2	4	The impact of nutrients on animal health via drinking of impacted surface water is assumed to be very low. Nitrate in water used for animal drinking water can be as high as 100 mg/l NO3 before any risk occur	None required
		Organic pollutants	1	3	3	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on the general public drinking surface water is low	None required
		Other			0		
	10.4	Microbiological	3	2	6	Drinking groundwater impacted by pathogens may cause recoverable conditions, probability is 1:100 000 after once-off application	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	None required
		Nutrient	2	3	6	Leaching of nitrate to groundwater at sites after high once-off sludge application is low (1:10 000) but the consequence to animals consuming groundwater is recoverable. Nitrate in groundwater can be as high as 100 mg/l without negative effects on grazing animals	None required
		Organic pollutants	2	1	2	Organic pollutants are insoluble and has low mobility in soil profile and it is highly unlikely that animals would be impacted	None required
		Other			0		
	10.5	Microbiological	2	3	6	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for certain time periods after application for grazing animals
		Stability	2	2	4	Odours and volatile pollutants from unstabilised sludge may have recoverable effects for animals	None required
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	3	6	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for certain time periods after application for grazing animals

		Other			0		
	10.6	Microbiological	3	4	12	Grazing animals ingesting sludge with high pathogen content on application sites could cause moderate effects to the animal, and it can possibly happen.	Access restrictions for a certain period after sludge application and management requirements (incorporate sludge into the soil) should be implemented.
		Stability	1	1	1	NA	
		Metal	4	3	12	Grazing animals ingesting sludge on sites that received sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen.	Restrictions on sludge quality used for rehabilitation of sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented. Sludge should be incorporated into the soil.
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	10.7	Microbiological	4	4	16	Grazing animals ingesting sludge on plants with high pathogen content could cause moderate effects to the animal, and it can possibly happen if sludge is applied after planting.	Access restrictions for a certain period after sludge application and management requirements (incorporate sludge into the soil, apply sludge before planting) should be implemented.
		Stability	1	1	1	NA	
		Metal	4	3	12	Grazing animals on sites that received sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen.	Restrictions on sludge quality used for sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented. Sludge should be incorporated into the soil.
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	10.8	Microbiological	3	3	9	Pathogens carried by vectors could cause recoverable conditions and could occur (1:10 000)	Apply vector attraction reduction measures to eliminate vectors
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures, unstable sludge should not be allowed for land application
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	1	1	1	NA	NA
		Other			0		

Fauna	11.1	Microbiological	3	3	9	Natural fauna on sites that received sludge with high pathogen content could cause moderate effects to the animal, but the probability is low after once-off application.	None required
		Stability	1	1	1	NA	
		Metal	4	2	8	Fauna on sites that received sludge with high metal content could cause toxic effects to the animal, but there's a rare chance that it will happen due to several barriers in pathway and once-off application.	None required
		Nutrient	1	1	1	NA	
		Organic pollutants	3	1	3	Organic pollutants in the sludge may pose a risk to animals but the probability is highly unlikely due to the insolubility of the constituents	None required
		Other			0		
	11.2	Microbiological	3	3	9	Fauna ingesting soil on sites that were rehabilitated with sludge with high pathogen content could cause moderate effects to the animal, but the probability is low after once-off sludge application.	None required
		Stability	1	1	1	NA	
		Metal	3	3	9	Fauna ingesting soil on sites that received sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen.	None required
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	11.3	Microbiological	3	2	6	Drinking surface water contaminated with pathogens may cause recoverable conditions, probability is rare (1:100 000)	None required
		Stability	2	2	4	Drinking surface water impacted by vectors may cause recoverable effects, probability is rare (1:100 000)	None required
		Metal	3	2	6	Solubility of metals in sludge is very low and the impact on animals through drinking metal polluted surface water is assumed to be very low	None required
		Nutrient	2	2	4	The impact of nutrients on animal health via drinking of impacted surface water is assumed to be very low. Nitrate in water used for animal drinking water can be as high as 100 mg/l NO3 before any risk occur	None required
		Organic pollutants	2	1	2	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on animals drinking surface water is low	None required
		Other			0		

	11.4	Microbiological	3	2	6	Drinking groundwater impacted by pathogens may cause recoverable conditions, probability is rare after once-off application (1:100 000)	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	None required
		Nutrient	2	2	4	Leaching of nitrate to groundwater at sites after high sludge application rate is probable (1:1 000) but the consequence to animals consuming groundwater is recoverable. Nitrate in groundwater can be as high as 100 mg/l without negative effects on grazing animals	None required
		Organic pollutants	2	2	4	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000)	None required
		Other			0		
	11.5	Microbiological	2	2	4	Inhalation of airborne pathogens may cause recoverable conditions but the probability is rare	None required
		Stability	2	2	4	Odours and volatile pollutants from unstabilised sludge may have recoverable effects for animals	None required
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	2	4	Inhalation of airborne organic pollutants may cause recoverable conditions	None required
		Other			0		
	11.6	Microbiological	4	2	8	Fauna ingesting sludge with high pathogen content could cause moderate effects to the animal, but it would be rare after once-off application.	None required
		Stability	1	1	1	NA	
		Metal	4	2	8	Fauna ingesting sludge with high metal content could cause toxic effects to the animal, but it will happen only on rare occasions after once-off application.	None required
		Nutrient	1	1	1	NA	
		Organic pollutants	2	2	4	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	11.7	Microbiological	3	2	6	Surface water contaminated with pathogens may cause deterioration in biodiversity of aquatic animals, but it would be rare after once-off application	None required
		Stability	2	2	4	Drinking surface water impacted by vectors may need intervention to maintain aquatic biodiversity, probability is rare (1:100 000)	None required
		Metal	4	2	8	Solubility of metals in sludge is very low but the impact on aquatic animals in polluted surface water may be severe. However the probability is rare after once-off application	None required

		Nutrient	3	3	9	The impact of nutrients on aquatic live in impacted surface water may be moderate and the probability is low. N as high as 2.5 mg/l N can cause decrease in biodiversity.	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Organic pollutants	3	1	3	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on the aquatic animals is low	None required
		Other			0		

Continuous high loading rates: **Forestry, instant lawn, canola**	Microbiological	Pathogens, disease causing issues
	Stability	Odours, vector attraction, moisture content, pH
	Metal	Potentially harmful metals, Cd, As, Cr, etc.
	Nutrient	N, P
	Organic pollutants	Pesticides, PAH, etc.
	Other	Management issues

Receptor	Pathway no	Issue	Risk to receptor			Notes	Mitigating factors
			Conse-quence	Proba-bility	Risk rating		
Workers @ application site	1.1	Microbiological	3	5	15	Workers @ application sites could be moderately by direct contact with sludge with high pathogens, and the probability is high since it is continuous high loading rates.	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	1	1	1	NA to direct contact	None required
		Metal	1	5	5	Metals have no impact via dermal contact	None required
		Nutrient	1	5	5	Nutrients have no impact via dermal contact	None required
		Organic pollutants	1	5	5	Organic pollutants have no impact via direct contact	None required
		Other			0		
	1.2	Microbiological	3	5	15	Inhalation of airborne pathogens may cause recoverable conditions in 1:100 workers due to continuous high application	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	3	5	15	Odours and volatile pollutants from unstabilised sludge may have moderate consequences for workers	Land application of unstabilised sludge should not be allowed
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Inhalation of airborne organic pollutants may cause recoverable conditions on rare occasions since sludge normally has a low organic pollutant content (1:100000)	None required
		Other			0		
	1.3	Microbiological	1	1	1	Inhalation of incinerator emissions not applicable at application sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	1.4	Microbiological	3	3	9	Ingestion of pathogens may cause recoverable conditions and thus could occur (1:10 000)	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE

		Stability	2	3	6	Vectors may cause self treatable conditions	None required
		Metal	2	3	6	Metal ingestion may cause self treatable conditions but probability is 1:10 000	None required
		Nutrient	1	3	3	Nutrients have no impact via ingestion	None required
		Organic pollutants	3	2	6	Organic pollutants may cause recoverable conditions and thus could occur only on rare occasions (1:100 000)	None required
		Other			0		
	1.5	Microbiological	3	5	15	Inhalation of airborne pathogens may cause recoverable conditions and can occur at sites where high sludge applications are frequent	Workers should be informed of health risk, how to decrease risk and be equipped with proper PPE
		Stability	1	1	1	NA	
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Inhalation of airborne organic pollutants may cause recoverable conditions on rare occasions since sludge normally has a low organic pollutant content (1:100000)	None required
		Other			0		
	1.6	Microbiological	3	3	9	Pathogens carried by vectors could cause recoverable conditions and thus could occur (1:10 000)	Apply vector attraction reduction measures, beneficial use of unstable sludge should not be allowed
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures, beneficial use of unstable sludge should not be allowed
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	1	1	1	NA	NA
		Other			0		
General population	2.1	Microbiological	3	4	12	Pathogens will cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites for a specified period during and after sludge application
		Stability	2	4	8	Vectors and odours may cause self treatable conditions	Access restrictions for general public at application sites for a specified period during and after sludge application
		Metal	1	3	3	Metals have no impact via dermal contact	None required
		Nutrient	1	3	3	Nutrients have no impact via dermal contact	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites for a specified period during and after sludge application
		Other			0		
	2.2	Microbiological	3	4	12	Ingestion of pathogens may cause recoverable conditions and is a possibility (1:1 000)	Access restrictions for general public at application sites for a specified period during and after sludge

							application
		Stability	2	4	8	Vectors may cause self treatable conditions	Unstable sludge should not be considered for land application
		Metal	2	4	8	Metal ingestion may cause self treatable conditions and probability is possible (1:1 000)	None required
		Nutrient	1	3	3	Nutrients have no impact via ingestion	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at application sites for a specified period during and after sludge application
		Other			0		
	2.3	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions in general public	Access restrictions for general public at application sites for a specified period during and after sludge application, buffer zones between application sites and dwellings
		Stability	3	3	9	Odours and volatile pollutants from unstabilised sludge may have moderate consequences for general public	Unstable sludge should not be considered for land application
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for general public at application sites for a specified period during and after sludge application, buffer zones between application sites and dwellings
		Other			0		
	2.4	Microbiological	1	1	1	Inhalation of incinerator emissions not applicable to land application sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	2.5	Microbiological	4	4	16	Ingestion of crops grown on soil amended with sludge with high pathogen content could possibly have severe consequences	Crop restrictions should apply if the application site is to be used for crop production. Crops for human consumption should rather be prohibited. Management requirements should be implemented (when to harvest)
		Stability	1	1	1	NA	None required
		Metal	4	4	16	Ingestion of crops grown on soil amended with sludge with high metal content could possibly have severe consequences	Crop restrictions should apply if the application site is to be used for crop production. Crops for human consumption should rather be prohibited.
		Nutrient	1	1	1	Ingestion of nutrients don't have negative effects	None required

		Organic pollutants	1	1	1	Organic pollutants are not taken up by plants	None required
		Other	1	1	1		
	2.6	Microbiological	3	3	9	Ingesting meat from animals grazing on sludge amended soils with high pathogen content could have moderate consequences for humans. Pathway has several barriers, reducing the risk.	Crop restriction and management requirements should apply if the application site is to be used for animal grazing.
		Stability	1	1	1		None required
		Metal	3	3	9	Ingesting meat from animals grazing on sludge amended soils with high metal content could have moderate consequences for humans. Pathway has several barriers, reducing the risk.	Crop restriction and management requirements should apply if the application site is to be used for animal grazing.
		Nutrient	1	1	1		None required
		Organic pollutants	1	1	1	Organic pollutants are not taken up by plants	None required
		Other	1	1	1		None required
	2.7	Microbiological	3	5	15	Drinking surface water contaminated with pathogens may cause recoverable conditions and since its continuous high application the probability for surface water to become contaminated due to sludge application is possible (1:100)	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	2	2	4	Drinking surface water impacted by vectors may cause self treatable conditions, probability is rare (1:100 000)	None required
		Metal	3	3	9	Solubility of metals in sludge is very low and the impact to general public through drinking metal polluted surface water is assumed to be very low	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Nutrient	2	3	6	The impact of nutrients on human health via drinking of impacted surface water is assumed to be very low. Nitrate in drinking water can be as high as 20 mg/l N before any risk occur	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Organic pollutants	1	3	3	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on the general public drinking surface water is low	None required
		Other			0		
	2.8	Microbiological	1	1	1	Pathway too many barriers	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	2.9	Microbiological	2	1	2	Vaguely possible under conditions of catastrophic flooding. However under these circumstances dilutions will be high and the threat of bioaccumulation low	None required
		Stability	1	1	1	NA	

		Metal	2	1	2	Vaguely possible under conditions of catastrophic flooding. However under these circumstances dilutions will be high and the threat of bioaccumulation low	None required
		Nutrient	1	1	1	NA	
		Organic pollutants	2	1	2	Organic pollutants are insoluble	None required
		Other			0		
	2.10	Microbiological	2	4	8	Impact on general public bathing in surface water impacted by high microbiological sludge after continuous high rate application is possible (1: 1000)	None required
		Stability	1	1	1	No impact	None required
		Metal	1	1	1	No impact	None required
		Nutrient	1	1	1	No impact	None required
		Organic pollutants	1	1	1	Organic pollutants are insoluble	None required
		Other			0		
	2.11	Microbiological	3	5	15	Drinking groundwater impacted by pathogens may cause recoverable conditions, and the probability is 1:100 since it is continuous high rate application	Buffer zones between application sites and groundwater (depth to aquifer)
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	None required
		Nutrient	2	5	10	Leaching of nitrate to groundwater at sites due to continuous high rate application is a possibility (1:100) but the consequence to humans consuming groundwater is self treatable. N in groundwater can be as high as 20 mg/l before any risk to babies	Buffer zones between application sites and groundwater (depth to aquifer)
		Organic pollutants	2	1	2	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000)	None required
		Other			0		
	2.12	Microbiological	2	4	8	Bathing in groundwater impacted by pathogens may cause self treatable conditions, the probability is 1:1 000 since groundwater contamination with pathogens after continuous high rate sludge application is possible	Buffer zones between application sites and groundwater (depth to aquifer)
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low, bathing in groundwater will have no impact	None required
		Nutrient	1	5	5	Leaching of nitrate to groundwater could happen regularly after continuous high rate sludge application (1:100 000) but the consequence to humans bathing in groundwater is low.	None required
		Organic pollutants	1	1	1	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000) and the impact to humans bathing in groundwater is low	None required
		Other			0		

	2.13	Microbiological	3	4	12	Ingestion of pathogens may cause recoverable conditions and can occur at sites that continuously receive sludge at high rates (1:1 000)	Access restrictions for general public, restrictions on sludge quality
		Stability	2	4	8	Vectors may cause self treatable conditions	None required
		Metal	2	4	8	Metal ingestion via soil may cause self treatable conditions and is possible (1:1 000)	None required
		Nutrient	1	2	2	Nutrients have no impact via ingestion of soil	None required
		Organic pollutants	3	1	3	Organic pollutants are insoluble	None required
		Other			0		
	2.14	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions and is possible that the general population would be affected during continuous high rate applications	Public access restrictions
		Stability	1	1	1	NA	None required
		Metal	1	1	1	NA	None required
		Nutrient	1	1	1	NA	None required
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions and is possible during continuous high rate application	Public access restrictions
		Other			0		
	2.15	Microbiological	3	3	9	Ingesting meat from animals eating sludge amended soils with high pathogen content could have moderate consequences for humans and could happen	Management requirements should apply if the rehabilitated site is to be used for animal grazing to reduce the risk of animals ingesting sludge. Access restrictions for grazing animals for a certain time period after sludge application
		Stability	1	1	1		None required
		Metal	3	2	6	Ingesting meat from animals eating sludge amended soils with high metal content could have moderate consequences for humans.	None required
		Nutrient	1	1	1		None required
		Organic pollutants	3	2	6	Ingesting meat from animals eating sludge amended soils with high organic pollutant content could have moderate consequences for humans.	None required
		Other	1	1	1		None required
	2.16	Microbiological	3	4	12	Pathogens carried by vectors could cause recoverable conditions and could occur (1:1 000)	Apply vector attraction reduction measures
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures, land application of unstable sludge should not be allowed
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	1	1	1	NA	NA
		Other			0		
Soi l	3.1	Microbiological	1	1	1	No impact on soil physical	NA

		Stability	1	1	1	properties	
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0	The organic material in sludge will have positive impacts on soil physical properties at application sites.	None required
	3.2	Microbiological	1	1	1	No impact on soil fertility and chemical properties	NA
		Stability	1	1	1		
		Metal	3	5	15	If sludge with high metal content is applied to soil, the metal content of the soils will increase, especially after frequent, high rate applications.	Management requirements should be implemented to protect the soil, i.e. maximum permissible levels for metals in soils should not be exceeded.
		Nutrient	1	5	5	Increase in soil fertility due to sludge application	None required
		Organic pollutants	2	4	8	If sludge with high organic pollutant content is applied continuously, it will influence soil quality.	Management requirements should be implemented to protect the soil.
		Other			0		
	3.3	Microbiological	2	3	6	Minimal threat of pathogenic effects	None required
		Stability			0	NA	NA
		Metal	2	3	6	Mortality highly unlikely. Effects, if any, likely to be localized and transitory.	None required
		Nutrient	2	3	6	Low risk of oxygen depletion and localized mortality	None required
		Organic pollutants	2	3	6	Mortality highly unlikely. Effects, if any, likely to be localized and transitory.	None required
		Other			0		
	3.4	Microbiological	3	4	12	Impact of pathogens on sediments will be moderate and continuous high rate application will contaminate surface water	Implement measures to protect surface water, i.e. buffer zones and run-off interception
		Stability	1	1	1	NA	
		Metal	3	4	12	Impact of metals on sediments will be moderate and continuous high rate application will contaminate surface water	Implement measures to protect surface water, i.e. buffer zones and run-off interception
		Nutrient	2	4	8	Impact of nutrients on sediments will be moderate and continuous high rate application will contaminate surface water	Implement measures to protect surface water, i.e. buffer zones and run-off interception
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
	3.5	Microbiological	1	1	1	Very low pathogenic risk	None required
		Stability			0	NA	
		Metal	1	1	1	Very low risk of contamination. If any then likely to be localized and transitory	None required
		Nutrient	1	1	1	Very low risk of enrichment. If any then likely to be localized and transitory	None required
		Organic pollutants	1	1	1	Very low risk of contamination. If any then likely to be localized and transitory	None required

		Other			0	NA	
	3.6	Microbiological	2	4	8	Impact of pathogens on wetlands may are manageable, probability is 1: 1 000. Wetland could act as a sterilization step to remove pathogens	None required
		Stability	1	1	1	NA	
		Metal	3	4	12	Impact of metals on wetlands may need intervention to rehabilitate, probability is rare (1: 100 000)	Buffer zones between application sites and wetlands. Run-off interception measures
		Nutrient	3	4	12	Impact of nutrients on wetlands may need intervention to rehabilitate, probability is rare (1: 100 000)	Buffer zones between application sites and wetlands. Run-off interception measures
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
Crops	4.1	Microbiological	1	1	1	Pathogens will not affect yield but will affect quality	None required
		Stability	1	1	1	NA	
		Metal	4	3	12	Metals may affect crop yield at high application rates (phytotoxicity)	Sludge quality should be specified for certain crops
		Nutrient	1	1	1	NA	
		Organic pollutants	1	1	1	Not taken up by plants	
		Other	1	1	1	NA	
	4.2	Microbiological	3	5	15	The pathogen content of sludge will moderately influence the quality of grazing crops and the probability is 1:100.	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability			0	NA	
		Metal	3	5	15	The metal content of sludge will influence the quality of grazing crops (high probability).	Restrictions on type of crop cultivated for animal feed and limits on the pollutant content of the sludge to be used.
		Nutrient			0	Nutrients will have positive effects on crops	None required
		Organic pollutants	1	1	1	The organic pollutant content of sludge will not influence the quality of grazing crops.	None required
		Other			0		
	4.3	Microbiological	3	5	15	The pathogen content of sludge will influence the quality of crops and the probability is high.	Restrictions on type of crop cultivated. Management requirements should be implemented, i.e. certain time should elapse after application before planting/harvesting.
		Stability			0	NA	
		Metal	3	5	15	The metal content of sludge will influence the quality of crops especially if the type of crop is sensitive too metal concentrations or metals are phytotoxic.	Restrictions on type of crop cultivated. If the crop is destined for human consumption, pollutant limits should apply.
		Nutrient			0	Nutrients will have positive effects on crops	None required
		Organic pollutants	1	5	5	The organic pollutant content of sludge will not influence the quality of crops.	None required
		Other			0		

Vegetation	5.1	Microbiological	1	5	5	Pathogens will not affect vegetation (yield, biodiversity, etc.) although the application rates are high	None required
		Stability	1	5	5	Odours and vectors will not affect vegetation (yield, biodiversity, etc.)	None required
		Metal	3	5	15	Metals could be phytotoxic to plants and result in deterioration of biodiversity.	The selection of the appropriate type of vegetation should include metal tolerant plant or plants that could be used for phyto remediation.
		Nutrient	1	5	5	Nutrients will have no negative impact on natural vegetation	None required
		Organic pollutants	1	5	5	Organic pollutants will not affect vegetation (yield, biodiversity, etc.)	None required
		Other			0		
Air	6.1	Microbiological	2	4	8	Pathogens in sludge influence air quality confined to working area, 1:1 000	Supply workers with PPE
		Stability	2	4	8	Odour nuisance to surrounding community	Vector attraction reduction options, unstable sludge should not be used for land application
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	4	8	Volatile organic pollutants confined to working area, 1:1 000	Supply workers with PPE
		Other			0		
	6.2	Microbiological	3	4	12	Pathogens in sludge influence air quality confined to working area, 1:1 000	Supply workers with PPE
		Stability	3	4	12	Odour nuisance to surrounding community	Vector attraction reduction options, unstable sludge should not be used for rehabilitation purposes
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	4	12	Volatile pollutants confined to working area, 1:1 000	Supply workers with PPE
		Other			0		
	6.3	Microbiological	2	3	6	Pathogens in sludge influence air quality confined to working area, 1:1 000	Supply workers with PPE
		Stability	2	4	8	Odour nuisance to surrounding community	Vector attraction reduction options, unstable sludge should not be used for rehabilitation purposes
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	3	6	Volatile pollutants confined to working area, 1:10 000	Supply workers with PPE
		Other			0		
	6.4	Microbiological	1	1	1	No incinerator emissions at land application sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		

Surface water	7.1	Microbiological	3	5	15	Recoverable impact due to pathogens via soil, could happen due to run-off after heavy rains	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Stability	1	1	1	NA	
		Metal	2	5	10	Temporary impact on fitness for use of surface water due to metals via soil, probable	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Nutrient	3	5	15	Recoverable impact due to nutrients via soil	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	7.2	Microbiological	4	5	20	Long-term impairment of fitness of use due to pathogens, could happen due to run-off after a rainstorm	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Stability	1	1	1	NA	
		Metal	3	5	15	Recoverable impact on fitness for use of surface water due to metals	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Nutrient	4	5	20	Long-term impairment of fitness of use due to nutrients	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	7.3	Microbiological	3	3	9	Recoverable impact due to airborne pathogens, low probability	None required
		Stability	1	1	1	NA	
		Metal	2	3	6	Temporary impact on fitness for use of surface water due to airborne metals, low probability	None required
		Nutrient	2	3	6	Temporary impact on fitness for use of surface water due to airborne nutrients, low probability	None required
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	7.4	Microbiological	3	2	6	Recoverable impact due to airborne pathogens via soil, rare probability	None required
		Stability	1	1	1	NA	
		Metal	2	2	4	Temporary impact on fitness for use of surface water due to airborne metals via soil, rare probability	None required
		Nutrient	2	2	4	Temporary impact on fitness for use of surface water due to airborne nutrients, rare probability	None required
		Organic pollutants	1	1	1	NA (low solubility)	None required

		Other			0		
	7.5	Microbiological	3	4	12	Pathogens may leach through soil to groundwater and impact on surface water. Moderate consequence and probable	Buffer zone between application sites and groundwater (depth to aquifer) will protect surface water as well
		Stability	1	1	1	NA	NA
		Metal	4	2	8	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a rare probability that groundwater will be impacted	None required
		Nutrient	4	5	20	Nutrients may cause long-term impairment of fitness for use due to the mobility of especially N, the probability is low after once-off high application	Buffer zone between application sites and groundwater (depth to aquifer) will protect surface water as well
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		
	7.6	Microbiological	2	3	6	Low intensity impact, low likelihood	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	2	2	4	Low intensity impact, rare probability	None required
		Other			0		
	7.7	Microbiological	2	2	4	Low intensity impact, rare probability	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	2	1	2	Low intensity impact, highly unlikely	None required
		Other			0		
Groundwater	8.1	Microbiological	3	3	9	Pathogens in sludge may migrate through the soil into groundwater. Due to regular high rate application the probability would be high	Buffer zone between application sites and groundwater (depth to aquifer)
		Stability	3	2	6	Low pH mobilize metals, may cause long-term impairment of fitness for use, rare probability	None required
		Metal	3	2	6	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a rare probability	None required
		Nutrient	4	5	20	Nutrients may cause long-term impairment of fitness for use due to the mobility of especially N. Due to regular high rate application the probability would be high	Buffer zone between application sites and groundwater (depth to aquifer)
		Organic pollutants	2	1	2	Low intensity impact, highly unlikely	None required
		Other			0		
	8.2	Microbiological	3	3	9	Pathogens in sludge may migrate through preferential pathways directly into groundwater, causing recoverable impacts, but the probability is low.	None required
		Stability	3	3	9	Low pH mobilize metals, may cause long-term impairment of fitness for use, low probability	None required
		Metal	4	2	8	Metals may cause long-term impairment of fitness for use, low likelihood of direct groundwater contamination	None required

		Nutrient	4	4	16	Nutrients may cause long-term impairment of fitness for use, direct contamination is possible	Buffer zone between application sites and groundwater (depth to aquifer)
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
	8.3	Microbiological	3	3	9	Pathogens in sludge may migrate through the soil into groundwater and into low lying areas, could happen after continuous high rate application.	None required
		Stability	4	2	8	Low pH mobilize metals, may cause long-term impairment of fitness for use of low lying areas, highly unlikely	None required
		Metal	4	2	8	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a rare probability	None required
		Nutrient	4	4	16	Nutrients may cause long-term impairment of fitness for use due to the mobility of especially N, it could happen after continuous high rate application	Buffer zone between application sites and groundwater (depth to aquifer)
		Organic pollutants	2	1	2	Low intensity impact, highly unlikely	None required
		Other			0		
	8.4	Microbiological	3	2	6	Long-term impairment of fitness of use due to pathogens, highly unlikely	None required
		Stability	1	1	1	NA	
		Metal	3	2	6	Recoverable impact on fitness for use of surface water due to metals, highly unlikely	None required
		Nutrient	4	4	16	Long-term impairment of fitness of use due to nutrients, probable	Buffer zone between land application sites and surface water bodies, implementation of run-off interception measures.
		Organic pollutants	2	1	2	Low intensity impact, highly unlikely (low solubility)	None required
		Other			0		
Marine environment	9.1	Microbiological	1	1	1	NA to land application sites	None required
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	9.2	Microbiological	3	3	9	Recoverable impact due to pathogens via surface water, probable after continuous high rate application	Protect surface water
		Stability	1	1	1	NA	
		Metal	2	3	6	Temporary impact on fitness for use of surface water due to metals, probable after continuous high rate application	None required
		Nutrient	3	3	9	Recoverable impact due to nutrients via surface water, probable after continuous high rate application	Protect surface water
		Organic pollutants	1	1	1	NA (low solubility)	None required
		Other			0		

	9.3	Microbiological	3	1	3	Pathogens in sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Stability			0	NA	
		Metal	3	1	3	Metals in sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Nutrient	3	1	3	Nutrients in sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Organic pollutants	3	1	3	Organic pollutants in sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely and insolubility of organic pollutants	None required
		Other			0	NA	
	9.4	Microbiological	1	1	1	NA to land application sites	None required
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	9.5	Microbiological	3	1	3	Air borne pathogens in sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Stability	1		0	NA	
		Metal	3	1	3	Metals in air borne sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Nutrient	3	1	3	Nutrients in air borne sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely	None required
		Organic pollutants	3	1	3	Organic pollutants in air borne sludge could impact on marine environment if the application site is close enough to the surf zone, highly unlikely and insolubility of organic pollutants	None required
		Other			0	NA	
Grazing animals	10.1	Microbiological	3	5	15	Grazing animals on sites that received sludge with high pathogen content at high loading rates could suffer moderate effects	Restrictions on type of crop cultivated for animal feed. Management requirements should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability	1	1	1	NA	
		Metal	4	5	20	Grazing animals on sites that received sludge with high metal content at high loading rates could suffer moderate effects	Restrictions on sludge quality used for high loading rates at sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented.
		Nutrient	1	1	1	NA	

		Organic pollutants	3	1	3	Organic pollutants in the sludge may pose a risk to animals but the probability is highly unlikely due to the insolubility of the constituents	None required
		Other			0		
	10.2	Microbiological	4	5	20	Grazing animals on sites that received sludge with high pathogen content could cause moderate effects to the animal, the probability is high after continuous high application rates.	Access restrictions for a certain period after sludge application and management requirements (incorporate sludge into the soil) should be implemented, i.e. certain time should elapse after application before grazing is allowed.
		Stability	1	1	1	NA	
		Metal	4	5	20	Grazing animals on sites that received sludge with high metal content could cause toxic effects to the animal, the probability is high after continuous high application rates	Restrictions on sludge quality used on sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented. Sludge should be incorporated into the soil.
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	10.3	Microbiological	3	5	15	Drinking surface water contaminated with pathogens may cause recoverable conditions, probability is high (1:100) after continuous high rate application	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Stability	2	3	6	Drinking surface water impacted by vectors may cause recoverable effects, probability is rare (1:100 000)	None required
		Metal	3	3	9	Solubility of metals in sludge is very low and the impact on animals through drinking metal polluted surface water is assumed to be very low	None required
		Nutrient	2	3	6	The impact of nutrients on animal health via drinking of impacted surface water is assumed to be very low. Nitrate in water used for animal drinking water can be as high as 100 mg/l NO3 before any risk occur	None required
		Organic pollutants	1	3	3	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on the general public drinking surface water is low	None required
		Other			0		
	10.4	Microbiological	3	3	9	Drinking groundwater impacted by pathogens may cause recoverable conditions, probability is 1:10 000 after continuous high rate application	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	None required

		Nutrient	2	4	8	Leaching of nitrate to groundwater at sites after continuous high rate sludge application is possible (1:1 000) but the consequence to animals consuming groundwater is recoverable. Nitrate in groundwater can be as high as 100 mg/l without negative effects on grazing animals	None required
		Organic pollutants	2	1	2	Organic pollutants are insoluble and has low mobility in soil profile and it is highly unlikely that animals would be impacted	None required
		Other			0		
	10.5	Microbiological	2	3	6	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for certain time periods after application for grazing animals
		Stability	2	2	4	Odours and volatile pollutants from unstabilised sludge may have recoverable effects for animals	None required
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	3	6	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for certain time periods after application for grazing animals
		Other			0		
	10.6	Microbiological	3	5	15	Grazing animals ingesting sludge with high pathogen content on application sites could cause moderate effects to the animal, and it is possible after continuous high rate application.	Access restrictions for a certain period after sludge application and management requirements (incorporate sludge into the soil) should be implemented.
		Stability	1	1	1	NA	
		Metal	4	5	20	Grazing animals ingesting sludge on sites that received sludge with high metal content could cause toxic effects to the animal, and it is possible after continuous high rate application.	Restrictions on sludge quality used for rehabilitation of sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented. Sludge should be incorporated into the soil.
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	10.7	Microbiological	4	4	16	Grazing animals ingesting sludge on plants with high pathogen content could cause moderate effects to the animal, and it can possibly happen if sludge is applied after planting.	Access restrictions for a certain period after sludge application and management requirements (incorporate sludge into the soil, apply sludge before planting) should be implemented.
		Stability	1	1	1	NA	

		Metal	4	3	12	Grazing animals on sites that received sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen.	Restrictions on sludge quality used for sites intended to be used for animal grazing. Maximum permissible levels for metals in the receiving soil should be implemented. Sludge should be incorporated into the soil.
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	10.8	Microbiological	3	3	9	Pathogens carried by vectors could cause recoverable conditions and could occur (1:10 000)	Apply vector attraction reduction measures to eliminate vectors
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures, unstable sludge should not be allowed for land application
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	1	1	1	NA	NA
		Other			0		
Fauna	11.1	Microbiological	3	5	15	Natural fauna on sites that received sludge with high pathogen content could cause moderate effects to the animal, possible after continuous high rate application.	None required
		Stability	1	1	1	NA	
		Metal	4	3	12	Fauna on sites that received sludge with high metal content could cause toxic effects to the animal, but there's a small chance that it will happen due to several barriers in pathway.	None required
		Nutrient	1	1	1	NA	
		Organic pollutants	3	1	3	Organic pollutants in the sludge may pose a risk to animals but the probability is highly unlikely due to the insolubility of the constituents	None required
		Other			0		
	11.2	Microbiological	2	4	8	Fauna ingesting soil on sites that were rehabilitated with sludge with high pathogen content could cause moderate effects to the animal, possible after continuous high rate application.	None required
		Stability	1	1	1	NA	
		Metal	2	4	8	Fauna ingesting soil on sites that received sludge with high metal content could cause toxic effects to the animal, but there's a low likelihood that it will happen.	None required
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		

	11.3	Microbiological	3	3	9	Drinking surface water contaminated with pathogens may cause recoverable conditions, probability is low (1:10 000)	None required
		Stability	2	2	4	Drinking surface water impacted by vectors may cause recoverable effects, probability is low (1:10 000)	None required
		Metal	3	3	9	Solubility of metals in sludge is very low and the impact on animals through drinking metal polluted surface water is assumed to be very low	None required
		Nutrient	2	3	6	The impact of nutrients on animal health via drinking of impacted surface water is assumed to be very low. Nitrate in water used for animal drinking water can be as high as 100 mg/l NO3 before any risk occur	None required
		Organic pollutants	2	1	2	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on animals drinking surface water is low	None required
		Other			0		
	11.4	Microbiological	3	3	9	Drinking groundwater impacted by pathogens may cause recoverable conditions, probability is low even after continuous high rate application (1:10 000)	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	None required
		Nutrient	2	4	8	Leaching of nitrate to groundwater at sites after high sludge application rate is probable (1:1 000) but the consequence to animals consuming groundwater is recoverable. Nitrate in groundwater can be as high as 100 mg/l without negative effects on grazing animals	None required
		Organic pollutants	2	2	4	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000)	None required
		Other			0		
	11.5	Microbiological	2	2	4	Inhalation of airborne pathogens may cause recoverable conditions but the probability is rare	None required
		Stability	2	2	4	Odours and volatile pollutants from unstabilised sludge may have recoverable effects for animals	None required
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	2	2	4	Inhalation of airborne organic pollutants may cause recoverable conditions	None required
		Other			0		
	11.6	Microbiological	4	4	16	Fauna ingesting sludge with high pathogen content could cause moderate effects to the animal, and it is possible after high rate application.	None required
		Stability	1	1	1	NA	

		Metal	4	4	16	Fauna ingesting sludge with high metal content could cause toxic effects to the animal, and it may after high rate application.	None required
		Nutrient	1	1	1	NA	
		Organic pollutants	2	2	4	Organic pollutants in the sludge may pose a risk to animals but the probability is rare due to the insolubility of the constituents	None required
		Other			0		
	11.7	Microbiological	3	3	9	Surface water contaminated with pathogens may cause deterioration in biodiversity of aquatic animals, it would be possible after high rate application	None required
		Stability	2	2	4	Drinking surface water impacted by vectors may need intervention to maintain aquatic biodiversity, probability is rare (1:100 000)	None required
		Metal	4	3	12	Solubility of metals in sludge is very low but the impact on aquatic animals in polluted surface water may be severe. However the probability is possible after high rate application	None required
		Nutrient	3	3	9	The impact of nutrients on aquatic live in impacted surface water may be moderate and the probability is low. N as high as 2.5 mg/l N can cause decrease in biodiversity.	Buffer zones between application sites and surface water bodies. Run-off interception measures
		Organic pollutants	3	1	3	Solubility of organic pollutants are low and it would not end up in a soluble form in the surface water, thus the impact on the aquatic animals is low	None required
		Other			0		

Landfill cover		
	Microbiological	Pathogens, disease causing issues
	Stability	Odours, vector attraction, moisture content, pH
	Metal	Potentially harmful metals, Cd, As, Cr, etc.
	Nutrient	N, P
	Organic pollutants	Pesticides, PAH, etc.
	Other	Management issues

Receptor	Pathway no	Issue	Risk to receptor			Notes	Mitigating factors
			Conse-quence	Proba-bility	Risk rating		
Workers @ application site	1.1	Microbiological			0	Assume compliance with OSH Act and Equip worker with PPE	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	1.2	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	1.3	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	1.4	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	1.5	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	1.6	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
General population	2.1	Microbiological	3	2	6	Pathogens will cause recoverable conditions, rare probability (mixing with other material) (1:100 000)	None required
		Stability	2	2	4	Vectors may cause self treatable conditions	None required

		Metal	1	2	2	Metals have no impact via dermal contact	None required
		Nutrient	1	2	2	Nutrients have no impact via dermal contact	None required
		Organic pollutants	3	1	3	Organic pollutants may cause recoverable conditions, rare probability (1:100 000)	None required
		Other			0		
	2.2	Microbiological	3	3	9	Ingestion of pathogens may cause recoverable conditions and it could occur (1:10 000)	Access restrictions for general public at landfill sites
		Stability	2	3	6	Vectors may cause self treatable conditions	Access restrictions for general public at landfill sites
		Metal	2	2	4	Metal ingestion may cause self treatable conditions but probability is very low (1:100 000)	None required
		Nutrient	1	3	3	Nutrients have no impact via ingestion	None required
		Organic pollutants	3	3	9	Organic pollutants may cause recoverable conditions and it could occur (1:10 000)	Access restrictions for general public at landfill sites
		Other			0		
	2.3	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for general public at landfill sites, buffer zones between landfill sites and dwellings
		Stability	3	5	15	Odours regularly influence general public	Access restrictions for general public at landfill sites, buffer zones between landfill sites and dwellings
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for general public at landfill sites, buffer zones between landfill sites and dwellings
		Other			0		
	2.4	Microbiological	1	1	1	Inhalation of incinerator emissions not applicable to landfill sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	2.5	Microbiological	1	1	1	It is assumed that the general public is not allowed onto landfill sites and that no plants grow on these sites	Access restrictions to general public
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	2.6	Microbiological	1	1	1	Not applicable to landfill sites. It is assumed that no animals are allowed on site	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	2.7	Microbiological	1	1	1	Assume compliance with Minimum requirements to protect	
		Stability	1	1	1		

		Metal	1	1	1	surface water	
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	2.8	Microbiological	1	1	1	Assume compliance with Minimum requirements to protect surface water. multiple barrier pathway	
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	2.9	Microbiological	2	1	2	Vaguely possible under conditions of catastrophic flooding. However under these circumstances dilutions will be high and the threat of bioaccumulation low	Maintain buffer zones between disposal sites and the sea
		Stability	1	1	1	NA	
		Metal	2	1	2	Vaguely possible under conditions of catastrophic flooding. However under these circumstances dilutions will be high and the threat of bioaccumulation low	Maintain buffer zones between disposal sites and the sea
		Nutrient	1	1	1	NA	
		Organic pollutants	2	1	2	Vaguely possible under conditions of catastrophic flooding. However under these circumstances dilutions will be high and the threat of bioaccumulation low	Maintain buffer zones between disposal sites and the sea
		Other			0		
	2.10	Microbiological			0	Assume compliance with Minimum requirements to protect surface water	None required
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.11	Microbiological			0	Assume liners will protect groundwater	None required
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.12	Microbiological			0	Assume liners will protect groundwater	None required
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.13	Microbiological	3	1	3	Assume compliance with Minimum Requirements	Access restrictions for general public at landfill sites
		Stability	2	1	2		
		Metal	2	1	2		
		Nutrient	1	1	1		
		Organic pollutants	3	1	3		
		Other			0		
	2.14	Microbiological	3	2	6	Inhalation of airborne pathogens may cause recoverable conditions on rare occasions	Buffer zones between landfill sites and dwellings
		Stability	1	1	1	NA	

		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	2	6	Inhalation of airborne organic pollutants may cause recoverable conditions on rare occasions	Buffer zones between landfill sites and dwellings
		Other			0		
	2.15	Microbiological	1	1	1	Assume no grazing animals are allowed on site	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	2.16	Microbiological	3	3	9	Pathogens carried by vectors could cause recoverable conditions and thus could occur (1:10 000)	Apply vector attraction reduction measures
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	1	1	1	NA	NA
		Other			0		
Soil	3.1	Microbiological			0	Not applicable to landfill sites. Assume compliance to Minimum Requirements	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	3.2	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	3.3	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	3.4	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	3.5	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	3.6	Microbiological			0		
		Stability			0		
		Metal			0		

		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Crops	4.1	Microbiological			0	Not applicable to landfill sites. No crops are grown on site	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	4.2	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	4.3	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Vegetation	5.1	Microbiological	1	4	4	Pathogens will not affect vegetation (yield, biodiversity, etc.)	None required
		Stability	1	4	4	Odours and vectors will not affect vegetation (yield, biodiversity, etc.)	None required
		Metal	4	4	16	Metals could be phytotoxic to plants and result in loss of biodiversity	Landfill sites should be considered as sacrificial land
		Nutrient	1	4	4	Nutrients will have no negative impact on natural vegetation	None required
		Organic pollutants	1	4	4	Organic pollutants will not affect vegetation (yield, biodiversity, etc.)	None required
		Other			0		
Air	6.1	Microbiological	3	4	12	Volatile pollutants confined to working area, 1:1 000	Supply workers with PPE
		Stability	4	5	20	Odour nuisance to surrounding community	Vector attraction reduction options, Buffer zone between landfill sites and dwellings
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	4	12	Volatile pollutants confined to working area, 1:1 000	Supply workers with PPE
		Other			0		
	6.2	Microbiological	3	4	12	Volatile pollutants confined to working area, 1:1 000	Supply workers with PPE
		Stability	4	5	20	Odour nuisance to surrounding community	Vector attraction reduction options, Buffer zone between landfill sites and dwellings
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	4	12	Volatile pollutants confined to working area, 1:1 000	Supply workers with PPE
		Other			0		
	6.3	Microbiological	1	1	1	Impact on air quality through the soil is highly unlikely	None required
		Stability	1	1	1		
		Metal	1	1	1		

		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	6.4	Microbiological	1	1	1	No incinerator emissions at landfill sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
Surface water	7.1	Microbiological			0	Assume compliance with Minimum requirements to protect surface water	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	7.2	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	7.3	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	7.4	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	7.5	Microbiological			0	Assume liners will protect groundwater	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	7.6	Microbiological	2	3	6	Low intensity impact, low likelihood	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	2	2	4	Low intensity impact, rare probability	None required
		Other			0		
	7.7	Microbiological	2	2	4	Low intensity impact, rare probability	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	2	1	2	Low intensity impact, highly unlikely	None required
		Other			0		

Groundwater	8.1	Microbiological			0	Assume liners will protect groundwater	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	8.2	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	8.3	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	8.4	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Marine environment	9.1	Microbiological	1	1	1	Assumes no deliberate discharge of sludge waste through sea outfalls and that the existing buffers between disposal site and the sea are intact	None required
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	9.2	Microbiological	1	1	1		
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	9.3	Microbiological	1	1	1		
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	9.4	Microbiological	1	1	1		
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	9.5	Microbiological	1	1	1		
		Stability			0		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		

		Other			0		
Grazing animals	10.1	Microbiological			0	Assume no grazing animals allowed on landfill sites	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.2	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.3	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.4	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.5	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.6	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.7	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.8	Microbiological			0		
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Fauna	11.1	Microbiological	1	5	5	Low impact, multiple barrier pathway	None required
		Stability	1	1	1	NA	NA
		Metal	1	4	4	Low impact, very little vegetation on landfill sites, multiple barrier pathway	None required

		Nutrient	1	4	4	Low impact, very little vegetation on landfill sites, multiple barrier pathway	None required
		Organic pollutants	1	5	5	Low impact, multiple barrier pathway	None required
		Other			0		
	11.2	Microbiological	2	3	6	Intervention may be required to maintain biodiversity, low likelihood	None required
		Stability	1	1	1	NA	NA
		Metal	2	3	6	Intervention may be required to maintain biodiversity, low likelihood	None required
		Nutrient	1	3	3	No negative impact	None required
		Organic pollutants	2	3	6	Intervention may be required to maintain biodiversity, low likelihood	None required
		Other			0		
	11.3	Microbiological	1	1	1	Assume compliance with Minimum requirements to protect surface water	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	11.4	Microbiological	1	1	1	Assume compliance with Minimum requirements to protect groundwater	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	11.5	Microbiological	2	2	4	Inhalation of airborne pathogens may need intervention to maintain biodiversity on rare occasions	None required
		Stability	1	1	1	NA	NA
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	2	2	4	Inhalation of airborne organic pollutants may need intervention to maintain biodiversity on rare occasions	None required
		Other			0		
	11.6	Microbiological	2	3	6	Intervention may be required to maintain biodiversity, low likelihood	None required
		Stability	1	1	1	NA	NA
		Metal	2	3	6	Intervention may be required to maintain biodiversity, low likelihood	None required
		Nutrient	1	3	3	No negative impact	None required
		Organic pollutants	2	3	6	Intervention may be required to maintain biodiversity, low likelihood	None required
		Other			0		
	11.7	Microbiological	1	1	1	Assume compliance with Minimum requirements to protect surface water	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		

Appendix 2: Example of equations

Example 1: Calculating the allowable mass of sewage sludge with soil for use as a vegetative layer using the EEC principle (Dollar, 2006).

A landfill with a surface area of 70 ha is to be covered. The 200 mm topsoil or vegetative layer is to contain sewage sludge as a soil conditioner.

Sludge properties:

Zn concentration from TCLP test	: 5.8 mg Zn/kg dry solids
Sludge moisture content	: 20% solids
Sludge density	: 600 kg/m^3

Solution: (following the procedure in Section 8.6 of the MRHW)

LC_{50} = 7 mg/l

AE = 0.1 x LC_{50}

AE = 0.1 x 7 mg/l

AE = 700 ppb

EEC = AE

g/ha/month x 0.66 = AE

= 700 / 0.66

= 1061 g/ha/month

but, this is a once-off application, therefore

EEC = 1061 g/ha

Mass of sludge (dry solids) = 1061 g/ha / 5.8 mg/kg

= 18.293 tonnes/ha

Mass of sludge (wet mass) = 18.293 / (20/100) tonnes/ha

= 91.465 tonnes/ha

Volume of sludge = 91.465 tonnes/ha / 600 kg/m^3

= 152.4 m^3/ha

Volume of vegetative layer/ha = 0.2 x 1000 x 1000 m^3/ha

= 200 000 m^3/ha (this is the final, compacted volume)

The moisture in the sludge impacts on the compaction density that can be achieved and in fact, on the optimum moisture content and density of the mixture. The actual mass of soil can therefore not be determined for this example since a series of compaction trails of soil and sludge mixtures should be undertaken. Once a suitable ratio is chosen, the maximum mass of sludge permitted in the compacted layer is 91.5 tonnes/ha. Despite the maximum permissible load in terms of the EEC procedure, the properties of the mixture must still be considered for construction of the cover.

Appendix 3: Parameters and analytical methods required for classification of sludge and monitoring of sludge, water and soil samples

Appendix 3.1: Analyses required for classification of sludge

Characteristic	Parameter	Guidance on methodology and/or recommended extraction method
Physical characteristics	pH	Direct measurement pH on saturated paste or solution
	Total solids (TS)	Standard method 2540B[1]
	Volatile suspended solids (VSS)	Standard method 2540E[2]
	Volatile Fatty Acids (VFA)	Adapted from Standard methods. The full method is detailed in Volume 1, Appendix 2.
Nutrients	Total Kjeldahl Nitrogen (TKN)	The suggested method description has been attached in Volume 1, Appendix 2.
	Total Phosphorus (TP)	The suggested method description has been attached in Volume 1, Appendix 2.
	Potassium (K)	The suggested method description has been attached in Volume 1, Appendix 2.
Metals and micro-elements	Arsenic Cadmium Chromium Copper Lead Mercury Nickel Zinc (Any other metal or element identified during the comprehensive characterisation detailed in Volume 1)	For land disposal the TCLP test is recommended US EPA Method 1311, 1992 Note: A semi-quantitative ICP scan would give concentrations for all mentioned metals. Remind the laboratory to manage the interferences on the ICP appropriately, especially for compounds such as Arsenic.
Microbiological quality	Faecal coliforms	Membrane filter/ m-FC medium
	Total viable Helminth ova	See recommended new method further on in this Appendix

[1,2] Standard Methods for the Examination of Water and Wastewater, 20th edition (1998) or latest, by Leonore S. Clesceri, Arnold E. Greenbert and R. Rhodes Trussell.

Appendix 3.2: Sludge analyses required for monitoring purposes

Characteristic		Parameter	Guidance on methodology and/or recommended extraction method
Physical characteristics		pH	Direct measurement pH on saturated paste or solution
		Total solids (TS)	Standard method 2540B[1]
		Volatile suspended solids (VSS)	Standard method 2540E[2]
		Volatile Fatty Acids (VFA)	Adapted from Standard methods. The full method is detailed in Volume 1, Appendix 2.
Chemical characteristics	Nutrients	Total Kjeldahl Nitrogen (TKN)	The suggested method description has been attached in Volume 1, Appendix 2.
		Total Phosphorus (TP)	The suggested method description has been attached in Volume 1, Appendix 2.
		Potassium (K)	The suggested method description has been attached in Volume 1, Appendix 2.
	Metals and micro-elements	Arsenic Cadmium Chromium Copper Lead Mercury Nickel Zinc (Any other metal or element identified during the comprehensive characterisation detailed in Volume 1)	For land disposal the TCLP test is recommended US EPA Method 1311, 1992 Note: A semi-quantitative ICP scan would give concentrations for all mentioned metals. Remind the laboratory to manage the interferences on the ICP appropriately.
Microbiological quality		Faecal coliforms	Membrane filter/ m-FC medium
		Total viable Helminth ova	See recommended new method further on in this Appendix

[1,2] Standard Methods for the Examination of Water and Wastewater, 20th edition (1998) or latest, by Leonore S. Clesceri, Arnold E. Greenbert and R. Rhodes Trussell.

Appendix 3.3: Surface and groundwater analyses required for monitoring purposes

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

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

Appendix 3.4: Soil analyses required for monitoring purposes

Characteristic	Parameter	Guidance on methodology and/or recommended extraction method
Nutrients	Total Kjeldahl Nitrogen (TKN)	The suggested method description has been attached in Volume 1, Appendix 2.
	Total Phosphorus (TP)	The suggested method description has been attached in Volume 1, Appendix 2.
Metals to assess compliance in terms of the TMT and MPL	Arsenic Cadmium Chromium Copper Lead Mercury Nickel Zinc (Any other metal or element identified during the comprehensive characterisation detailed in Volume 1)	Extraction of trace elements soluble in *aqua regia* solution. International Standard ISO 11466 Method Reference number: ISO11466:1995 (E) Note: A semi-quantitative ICP scan would give concentrations for all mentioned metals. Remind the laboratory to manage the interferences on the ICP appropriately.

Appendix 3.5: Recommended new procedure to determine Helminth ova in wastewater sludge

Note: This is a new method which was developed after Volume 1 of the New Sludge Guidelines has been published and differs from the method published in Volume 1.

<u>Method for analyses of sludge</u>

Note: It is always preferable to work with small sub-samples as eggs may not be as easily released from a large sample to float out of the sludge when doing the $ZnSO_4$ flotation technique. Rather increase the number of sub-samples than overload each test-tube in order to keep the number of tubes down.

The number of sub-samples will also be dependent on the helminth ova load expected. This will require knowledge of the epidemiology of helminths in the particular area in South Africa. Consequently, more sub-samples must be done in an area of low endemicity and less in a highly endemic area.

1. Mix the sludge sample well by swirling and stirring with a plastic rod. From the total sample take 4 x 15 mℓ sub-samples and place them into 4 x 50 mℓ test tubes. (If the solid content is high this should be sufficient sample. If it is low, take more 15 mℓ sub-samples).
2. Add either a few millilitres of 0.1% Tween80 or AmBic solution to the samples, vortex and add more wash solution. Repeat this procedure until the tubes are filled to approximately a centimetre from the top.
3. Place the 150µm sieve in a funnel in a retort stand with a plastic beaker underneath to catch the filtrate. Filter the well-mixed contents of the tubes one at a time, rinsing out each tube and washing this water through the sieve as well.
4. Pour the filtrate into test tubes and centrifuge at 1389g (±3000rpm) for 3 minutes. Suction off the supernatant fluids and discard. Combine the deposits into a suitable number of tubes so that there is not more than 1 mℓ in a 15 mℓ tube or 5 mℓ in a 50 mℓ tube
5. Re-suspend each of these deposits in a few millilitres of ZnSO and vortex well to mix. Keep adding more $ZnSO_4$ and mixing until the tube is almost full.
6. Centrifuge the tubes at 617g (±2000rpm) for 3 minutes. Remove from the centrifuge and pour the supernatant fluids through the 20µm filter, washing well with water.
7. Collect the matter retained on the sieve and wash it into test tubes.
8. Centrifuge the tubes at 964g (±2500rpm) for 3 minutes; remove & discard the supernatant fluid. Combine the deposits into one test tube, using water to recover all the eggs from the other tubes. Then centrifuge again at 964g for 3 minutes to get one deposit.
9. Once there is one final deposit, remove all of it using a plastic Pasteur pipette and place it onto one or more microscope slides. Place a coverslip over each deposit and examine microscopically using the 10x objective and the 40x objective to confirm any unsure diagnoses.
10. Each species of helminth ova is enumerated separately and reported as eggs per gram of sludge.

Note: Samples may be examined slightly differently from that described in step No. 10 above by doing the following:

The deposits are filtered through a 12µm ISOPORE membrane, which is then rinsed with distilled water. The membrane is air-dried, cut in half and placed on a microscope slide. Immersion oil is used to clear the membrane before examining under the microscope.

To test for viability:

Perform steps 1 to 8 of the procedure above and continue as follows:

9. Once there is a final deposit in the test tube, re-suspend it in 4 mℓ of 0.1 H_2SO_4. Before incubating mark the test tube with the level of liquid and incubate at a temperature of 26ºC for three to four weeks. Check the level of liquid in each one of the test tubes and add the reagent every time that is necessary, compensating for any evaporation that may occur.

10. Once the incubation time is over, homogenize the deposit and proceed to quantify the eggs. Remove all of the deposit using a plastic Pasteur pipette and place it onto one or more microscope slides. Place a coverslip over each deposit and examine microscopically using the 10x objective and the 40x objective to confirm any unsure diagnoses. Only those ova where the larva is observed are considered viable.

Equipment required and related information

1. A centrifuge with a swing-out rotor and buckets that can take 15 ml and/or 50 ml plastic conical test tubes.
2. Vortex mixer.
3. Retort Stand with at least 2 clamps on it.
4. Large plastic funnels to support the filters (±220 mm diameter).
5. Filters / Sieves : 1x 150µm; 1x 100µm; 1x 20µm.
6. Approx. 6 Plastic beakers (500 ml) & 3 Plastic wash bottles.
7. At least 4 glass “Schott” bottles (1lt, 2lt & 5lt sizes) for make-up and storage of the chemical solutions and de-ionized water.
8. Magnetic stirrer and stirring magnets.
9. 15 ml and 50 ml plastic conical test tubes.
10. 3 x Small glass beakers (100 ml).
11. Plastic Pasteur Pipettes & Plastic Stirring Rods.
12. Glass microscope slides (76 x 26 x 1,2 mm).
13. Square & Rectangular Cover-slips (22 x 22 mm & 22 x 40 mm).
14. A binocular compound microscope with 10x eyepieces, a 10x objective and a 40x objective.

Working out the g-force of your centrifuge

G-force (or g) = $(1,118 \times 10^{-5})\ r\ s^2 = 0,00001118 \times r \times s^2$

where : s = revolutions per minute (i.e. the speed you spin at)

r = the radius (the distance in centimetres from the centre of the rotor to the bottom of the bucket holding the tubes, when the bucket is in the swing-out position)

Reagents

Zinc Sulphate

$ZnSO_4$ (heptahydrate) is made up by dissolving 500g of the chemical in 880 ml de-ionised or distilled water.

A hydrometer must be used to adjust the specific gravity (SG) to 1.3, using more chemical if the SG is too low or more water if it is >1,3.

This high specific gravity facilitates the floating of heavier ova such as *Taenia* sp. (SG = 1.27). It is not critical if the SG of the $ZnSO_4$ solution is just over 1.3 but it should **never** be below this value!

Ammonium Bicarbonate

The AMBIC solution is essentially a saturated ammonium bicarbonate solution. Ammonium bicarbonate can be obtained from Merck Chemicals and is made up by dissolving 119g of the chemical in 1000 ml of de-ionised water.

0,1% Tween80

1 ml of Tween80 is measured out using a pipette and placed in 1000 ml of de-ionized or distilled water to give a 0,1% wash solution.

Note: Tween80 is extremely viscous and it is necessary to wash **all** of it out into the water in which it is made up, by alternately sucking up water and blowing it out using the same pipette.

Appendix 3.6: Toxicity Characteristic Leaching Procedure (TCLP) extraction for sludge destined for co-disposal (USEPA Method 1311)

Summary of method

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

Apparatus

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

TCLP solution 1

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

TCLP solution 2

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

Samples

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

TCLP extractions

Note that the TCLP test requires that a waste be pre-tested for its acid neutralization capacity. Those with low acid neutralization capacity are extracted with TCLP solution 1 (0.1 M Sodium Acetate Buffer, pH 4.93±0.05) and those with high acid neutralization capacity are extracted with TCLP solution 2 (0.1 M Acetic Acid, pH 2.88±0.05). Most sludges have a low acid neutralization capacity and will, therefore, be extracted with TCLP solution 1. After addition of lime, the acid neutralization capacity of the sludge is increased, but note that the treated sludge should be leached using the TCLP solution used for original sludge, i.e. in most cases TCLP solution 1, so that the results are directly comparable and one can evaluate the effect of the lime treatment. This is correct even though the pre-test used in the TCLP on the lime treated sludge may indicate that TCLP solution number 2 should be used.

A. Preliminary evaluation:

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

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

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

3. Measure the pH.

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

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

   5.1 Add 3.5 ml 1N HCL and stir briefly.

   5.2 Cover with a watch glass, heat to 50°C and hold at 50°C for ten minutes.

   5.3 Let cool to room temperature and record the pH.

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

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

B. Extraction for analysis of contaminants:

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

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

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

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

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

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

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

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

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

Appendix 4: Vector attraction reduction options

The following options are available to reduce the vector attraction potential. These options have been adopted from the USEPA Part 503 Rule.

Option 1: Reduction in Volatile Solids Content

Vector attraction is reduced if the fraction of volatile solids in the primary sludge is reduced by at least 38 percent during the treatment of the sludge. This percentage is the amount of volatile solids reduction that is attained by anaerobic or aerobic digestion plus any additional volatile solids reduction that occurs before the sludge leaves the treatment works, such as through processing in drying beds or lagoons, or by composting.

Digestion process efficiency can be measured by the reduction in the volatile solids content of the feed sludge to the digester and the sludge withdrawn from the digester. Anaerobic digestion of primary sludge generally results in a reduction of between 40 and 60% of the volatile solids.

O'Shaunessy's formula can be used to calculate the volatile solids (VS) reduction in a digester:

VS reduction (%) = $\{(V_i – V_o)/ V_i – (V_i \text{ x } V_o)\}$x100

Where V_i = volatile fraction in feed sludge

V_o = volatile fraction in digested sludge

Example of calculation of VS reduction

Assume volatile solids in feed sludge	=	84%		
Therefore volatile fraction of feed sludge	=	0.84	=	V_i
Assume volatile solids of digested sludge	=	68%		
Therefore volatile fraction of digested sludge	=	0.68	=	V_o

VS reduction (%) = {(0.84-0.68) / 0.84 – (0.84 x 0.68)} x 100

= 59%

Option 2: Additional Digestion of Anaerobically Digested Sludge

Frequently, primary sludge is recycled to generate fatty acids or the sludge is recycled through the biological wastewater treatment section of a treatment works or has resided for long periods of time in the wastewater collection system. During this time, the sludge undergoes substantial biological degradation. If the sludge is subsequently treated by anaerobic digestion for a period of time, it adequately reduces vector attraction. Because the sludge will have entered the digester already partially stabilized, the volatile solids reduction after treatment is frequently less than 38 percent.

Under these circumstances, the 38 percent reduction required by Option 1 may not be achievable. Option 2 allows the operator to demonstrate vector attraction reduction by testing a portion of the previously digested sludge in a **bench-scale unit** in the laboratory. Vector attraction reduction is demonstrated if, after anaerobic digestion of the sludge for an additional 40 days at a temperature between 30º and 37ºC, the volatile solids in the sludge are reduced by less than 17 percent from the beginning to the end of the bench test.

Option 3: Additional Digestion of Aerobically Digested Sludge

This option is appropriate for aerobically digested sludge that cannot meet the 38 percent volatile solids reduction required by Option 1. This includes activated sludge from extended aeration plants, where the minimum residence time of sludge leaving the wastewater treatment processes section generally exceeds 20 days. In these cases, the sludge will already have been substantially degraded biologically prior to aerobic digestion.

Under this option, aerobically digested sludge with 2 percent or less solids is considered to have achieved vector attraction reduction, if in the laboratory after 30 days of aerobic digestion in a batch test at 20ºC, volatile solids are reduced by less than 15 percent. This test is only applicable to liquid aerobically digested sludge.

Option 4: Specific Oxygen Uptake Rate (SOUR) for Aerobically Digested Sludge

Frequently, aerobically digested sludge is circulated through the aerobic biological wastewater treatment process for as long as 30 days. In these cases, the sludge entering the aerobic digester is already partially digested, which makes it difficult to demonstrate the 38 percent reduction required by Option 1.

The specific oxygen uptake rate (SOUR) is the mass of oxygen consumed per unit time per unit mass of total solids (dry-weight basis) in the sludge. Reduction in vector attraction can be demonstrated if the SOUR of the sludge that is used or disposed, determined at 20ºC, is equal to or less than 2 milligrams of oxygen per hour per gram of total sludge (dry-weight basis). This test is based on the fact that if the sludge consumes very little oxygen, its value as a food source for micro organisms is very low and therefore micro-organisms are unlikely to be attracted to it. Other temperatures can be used for this test, provided the results are corrected to a 20 ºC basis. This test is only applicable to liquid aerobic sludge withdrawn from an aerobic treatment process.

Option 5: Aerobic Processes at Greater than 40 ºC

This option applies primarily to composted sludge that also contains partially decomposed organic bulking agents. The sludge must be aerobically treated for 14 days or longer, during which time the temperature must always be over 40ºC and the average temperature must be higher than 45ºC.

This option can be applied to other aerobic processes, such as aerobic digestion, but Options 3 and 4 are likely to be easier to meet than the other aerobic processes.

Option 6: Addition of Alkaline Material

Sludge is considered to be adequately reduced in vector attraction if sufficient alkaline material is added to achieve the following:

- Raise the pH to at least 12, measured at 25 ºC, and without the addition of more alkaline material, maintain a pH of 12 for at least 2 hours.
- Maintain a pH of at least 11,5 without addition of more alkaline material for an additional 22 hours.

The conditions required under this option are designed to ensure that the sludge can be stored for at least several days at the treatment works, transported, and then used or disposed without the pH falling to the point where putrefaction occurs and vectors are attracted.

Option 7: Moisture Reduction of Sludge Containing no Un-stabilised Solids

Under this option, vector attraction is considered to be reduced if the sludge does not contain unstabilised solids generated during primary treatment and if the solids content of the sludge is at least

75% before the sludge is mixed with other materials. Thus, the reduction must be achieved by removing water, not by adding inert materials.

It is important that the sludge does not contain un-stabilised solids because the partially degraded food scraps likely to be present in such sludge would attract birds, some mammals, and possibly insects, even if the solids content of the sludge exceeds 75 percent. In other words, simply dewatering primary sludge to a 75% solid is not adequate to comply with this option. Activated sludge, humus sludge and anaerobically digested sludge can, however be dewatered to 75% solids and comply with option 7.

Option 8: Moisture Reduction of Sludge Containing Unstabilised Solids

The ability of any sludge to attract vectors is considered to be adequately reduced if the solids content of the sludge is increased to 90 percent or greater, regardless of whether this contains primary sludge or raw unstabilised sludge. The solids increase should be achieved by removal of water and not by dilution with inert solids. Drying to this extent severely limits biological activity and strips off or decomposes the volatile compounds that attract vectors.

The way dried sludge is handled, including storage before use or disposal, can again create the opportunity for vector attraction. If dried sludge is exposed to high humidity, the outer surface of the sludge will increase in moisture content and possibly attract vectors. This should be properly guarded against.

Option 9: Sludge Injection

Vector attraction reduction can be demonstrated by injecting the sludge below the ground surface. Under this option, no significant amount of sludge can be present on the land surface within 1 hour of injection, and if the sludge is Microbiological Class A or B, it must be injected within 8 hours after discharge from the pathogen-reducing process.

Note: Microbiological class A and B can be applied to soil much later than 8 hours after discharge from the pathogen-reducing process if another vector attraction reduction option such as dewatering and/or drying is applied. The time periods referred to in Option 9 are intended for liquid sludge application of Microbiological classes A and B.

Injection of sludge beneath the soil places a barrier of earth between the sludge and vectors. The soil removes water from the sludge, which reduces the mobility and odour of the sludge. Odour is usually present at the site during the injection process, but quickly dissipates once injection is complete. This option is applicable to all land disposal options and co-disposal on landfill.

Option 10: Incorporation of Sludge into the Soil

Under this option, sludge must be incorporated into the soil within 6 hours of application to or placement on the land. Incorporation is accomplished by ploughing or by some other means of mixing the sludge into the soil. If the sludge is Microbiological class A or B with respect to pathogens, the time between processing and application or placement must not exceed 8 hours – the same as for injection under Option 9. See the note under Option 9. This option is applicable to all land disposal options and co-disposal on landfill.

Note: Practical restrictions, such as the ability of the plough to function immediately after application, could cause delays in the incorporation of the sludge within the 6 hours. This could cause the development of odours and increase risk of vector attraction. In these cases the sludge producer needs to monitor the development of odours and manage the situation diligently.

Appendix 5: Sampling methods and procedures for water and soil samples

WATER SAMPLING[1] PROCEDURE

Sampling equipment needed

- Equipment to collect microbiological samples

  Sterile sample bottles (see Table 14 and 15 for the type of sample bottle needed)

  Sealed container or cool box which can be kept cool (preferably with ice)

- Equipment to collect chemical and physical samples

  Correct sample bottles (see Table 14 and 15 for the different types of sample bottles required)

  Cooler box with ice (if necessary)

Special precautions

- Microbiological water samples

  Keep sample bottle closed and in a clean condition up to the point where it has to be filled with the water to be sampled.

  Do not rinse bottle with any water prior to sampling.

  When samples for chemical and microbiological analysis are to be collected from the same location, the microbiological sample should be collected first to avoid the danger of microbiological contamination of the sampling point.

  The sampler (person taking the sample) should wear gloves (if possible) or wash his/her hands thoroughly before taking each sample. Avoid hand contact with the neck of the sampling bottle.

- Chemical water samples

  Some plastic caps or cap liners may cause metal contamination of the water sample. Please consult with the laboratory on the correct use of bottle caps.

  Keep sample bottle closed and in a clean condition up to the point where it has to be filled with the water to be analysed.

  Never leave the sample bottles (empty or filled with the water sample) unprotected in the sun.

  After the sample has been collected the sample bottle should be placed directly in a cooled container (e.g. portable cooler box). Try and keep cooled container dust-free.

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[1] For more detail on the water sampling procedure, consult the following documents:
Department of Water Affairs and Forestry. 1998. Waste Management Series. Minimum Requirements for Water Monitoring at Waste Management Facilities.
WRC. 2000. Quality of domestic water supplies. Volume 2:Sampling Guide. WRC no TT117/99.

SURFACE WATER SAMPLING TECHNIQUE

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

- At the sampling point remove cap of sample bottle but do not contaminate inner surface of cap and neck of sample bottle with hands.
- Take samples by holding bottle with hand near base and plunge the sample bottle, neck downward, below the water surface (wear gloves to protect your hands from contact with the water).
- Turn bottle until neck points slightly upward and mouth is directed toward the current (can also be created artificially by pushing bottle forward horizontally in a direction away from the hand).
- Fill sample bottle without rinsing and replace cap immediately.
- Before closing the sample bottle, preserve the sample (if applicable, see Table 14) and leave ample air space in the bottle (at least 2.5 cm) to facilitate mixing by shaking before examination.
- Label the sample
- Submit for analysis to a reputable analytical laboratory.

Composite Borehole Water Sampling

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

- Activate the pump and remove (purge) at least three times the volume of water contained in the hole.
- Collect a water sample in a clean container (see Table 15).
- Filter and preserve the sample (if applicable, see Table 15) and submit for analysis to a reputable analytical laboratory.

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

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

SOIL SAMPLING[2]

Sampling equipment needed

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

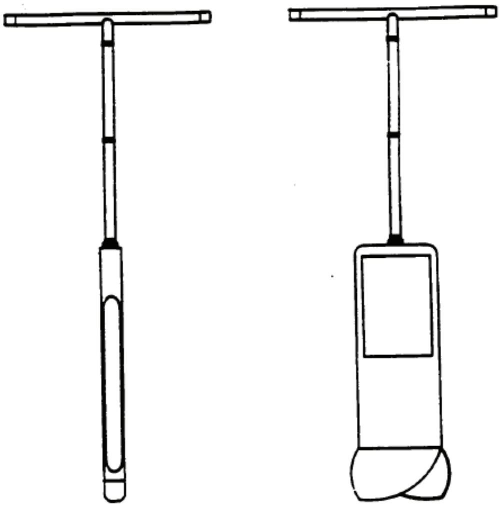

Figure 5A: Soil augers

Number of samples

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

Sampling procedure

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

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[2] For more information on soil sampling procedures, consult the following documents:
USEPA Environmental Response Team. 2000. Standard operating procedures: Soil sampling
USEPA 1989. Soil sampling quality assurance: User's Guide. EPA 600/8-89/046

1. Clear the area to be sampled of any surface debris (e.g. twigs, rocks, litter).

2. Begin augering and after reaching the desired depth, slowly and carefully remove the auger from the hole. Deposit the soil onto a plastic sheet spread near the hole. For soil monitoring at disposal sites these depths are 0-100 mm, 100-200 mm, 200-300 mm, 300-400 mm and 400-500 mm.

3. Place the samples into plastic or other appropriate containers, secure the caps tightly and label the sample.

4. If composite samples are to be collected, place a sample from another sampling site into the same container and mix thoroughly. When compositing is complete, place the sample into appropriate, labeled containers and secure the caps tightly.

5. Preserve the samples as recommended in Table A3 and submit to a reputable laboratory

Table 5a: Recommended soil sample containers, preservation and holding times

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

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

1. A shovel is used to remove a one to two inch layer of soil from the vertical face of the pit where sampling is to be done.

2. Samples are taken using a trowel, scoop, or coring device at the desired intervals. Be sure to scrape the vertical face at the point of sampling to remove any soil that may have fallen from above, and to expose fresh soil for sampling.

3. Place the samples into plastic or other appropriate containers, secure the caps tightly and label the sample.

4. If composite samples are to be collected, place a sample from another sampling site into the same container and mix thoroughly. When compositing is complete, place the sample into appropriate, labeled containers and secure the caps tightly.

5. Preserve the samples as recommended in Table A3 and submit to a reputable laboratory

LIST OF ACRONYMS

DEAT	Department of Environmental Affairs and Tourism
DWAF	Department of Water Affairs and Forestry
ECA	Environment Conservation Act 73 of 1989
EEC	Estimated Environmental Concentration
EIA	Environmental Impact Assessment
NEMA	National Environmental Act, No. 107 of 1998
NWA	National Water Act 36 of 1998
RoD	Record of Decision
WWTP	Wastewater treatment plant
TMT	Total Maximum Threshold Value
MPL	Maximum Permissible Level
TCLP	Toxicity Characteristic Leaching Procedure
AE	Acceptable Exposure

DEFINITIONS AND DESCRIPTION OF KEY TERMS

Acceptable exposure:	The concentration of a substance that will have minimal effect on the environment or human health.
Agricultural land:	Land on which a food crop, a feed crop, or a fibre crop is grown. This includes grazing land and forestry.
Agronomic rate:	The sludge application rate (dry-weight basis) designed (i) to provide the amount of nitrogen needed by the food crop, feed crop, fibre crop, cover crop, or vegetation grown on the land and (ii) to minimise the amount of nitrogen in the sewage sludge that passes below the root zone of the crop or vegetation grown on the land to the groundwater.
Agricultural use:	The use of sludge to produce agricultural products. It excludes the use of sludge for aquaculture and as an animal feed.
Annual pollutant loading rate:	The maximum amount of a pollutant that can be applied to an area of land during a 365-day period.
Assimilative capacity:	This represents the ability of the receiving environment to accept a substance without risk.
Available metal content (Soil):	Specific to Volume 2. Metal fraction extracted with ammonium nitrate in soil samples.
Beneficial uses:	Use of sludge with a defined benefit, such as a soil amendment.
Bioavailability:	Availability of a substance for uptake by a biological system.
Biosolids:	Stabilised Sludge. Organic solids derived from biological wastewater treatment processes that are in a state that they can be managed to sustainably utilise the nutrient, soil conditioning, energy, or other value.
Bund wall:	A properly engineered and constructed run-off interception device around a waste disposal site or down slope of a waste disposal site.
Co-disposal (liquid with dry waste):	The mixing of high moisture content or liquid waste with dry waste. This affects the water balance and is an acceptable practice on a site equipped with leachate management measures.
Co-disposal (dewatered sludge with dry waste):	The mixing of dewatered sludge with dry waste in a general landfill site or hazardous landfill site without affecting the water balance of the site.
Composting:	The biological decomposition of the organic constituents of sludge and other organic products under controlled conditions.
Contaminate:	The addition of foreign matter to a natural system. This does not necessarily result in pollution, unless the attenuation capacity of the natural system is exceeded.
Controlled access:	Where public or livestock access to sludge application areas is restricted or controlled, such as via fences or signage, for a period of time stipulated by this guideline.
Cradle-to-grave:	A policy of controlling a Hazardous Waste from its inception to its ultimate disposal
Cumulative pollutant loading rate:	The maximum amount of a pollutant that can be applied to a unit area of land.
Cut-off trench:	A properly engineered and constructed trench to intercept and collect run-off .
Dedicated land disposal:	Sites that receive repeated applications of sludge for the sole purpose of final disposal.
Delisting:	If the estimated environmental concentration (EEC) is less than the Acceptable Exposure (AE) which is 10% of the LC_{50}, the waste can be delisted, i.e. be moved to a lower Hazard Rating or even disposed of at a General Waste landfill with a leachate collection system.
Dewatering:	Dewatering processes reduce the water content of sludge to minimise the volumes for transport and improve handling characteristics. Typically, dewatered sludge can be handled as a solid rather than as liquid matter.
Disinfection:	A process that destroys, inactivates or reduces pathogenic microorganisms.
Disposal:	The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into the environment (land, surface water, ground water, and air).
Disposal site:	A site used for the accumulation of waste with the purpose of disposing or treatment of such waste. See also Waste Disposal Site
Domestic sewage:	Waste and wastewater from humans or household operations that is discharged to, or otherwise

enters a treatment works.

Dose: In terms of monitoring exposure levels, the amount of a toxic substance taken into the body over a given period of time. See also $LD_{50.}$

Domestic waste: Waste emanating, typically, from homes and offices. Although classified as a General Waste, this waste contains organic substances and small volumes of hazardous substances.

Dose-response: How an organism's response to a toxic substance changes as its overall exposure to the substance changes. For example, a small dose of carbon monoxide may cause drowsiness; a large dose can be fatal.

Drying: A process to reduce the water content further than a dewatering process. The solids content after a drying process is typically > 75%.

Dry-weight (DW) basis: The method of measuring weight where, prior to being weighed, the material is dried at 105ºC until reaching a constant mass (i.e., essentially 100% solids content).

Dump: A land site where wastes are discarded in a disorderly or haphazard fashion without regard to protecting the environment. Uncontrolled dumping is an indiscriminate and illegal form of waste disposal. Problems associated with dumps include multiplication of disease-carrying organisms and pests, fires, air and water pollution, unsightliness, loss of habitat, and personal injury.

E. coli: A group of bacteria normally found in the intestines of humans and animals. Most types of *E. coli* are harmless, but some active strains produce harmful toxins and can cause severe illness. In sanitary bacteriology, *Escherichia coli* is considered the primary indicator of recent faecal pollution.

Ecotoxicity: Ecotoxicity is the potential to harm animals, plants, ecosystems or environmental processes.

Emission: The release or discharge of a substance into the environment. Generally refers to the release of gases or particulates into the air.

Emission Standards: Government standards that establish limits on discharges of pollutants into the environment (usually in reference to air).

Environment: Associated cultural, social, soil, biotic, atmospheric, surface and groundwater aspects associated with the disposal site that could potentially be, impacted upon by the disposal.

Environmental Impact Assessment (EIA): An investigation to determine the potential detrimental or beneficial impact on the surrounding communities, fauna, flora, water, soil and air arising from the development or presence of a waste disposal site.

Estimated Environmental Concentration (EEC): The Estimated Environmental Concentration represents the concentration of a substance in the aquatic environment when introduced under worst case scenario conditions, i.e., directly into a body of water. It is used to indicate possible risk, by comparison with the minimum concentration estimated to adversely affect aquatic organisms or to produce unacceptable concentrations in biota, water or sediment.

Faecal coliform: *Faecal coliforms* are the most commonly used bacterial indicator of faecal pollution. *Faecal coliforms* are bacteria that inhabit the digestive system of all warm-blooded animals, including humans.

Freeboard: Vertical distance from the normal water surface to the top of a confining wall.

Hazard Rating: A system for classifying and ranking Hazardous waste according to the degree of hazard they present.

Hazardous waste: Waste that may, by circumstances of use, quantity, concentration or inherent physical, chemical or infectious characteristics, cause ill health or increase mortality in humans, fauna and flora, or adversely affect the environment when improperly treated, stored, transported and disposed of.

Helminth ova: The eggs of parasitic intestinal worms.

Incineration: Incineration is both a form of treatment and a form of disposal. It is simply the controlled combustion of waste materials to a non-combustible residue or ash and exhaust gases, such as carbon dioxide and water.

Integrated Environmental Management (IEM): A code of practice ensuring that environmental considerations are fully integrated into the management of all activities in order to achieve a desirable balance between conservation and development.

Land application: The spraying or spreading of wastewater sludge onto the land surface; the injection of wastewater sludge below the land surface; or the incorporation of wastewater sludge into the soil so that the wastewater sludge can either condition the soil or fertilise crops or vegetation grown in the soil.

Land disposal:	Application of sludge where beneficial use is not an objective. Disposal will normally result in application rates that exceed agronomic nutrient requirements or cause significant contaminant accumulation in the soil.
Landfill:	To dispose of waste on land, whether by use of waste to fill in excavation or by creation of a landform above grade, where the term "fill" is used in the engineering sense.
LC_{50}:	The median lethal dose is a statistical estimate of the amount of chemical, which will kill 50% of a given population of aquatic organisms under standard control conditions. The LC50 is expressed in mg/l.
LD_{50}:	The median lethal dose is a statistical estimate of the amount of chemical, which will kill 50% of a given population of animals (e.g. rats) under standard control conditions.
Leachate:	An aqueous solution with a high pollution potential, arising when water is permitted to percolate through decomposing waste.
Liner:	A layer of low permeability placed beneath a landfill and designed to direct leachate to a collection drain or sump, or to contain leachate. It may comprise natural materials, synthetic materials, or a combination thereof.
Maximum available threshold (MAT):	The maximum available (NH_4NO_3 extractable) metal concentration allowed for soils receiving sludge.
Maximum permissible level:	The maximum total metal concentration allowed in soils at sludge disposal sites. Soil remediation would not be necessary except if this level is exceeded.
Minimum Requirement:	A standard by means of which environmentally acceptable waste disposal practices can be distinguished from environmentally unacceptable waste disposal practices.
Monthly average:	The arithmetic mean of all measurements taken during a given month.
Most probable number (MPN):	A unit that expresses the amount of bacteria per gram of total dry solids in wastewater sludge.
Off-site:	Sludge disposal site outside the boundaries of the wastewater treatment plant (WWTP)
On-site:	Sludge disposal site within the boundaries of the wastewater treatment plant (WWTP)
Pathogenic organisms:	Disease-causing organisms. This includes, but is not limited to, certain bacteria, protozoa, viruses, and viable Helminth ova.
pH:	The logarithm of the reciprocal of the hydrogen ion concentration. The pH measures acidity/alkalinity and ranges from 0 to 14. A pH of 7 indicates the material is neutral. Moving a pH of 7 to 0, the pH indicates progressively more acid conditions. Moving from a pH of 7 to 14, the pH indicates progressively more alkaline conditions.
Pollution:	The direct or indirect alteration of the physical, chemical or biological properties of a (water) resource so as to make it less fit for any beneficial purpose for which it may reasonably be expected to be used; or harmful or potentially harmful to the welfare, health or safety of human beings; to any aquatic or non-aquatic organisms; to the resource quality; or to property.
Primary treatment:	Treatment of wastewater prior to other forms of treatment and involving settling and removal of suspended solids.
Qualified person:	A person is suitably qualified for a job as a result of one, or any combination of that person's formal qualifications, prior learning, relevant experience; or capacity to acquire, within a reasonable time, the ability to do the job.
Receptor:	Sensitive component of the ecosystem that reacts to or is influenced by environmental stressors.
Recycle:	The use, re-use, or reclamation of a material so that it re-enters the industrial process rather than becoming a waste.
Rehabilitation:	Restoring a waste site for a new industrial function, recreational use, or to a natural state.
Remediation:	The improvement of a contaminated site to prevent, minimize or mitigate damage to human health or the environment. Remediation involves the development and application of a planned approach that removes, destroys, contains or otherwise reduces the availability of contaminants to receptors of concern.

Residue: A substance that is left over after a waste has been treated or destroyed.

Responsible person: A person(s), who takes professional responsibility for ensuring that all or some of the facets of the handling and disposal of Hazardous Waste are properly directed, guided and executed, in a professionally justifiable manner.

Restricted agricultural use: Use of sludge in agriculture is permitted but restrictions apply (crop restrictions, access restrictions, etc.).

Risk: The scientific judgement of probability of harm. This basic and important concept has two dimensions: the consequences of an event or set of circumstances and the likelihood of particular consequences being realised. Both dimensions apply to environmental risk management with it generally being taken that only adverse consequences are relevant.

Risk assessment: The evaluation of the results of risk analysis against criteria or objectives to determine acceptability or tolerability of residual risk levels, or to determine risk management priorities (or the effectiveness or cost-effectiveness of alternative risk management options and strategies).

Risk management: The systematic application of policies, procedures and practices to identify hazards, analysing the consequences and the likelihood associated with those hazards, estimating risk levels, assessing those risk levels against relevant criteria and objectives, and making decisions and acting to reduce risk levels to acceptable environmental and legal standards.

Secondary Treatment: Treatment of wastewater that typically follows primary treatment and involves biological processes and settling tanks to remove organic material.

Sludge-amended soil: Soil to which sludge has been added.

Sludge: Solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Wastewater sludge includes, but is not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and material derived from wastewater sludge in a wastewater sludge incinerator. It does not include the grit and screenings generated during preliminary treatment of domestic wastewater in a treatment works.

Soil organisms: A broad range of organisms, including microorganisms and various invertebrates living in or on the soil.

Specific oxygen uptake rate (SOUR): The mass of oxygen consumed per unit time per unit mass of total solids (dry-weight basis).

Stabilisation: The processing of sludge to reduce volatile organic matter, vector attraction, and the potential for putrefaction and offensive odours.

Stabilised sludge: Organic solids derived from biological wastewater treatment processes that are in a state that they can be managed to utilise the nutrient, soil conditioning, energy, or other value.

Sterilise: Make free from microorganisms.

Supplier: A person or organisation that produces and supplies sludge for use. This includes a water business producing and treating sludge and processors involved in further treatment.

Surface water interception mechanism: A mechanism placed between the disposal site and the surface water body to intercept possible run-off from the disposal site before it can reach the water body.

Sustainability: Being able to meet the needs of present and future generations by the responsible use of resources.

Sustainable use: The use of nutrients in sludge at or below the agronomic loading rate and/or use of the soil conditioning properties of sludge. Sustainable use involves protection of human health, the environment and soil functionality.

Total investigative level (TIL): The total metal concentration in agricultural soils where further investigation is necessary before sludge application can commence.

Total load capacity: The capacity of a landfill site to accept a certain substance or the amount of a substance, which can be safely disposed of at a certain site. The total load capacity is influenced by the concentration levels and mobility of the waste, and by the landfill practice and design.

Total maximum threshold (TMT): The maximum total metal concentration allowed in agricultural soils receiving sludge.

Total metal content: Metal fraction extracted using an *aqua regia* solution (HCl/HNO_3 solution).

Total trigger value The total metal concentration in soils at disposal sites indicating that additional management

(TTV):	options should be implemented to reduce the impact on the soil.
Toxic:	Poisonous.
Toxicity:	An intrinsic property of a substance which can cause harm or a particular adverse effect to humans, animals or plants at some dose.
Toxicity Characteristic Leaching Procedure (TCLP):	A test developed by the USA Environmental Protection Agency to measure the ability of a substance to leach from the waste into the environment. It thus measures the risk posed by a substance to groundwater.
Transporters:	A person, organisation, industry or enterprise engaged in or offering to engage in the transportation of waste.
Treatment:	Treatment is used to remove, separate, concentrate or recover a hazardous or toxic component of a waste or to destroy or, at least, to reduce its toxicity in order to minimise its impact on the environment.
Unrestricted agricultural use:	Sludge is of such good quality that it can be used in agricultural practices without any restrictions.
VAR:	Vector Attraction Reduction.
Vector attraction:	The characteristic of wastewater sludge that attracts rodents, flies, mosquitoes, or other organisms capable of transporting infectious agents.
Vectors:	Any living organisms that are capable of transmitting pathogens from one organism to another, either: (i) mechanically by transporting the pathogen or (ii) biologically by playing a role in the lifecycle of the pathogen. Vectors include flies, mosquitoes or other insects, birds, rats and other vermon.
Waste:	An undesirable or superfluous by-product, emission, or residue of any process or activity, which has been discarded, accumulated or stored for the purpose of discarding or processing. It may be gaseous, liquid or solid or any combination thereof and may originate from a residential, commercial or industrial area.
Waste disposal site:	Any place at which more than 100 kg of a Hazardous Waste is stored for more than 90 days or a place at which a dedicated incinerator is located.
Waste Permit:	An authorisation in terms of the Environment Conservation Act (Act No. 73 of 1989) to establish, provide or operate any disposal site (See definition of disposal site)
Wastewater Sludge:	The material recovered from predominantly domestic wastewater treatment plants. (Also see Sludge)
Wastewater Treatment Plant (WWTP):	Any device or system used to treat (including recycling and reclamation) either domestic wastewater or a combination of domestic wastewater and industrial waste of a liquid nature.
Water Use Authorisation:	An entitlement to undertake a water use in terms of the National Water Act (Act No. 36 of 1998). An authorisation may be a water use license, permissible under a general authorisation, an existing lawful water use, or a Schedule I water use.
Wet weight:	Weight measured of material that has not been dried (see Dry-weight basis).