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

VOLUME 3: REQUIREMENTS FOR THE ON-SITE AND OFF-SITE DISPOSAL OF SLUDGE

by

JE Herselman and HG Snyman

GOLDER ASSOCIATES AFRICA, PO Box 6001, Halfway House, 1685, South Africa

Report to the Water Research Commission on the Project: "Development of the South African wastewater sludge disposal guidelines dealing with land and ocean disposal, beneficial use, use in commercial products and thermal treatment"

Project Leader: JE Herselman

WRC Report No. 1622/1/09
ISBN 978-1-77005-864-4
Set No. 978-1-77005-420-0

JUNE 2009

DISCLAIMER

This report has been reviewed by the Water Research Commission (WRC) and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the WRC, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

EXECUTIVE SUMMARY

The South African wastewater industry often views wastewater sludge as a waste product that should be managed as such. Due to the cost of the handling and disposal, sludge is increasingly being stored on site and many local authorities and service providers are failing to successfully manage the sludge in an environmentally acceptable manner.

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 possible presence of human pathogens mean that sludge cannot always be beneficially used.

The premise of Volume 3 of the Sludge Guidelines is that sludge that cannot be used beneficially should be disposed of in a way that will ensure minimal negative impacts on the environment. Sludge disposed of at a site other than that of the wastewater treatment plant (WWTP) itself, **would** fall under the definition of waste, as stipulated in Section 1 of the Environmental Conservation Act, 1989 (Minimum Requirements, latest edition). It was decided to use the Minimum Requirements as basis for sludge disposal (on-site and off-site) and most of the restrictions and requirements were adopted from these documents. The Minimum requirements are living documents which are periodically updated and the sludge producer and sludge user will be referred to these documents where applicable. Especially in the case of co-disposal on landfill, Volume 3 of the Sludge Guidelines should be seen as a procedural guideline where the principles of waste disposal are stated and the sludge producer is directed along the path of waste classification, hazard rating and delisting of sludge for co-disposal.

A survey of South African WWTPs (234 plants) indicated that a wide variety of disposal options are used in South Africa. The disposal option used by most of the treatment facilities is on-site **waste piles** (33%), either as the only disposal method or as a temporary measure before it is removed to a landfill or utilized beneficially. The sludge is dried in drying beds or paddies and then put on heaps until the municipalities' parks division, farmers or the public utilize it. Another popular disposal option is the use of **sludge ponds** (13%) where sludge is continuously pumped into a dam that may or may not be lined. A number of treatment facilities use **sludge lagoons** (6%) to dry the sludge. These lagoons are shallow, bounded disposal dams into which wet sludge is pumped alternating between lagoons in order to allow the sludge to dry out. **Irrigation** (9%) with liquid wastewater sludge using high-pressure nozzles connected to a sludge line on a dedicated land disposal (DLD) site is a popular option if sufficient soil is available, while some facilities **flood** irrigate (2%) the DLD site with the liquid sludge. At some WWTP's dried sludge is applied to DLD sites (2%). Only 3% of the surveyed WWTP used **landfills** to dispose of the sludge and 2% disposed of wastewater sludge to the marine environment.

The Guidelines for the on-site and off-site disposal of sludge are 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 issues 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 eliminate the issues that are insignificant. The risk assessment included the following steps:

- Source characterization (characteristics of sludge including pathogens, 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
- Identification of mitigating factors. Receptors can 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 disposal as for agricultural use. An additional option was added for co-disposal on landfill where daily cover is required. The Pollutant class classification 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, for Volume 3 it is recommended that the Pollutant class for disposal purposes be based on the leachable metal fraction (quality of leachate that will originate from the waste body) in the sludge.

There are several restrictions and requirements for land disposal of sludge to ensure that the environment will be protected against the adverse effects of sludge disposal. For all new sludge disposal sites an Environmental Impact Assessment (EIA) may be requested by the authorising authority (DWAF/DEAT) before a Record of Decision (ROD)/Water Use Authorisation will be granted. With regard to the issuing and enforcement of a waste disposal 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. Once a candidate disposal site has been found feasible for development and approved by DWAF/DEAT, further detailed investigation and reporting are required and will include the assessment of the environmental impact of a disposal site.

At all new and existing sludge disposal sites for land disposal, there would be a site selection process, initial site investigation, areas where sludge disposal is not allowed that should be eliminated, buffer zones to be introduced between the waste body and surface and groundwater. There are also restrictions based on sludge quality. Management requirements for land disposal include odour control, run-off collection, leachate collection (at lined facilities), surface water protection measures, groundwater protection measures, soil quality requirements, restrictions on crop production, grazing animals and public access restrictions.

Monitoring requirements for land disposal are introduced to serve as early warning systems of when disposal should be terminated and this includes sludge monitoring, groundwater monitoring, surface water monitoring, soil monitoring, methane gas monitoring and air quality monitoring. Closure and remediation plans for land disposal should be developed and implemented if the monitoring data indicates any environmental degradation. Records should be kept at the land disposal site including records on all the above requirements.

Since wastewater sludge is an industry specific waste, specific restrictions and requirements for sludge co-disposal on landfill apply as detailed in the *Minimum Requirements for the Handling, Classification and Disposal of Hazardous waste* (latest edition) and *Minimum Requirements for Waste Disposal by Landfill* (latest edition) or any update thereto. These include specific water balance studies at the landfill site, site stability assessments, hazard rating of sludge, minimum solids content of sludge destined for co-disposal, the delisting procedure for sludge, co-disposal ratios, management requirements for sludge co-disposal at landfill, public access restrictions and run-off collection and management both during operation and after closure.

South Africa has never seriously considered marine disposal for sludge disposal and it is unlikely that it presents an economically viable or environmentally acceptable option. The recently published *"Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa"* (DWAF, 2004), which was drawn up using wide consultation amongst competent authorities and stakeholders, and with detailed reference to global experience, outlines DWAF's new thinking around discharges to sea. This document presents a revised set of basic principles, stipulates a set of ground rules and presents a detailed management framework. A major shift in approach is signalled by the change from an effluent standards approach (i.e. enforcing compliance with effluent standards) to an approach which focuses on receiving water quality objectives which support the maintenance of fitness for use. The marine disposal section of Volume 3 leans very heavily on this policy. The following points were used as a basis: basic principles for waste disposal to sea, ground rules related to municipal wastewater and monitoring and contingency plans.

Sludge disposal is seen as a last resort and sludge producers will have to provide proof of alternative beneficial uses that were considered as well as feasibility studies conducted. The environmental risk cannot be removed completely from sludge disposal, but disposal can be managed in such a way that the risk will be minimal. With all the monitoring required for sludge disposal to land, enough early warning systems should be present to inform the sludge producer/disposal site operator of when the environmental risks becomes unacceptable and when closure and remediation plans should be implemented.

TABLE OF CONTENTS

SECTION **PAGE**

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1 INTRODUCTION

The South African wastewater industry often views wastewater sludge as a waste product that should be managed as such. Due to the cost of handling and disposal, sludge is increasingly being stored on site and many local authorities and service providers are failing to successfully manage the sludge in an environmentally acceptable manner.

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 means that sludge cannot always be used beneficially.

1.1 Purpose of Volume 3

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 management option. Volume 1 details the characterisation, classification and selection of options for sludge management while Volume 2 addresses the requirements for use of sludge in agriculture (both these documents are available from the WRC).

The premise of Volume 3 of the Sludge Guidelines is that sludge that cannot be used beneficially should be disposed of in a manner to ensure minimal negative impacts on the environment. Wastewater sludge disposed of at a site other than that of the WWTP itself, would fall under the definition of waste, as stipulated in Section 1 of the Environmental Conservation Act, 1989 (Minimum Requirements, latest edition). It was agreed that the Minimum Requirements would be used as the basis for disposal options of sludge and most of the restrictions and requirements were adopted from these documents. The Minimum requirements are living documents which are periodically updated and the sludge producer and sludge user will be referred to these documents where applicable. Especially in the case of co-disposal on landfill, Volume 3 of the Sludge Guidelines should be seen as a procedural guideline where the principles of waste disposal are stated and the sludge producer is directed along the path of waste classification, hazard rating and delisting of sludge for co-disposal.

Volume 3 describes the requirements and restrictions related to the on-site and off-site disposal of sludge. The Volume gives detailed requirements and guidance on:

- Managing and phasing out of uncontrolled and informal on-site land disposal facilities (waste piles);
- Operating existing dedicated land disposal sites; and,
- The management, rehabilitation and phasing out of dedicated land disposal sites.

Guidance and requirements on other disposal options, such as:

- Off-site co-disposal of sludge in a general or hazardous landfill site;
- On-site disposal of sludge in a mono disposal landfill or lagoon; and,
- Disposal of sludge to the marine environment

are also described although these options are addressed in other guidelines and policies published by the Department of Water Affairs and Forestry and the reader is guided to the relevant sections. This Volume also mentions some waste specific details that should simplify the process.

This Volume should be used for:

- Managing and phasing out of uncontrolled waste pile facilities. The Department of Water Affairs and Forestry will no longer accept the indefinite storage of sludge in uncontrolled waste piles. This Volume assists with the implementation of a management and monitoring plan or, alternatively, the selection of alternative management options.
- Operating existing dedicated land disposal sites. This Volume assists the reader to determine what the environmental impacts of the current practices are and how to manage an existing dedicated land disposal site to minimise negative environmental impacts.
- Rehabilitation and phasing out of dedicated land disposal sites. If a dedicated land disposal site proves to have an unacceptable impact, it will have to be phased out in a responsible manner. This Volume details the steps to be taken to phase out a dedicated land disposal site that is having an unacceptable impact on the environment, in a responsible manner.
- Off-site disposal of sludge in a general or hazardous landfill site. This Volume addresses the co-disposal of sludge in municipal or commercial landfill facilities (both general and hazardous landfill facilities). Sludge disposal in a landfill should adhere to the *Waste Management Series. Minimum Requirements for Waste Disposal by Landfill* (latest edition) or any update thereto. This Volume assists the reader to understand the requirements stipulated in the Minimum Requirements by explaining the relevant sections that pertain to the management of sludge in landfill operations. The Volume details the process of delisting, dewatering and co-disposal ratio requirements.
- On-site disposal of sludge in a mono disposal landfill or lagoon. This Volume addresses the disposal of sludge in dedicated disposal facilities and sludge lagoons. These practices need to comply with the *Waste Management Series. Minimum Requirements for Waste Disposal by Landfill* (DWAF, latest edition). This Volume assists the reader to understand the requirements stipulated in the Minimum Requirements by explaining the relevant sections that pertain to the management of sludge in mono-disposal facilities and sludge lagoons. The Volume details the process of delisting, dewatering, liner and closure requirements.
- Disposal of sludge to the marine environment. This Volume refers to the latest information on the interpretation of the *"Operational Policy for the Disposal of Land-derived Water Containing Waste to the Marine Environment*" (DWAF, 2004) or any update thereto.

1.2 Extent of on-site land disposal and dedicated land disposal in South Africa

A survey of wastewater treatment plants (WWTPs) was conducted by Herselman *et al*. (2005) to determine the extent of on-site land disposal and dedicated land disposal (DLD) practices in South Africa. The survey of 234 WWTPs indicated that a wide variety of disposal options are used in South Africa. The disposal option used by most of the treatment facilities is on-site **waste piles** (33%), either as the only disposal method or as a temporary measure before it is removed to a landfill or utilized beneficially. The sludge is dried in drying beds or paddies and then put on heaps until the municipalities' parks division, farmers or the public utilize it. Another popular disposal option is **sludge ponds** (13%) where they continuously pump the sludge into a dam that may or may not be lined. A number of treatment facilities use **sludge lagoons** (6%) to dry the sludge. These lagoons are shallow, bounded disposal dams into which wet sludge is pumped. There are a number of these lagoons at one site that are used alternately in order to allow the sludge to dry out.

Irrigation (9%) with liquid wastewater sludge with high-pressure nozzles connected to a sludge line on a DLD site is a popular option if sufficient soil is available, while some facilities **flood** irrigate the soil (2%) with the liquid sludge. At some WWTPs dried sludge is applied to DLD sites (2%). Only 3% of the surveyed WWTP use **landfills** to dispose of the sludge and 2% dispose of wastewater sludge to the marine environment.

1.3 Definitions of sludge disposal options

The following sludge disposal options are considered in Volume 3 of the Sludge Guidelines:

1.3.1 Mono-fill

A **mono-fill** is a landfill site to which only one type of waste is disposed of, in this case, sludge. It is usually dewatered sludge that is deposited in depressions within the land in a regulated manner with containment of the contents. The full bottom and side containment of sludge-only landfills are of extreme importance. The most cost-effective sludge-only landfills are those where the natural soils at the site support such development. Environmental issues involving surface and groundwater are probably the most sensitive and important to the successful operation of sludge-only landfills (Lue-Hing *et al.,* 1992).

1.3.2 Waste piles

Waste piles are simply mounds of dewatered sludge placed on the land surface for final disposal without daily or final cover. The sludge becomes more concentrated and is further stabilised by continued anaerobic biological activity (Metcalf & Eddy, 1989). According to Lue-Hing *et al*. (1992) waste piles appear to represent the "worst case" scenario for groundwater contamination for land disposal of sludge because contaminants in the sludge can leach into the groundwater under a site. These leached contaminants can then migrate to wells from which drinking water is obtained. However, Herselman *et al*. (2005) found that environmental impact of waste piles on soil and groundwater was less than that of the liquid sludge land disposal options, including DLD and lagoons.

1.3.3 Lagoons

Lagoons are disposal sites where sludge with high water content is placed in an open excavated area. Lagoon disposal is a method that stabilizes sludge through anaerobic endogenous respiration while controlling odours using an aerobic water seal. Biosolids are typically introduced to the bottom of a 4 to 5 m deep lagoon. An aerobic zone near the water surface caps the biosolids and anaerobic liquid. The aerobic zone is maintained by natural convection and surface aeration. The performance of lagoons is affected by climate and is most appropriate in areas with high evaporation rates. The sludge is in effect dewatered by subsurface drainage and percolation which may pose a risk to groundwater. Sludge may be disposed in lagoons indefinitely or it may be removed periodically and disposed on waste piles (Metcalf & Eddy, 1989; Lue-Hing *et al*., 1992).

1.3.4 Dedicated land disposal (DLD)

At **dedicated land disposal (DLD)** sites, sludge is applied to the surface of the land on a routine basis where the objective is sludge disposal rather than sludge utilization. The sludge can be applied as liquid or dewatered sludge. By definition, dedicated land disposal sites should be designed to contain contaminants within the site or manage their movement off-site in a controlled, environmentally acceptable manner.

Dewatered sludge (more than 12% solids by mutual consent of the Reference Group of the project) application is usually used when the disposal site is located some distance from the treatment plant or when climate conditions make it necessary to store the sludge in a confined space for up to six months. Some plants have incorporated dewatered sludge application in nearby facilities. This application is usually governed by the need to store sludge during inclement weather or to achieve high application rates per hectare. Another reason for dewatered sludge application is that DLD involves the process used to stabilise the sludge.

If the sludge disposal site is located near the treatment plant it is often cheaper to apply the sludge in its liquid form. This type of operation eliminates the need for the operation of an expensive dewatering facility. Liquid sludge management depends on either the plant's ability to store liquid stabilised sludge for sufficient periods of time to assure adequate application time, or the plant's location being in a weather pattern that provides adequate application time on a routine basis.

1.3.5 Landfill

Traditionally, **landfill** is understood as the disposal of material into a natural depression or into an excavation in the ground, created either specifically for this purpose or as a result of previous mineral extraction activities (see Section 1.3.5). More broadly, it can be regarded as any form of deposition on or into land where the aim is disposal of the material, rather than amelioration or improvement. **Co-disposal** sites are those where wastewater sludge is accepted for disposal along with wastes from other sources, e.g. municipal solid waste on engineered waste disposal facilities (landfills). Stabilisation and dewatering of sludge is required before it can be disposed of to landfill. A daily soil cover minimises nuisance conditions such as odours and flies (Metcalf & Eddy, 1989).

1.3.6 Marine disposal

Apart from offshore dumping from floating platforms there are two main routes for the deliberate disposal of wastewater to sea:

- Surf zone discharges – This would include direct discharges, through short pipes, into estuaries or the intertidal/surf zone; and
- Offshore marine outfalls – This would include situations where a submarine pipeline, originating on shore, conveys wastewater from a head of works to a submerged discharge location on or near the seabed and beyond the surf zone (i.e. to the offshore marine environment). Also referred to in the literature as a long sea outfall/pipeline and ocean outfall/pipeline.

Offshore marine outfalls are generally far more effective than shoreline discharges in dissipating wastes and minimising environmental impacts.

2 APPROACH AND METHODOLOGY

Part 1 of the Guideline gives the reader background on the reason and motivation for the development of Volume 3 as well as a short summary of the approach followed to develop Volume 3. The approach and methodology are discussed in detail in the sections that follow.

2.1 Approach

The Guidelines for the on-site and off-site disposal of sludge is based on the following information:

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

The USEPA 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 application to land for a lifetime.

It was agreed by the project team and the Reference Group that this was the best way in which 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).

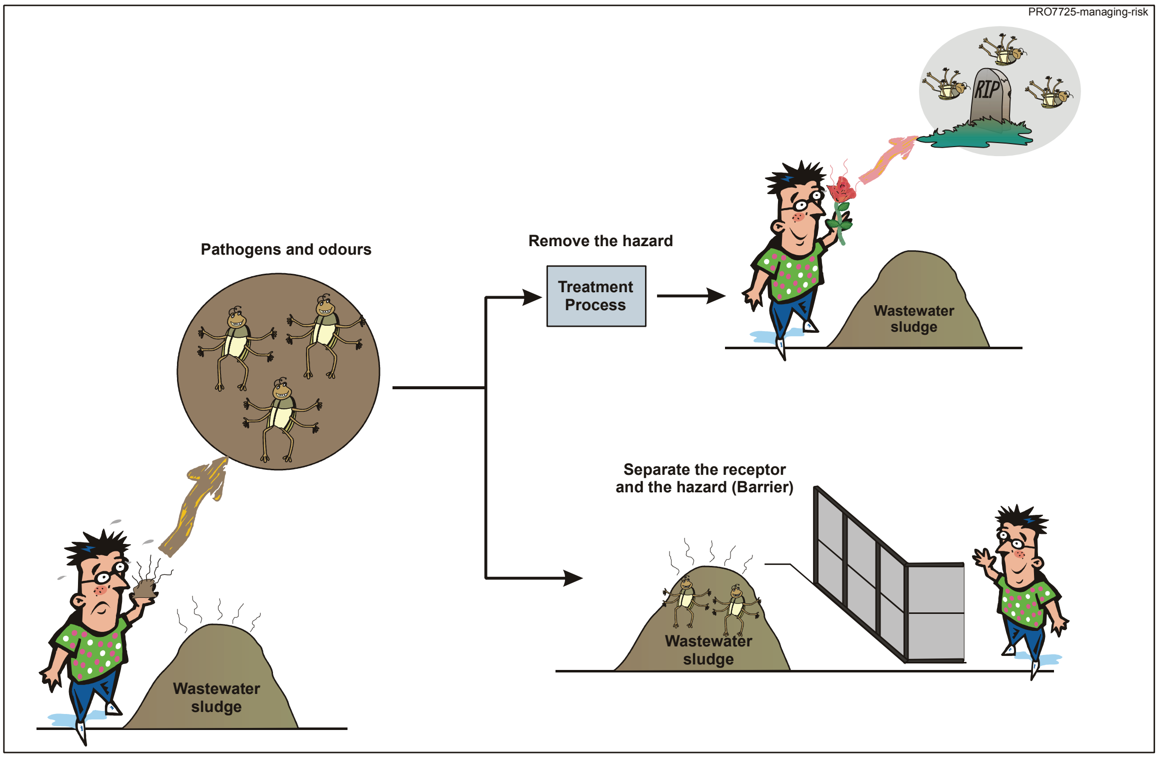

Figure 2.a: Visual representation of ways to protect receptors against potential harmful constituents in sludge

2.2 Methodology for Risk Assessment

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 land disposal of sludge. 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. 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

2.2.1 Source characterisation

The following characteristics of the sludge were considered:

- Microbiological – Pathogens
- Stability – Odours, vector attraction, moisture content, pH
- Metals – Potentially harmful metals like cadmium (Cd), arsenic (As), chromium (Cr) etc
- Nutrients – Nitrogen, Phosphorus
- Organic pollutants – Pesticides, polycyclic aromatic hydrocarbons (PAH), etc.
- Other – management issues

2.2.2 Receptors

The following eleven receptors that could be impacted by on-site and off-site sludge disposal were identified.

2.2.2.1 Workers

Workers at the wastewater treatment plant and at the land application site are in contact with the sludge on a daily basis, 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 omitted as a receptor during this study.

2.2.2.2 General public

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

The general public can also be indirectly exposed through:

- ingesting plants grown on disposal sites,
- ingesting meat of animals that grazed on disposal sites,

- drinking surface and/or groundwater contaminated by sludge disposal and
- eating fish from contaminated surface water,
- direct contact with surface and groundwater contaminated by sludge disposal is also included as indirect contact.

2.2.2.3 Soil

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

2.2.2.4 Crops

Crops grown on disposal sites may have elevated metal concentrations and may also be impacted by the pathogens and organic pollutants in the sludge. Although no crops are normally cultivated on disposal sites, it was still considered a receptor because some crops grow wild and are consumed by the general public.

2.2.2.5 Vegetation

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

2.2.2.6 Air

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

2.2.2.7 Surface water

The chemical quality of surface water bodies in close proximity to disposal sites may be negatively impacted as a result of run-off, either directly or indirectly, from sludge disposal sites.

2.2.2.8 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 nitrogen (N) content of sludge poses a serious threat to groundwater resources due to its mobility in the soil profile. Analysis of groundwater samples taken in the vicinity of sludge disposal sites indicated elevated N concentrations in 66% of the samples (Herselman *et al*., 2005).

2.2.2.9 Marine environment

The marine environment will obviously be a direct "receptor" in cases where it receives deliberate sludge discharges. However there are also possibilities, albeit relatively remote, of indirect effects arising from sludge disposal 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.

2.2.2.10 Grazing animals

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

2.2.2.11 Fauna

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

2.2.3 Pathways

The identified receptors may be impacted by sludge disposal 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 in most cases probably not reach the human receptor.

2.2.4 Population of risk ranking matrix

A risk ranking matrix was developed to systematically evaluate the significance of different source-receptor pathways and identify issues that will need to be managed through the guidelines. The matrix represents a systematic thought process of each of the characteristics of the source (microbiology, stability and pollutants) 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 on a given receptor. The consequence may vary from very severe (e.g. severe negative health condition to multiple parties requiring hospitalisation of the human receptor or permanent impairment of groundwater resource quality) to neutral (e.g. 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.c).

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

Receptors	No.	Possible pathways							
Workers	1.1	Sludge	→	Dermal absorption of toxic constituents					
	1.2	Sludge	→	Air	→	Human (inhalation of volatile pollutants)			
	1.3	Sludge	→	Air	→	Human (inhalation of incinerator emissions)			
	1.4	Sludge	→	Ingestion of toxic constituents					
	1.5	Sludge	→	Soil	→	Air	→	Human	
	1.6	Sludge	→	Vector	→	Human			
General population	2.1	Sludge	→	Dermal absorption of toxic constituents					
	2.2	Sludge	→	Ingestion of toxic constituents					
	2.3	Sludge	→	Air	→	Human (inhalation of volatile pollutants)			
	2.4	Sludge	→	Air	→	Human (inhalation of incinerator emissions)			
	2.5	Sludge	→	Soil	→	Plant	→	Human	
	2.6	Sludge	→	Soil	→	Plant	→	Animal	→ Human
	2.7	Sludge	→	Soil	→	Surface water	→	Human (ingestion)	
	2.8	Sludge	→	Soil	→	Surface water	→	Fish	→ Human
	2.9	Sludge	→	Marine environment	→	Biota	→	Human	
	2.10	Sludge	→	Soil	→	Surface water	→	Human (direct contact)	
	2.11	Sludge	→	Soil	→	Groundwater	→	Human (ingestion)	
	2.12	Sludge	→	Soil	→	Groundwater	→	Human (direct contact)	
	2.13	Sludge	→	Soil	→	Human			
	2.14	Sludge	→	Soil	→	Air	→	Human (inhalation of dust during disposal)	
	2.15	Sludge	→	Animal	→	Human			
	2.16	Sludge	→	Vector	→	Human			
Soil/sediments	3.1	Sludge	→	Soil physical properties					
	3.2	Sludge	→	Soil chemical and fertility					
	3.3	Sludge	→	Soil microbiological characteristics					
	3.4	Sludge	→	Surface water	→	Sediment			
	3.5	Sludge	→	Water Column	→	Sediment			
	3.6	Sludge	→	Surface water	→	Sediment			
Crops	4.1	Sludge	→	Soil	→	Commercial crops (yield)			
	4.2	Sludge	→	Soil	→	Grazing crops			
	4.3	Sludge	→	Soil	→	Commercial crops (quality)			
Vegetation	5.1	Sludge	→	Soil	→	Natural vegetation			
Air	6.1	Sludge	→	Air (before application)					
	6.2	Sludge	→	Air (during application)					
	6.3	Sludge	→	Soil	→	Air			
	6.4	Sludge	→	Air (incinerator emissions)					
Surface water	7.1	Sludge	→	Soil	→	Surface water			
	7.2	Sludge	→	Surface water					
	7.3	Sludge	→	Air	→	Surface water			
	7.4	Sludge	→	Soil	→	Air	→	Surface water	
	7.5	Sludge	→	Groundwater	→	Surface water			

	Possible pathways							
	7.6	Sludge	→	Birds	→	Surface water		
	7.7	Sludge	→	Vector	→	Surface water		
Groundwater	8.1	Sludge	→	Soil	→	Groundwater (direct effect of polluted soil)		
	8.2	Sludge	→	Groundwater				
	8.3	Sludge	→	Soil	→	Groundwater (seepage into low lying areas)		
	8.4	Sludge	→	Surface water	→	Groundwater		
Marine receptor	9.1	Sludge	→	Water column				
	9.2	Sludge	→	Surface water	→	Marine environment		
	9.3	Sludge	→	Marine environment				
	9.4	Sludge	→	Water column	→	Sea bed	→	Deposition centre
	9.5	Sludge	→	Air	→	Marine environment		
Grazing animals	10.1	Sludge	→	Soil	→	Plant	→	Animal
	10.2	Sludge	→	Soil	→	Animal (ingestion of sludge amended soil)		
	10.3	Sludge	→	Soil	→	Surface water	→	Animal
	10.4	Sludge	→	Soil	→	Groundwater	→	Animal
	10.5	Sludge	→	Soil	→	Animal (inhalation of volatile pollutants after/during application)		
	10.6	Sludge	→	Animal				
	10.7	Sludge	→	Plant	→	Animal		
	10.8	Sludge	→	Vector	→	Animal		
Fauna	11.1	Sludge	→	Soil	→	Plant	→	Fauna
	11.2	Sludge	→	Soil	→	Fauna (ingestion of sludge amended soil)		
	11.3	Sludge	→	Soil	→	Surface water	→	Fauna
	11.4	Sludge	→	Soil	→	Groundwater	→	Fauna
	11.5	Sludge	→	Soil	→	Fauna (inhalation of volatile pollutants after/during application)		
	11.6	Sludge	→	Fauna				
	11.7	Sludge	→	Surface water	→	Aquatic fauna		

The consequence and probability should be determined for each pathway that may impact a receptor (see Figure 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 sludge disposal options considered in Volume 3 (Appendix 1). Mitigating factors have been identified for medium to high and high risk situations. The outcome of the risk ranking and the mitigating factors are discussed for each receptor and sludge disposal option in the sections that follow.

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

KEY

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

Figure 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/emmissions 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

2.2.4.1 On-site mono disposal

Workers

The impact that wastewater sludge has on workers at the WWTP is not a sludge disposal issue but an occupational health and safety issue and the workers were thus excluded from the risk ranking matrix.

General public

From the risk ranking matrix (Appendix 1) it is clear that public health at mono disposal sites would be affected mainly by the microbiological and organic pollutant content of the sludge. Most of the pathways through which the general public could be impacted have multiple barriers in place 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 when considering public health. Both of these constituents could have an impact on human health but the probability would be low (1:10 000) with a risk rating of 9 (No risk) and the probability of recovery would be high. 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 to protect the general public against the potential negative impacts of sludge:

- Access restrictions – Public access must be restricted at all sludge disposal sites 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.
- Restrictions on grazing animals – the owner/operator should ensure that no animals are allowed to graze on the site. Regular ploughing of the area is required to minimise the possibility of plant growth that could serve as fodder for animals.
- Buffer zones –

  Depth to aquifer – >5 m (to protect groundwater)

  Distance from borehole – >400 m

  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 sludge disposal since it’s in direct contact with the sludge and its potential pollutants. Due to the high application rates of sludge at mono-disposal sites, the metals and organic pollutants present in sludge will cause chemical soil degradation. Intervention would be required to remediate the soil and the risk ranking is 18 (high risk). Without remediation these soils could not be considered for agricultural or residential use after closure of the disposal site due to the elevated concentrations of metals, pathogens and organic pollutants that may be present in the soil.

The implementation of maximum permissible levels (MPL) for metals is proposed for soils receiving sludge at high application rates. These MPL 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 increases. 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.

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 water which feeds into these systems. However, the probability that the sediments may need intervention to rehabilitate is low (1:10 000) with a risk ranking of 9 (no to low risk). The implementation of a buffer zone between the sludge disposal 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 disposal site be above the 1:100 year flood line.

Crops

It is assumed that the cultivation of agricultural crops will not be allowed at sludge disposal sites and therefore the impact of constituents present in sludge on crops was not included for sludge disposal sites.

Vegetation

The natural vegetation at sludge disposal 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 at a probability of 1:1000 (risk rating 16 – medium to high risk). Sludge disposal sites should be considered as “sacrificial” land where biodiversity would be compromised. Disposal sites should not be situated near areas where it could affect endangered plant species or its critical habitat.

Air quality

Sludge disposal will affect air quality before, during and after disposal. The odour associated with sludge disposal will regularly (1:100) have a severe influence on air quality and will impact the surrounding community (risk rating 20 – high risk). This will however depend on the distance between the disposal site and the community.

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 daily cover
- Buffer zones – Distance from dwellings – >500 m (to protect public from odours, vectors and volatile pollutants). This is just a guideline value and a health and odour buffer assessment should be undertaken to help gauge the necessity for a buffer of a specific width.
- Areas immediately upwind of a residential area in the prevailing wind direction(s) should not be considered for sludge disposal.

Surface water

Surface water sources in close proximity to sludge disposal 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 nutrients 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 – >400 m

  Depth to aquifer – >5 m above seasonal high (to protect groundwater)
- Bund walls or cut-off trenches should be erected around/down slope of mono-fills and waste piles. 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 authorisation conditions.

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). The probability for groundwater contamination will be even higher for unlined lagoons where liquid sludge is disposed.

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
- the soil has a low clay content (<20%)
- liquid sludge is disposed to lagoons

- liquid, anaerobically digested sludge is disposed (this type of sludge has a high soluble metal fraction)

The following management requirements are recommended to mitigate groundwater contamination:

- Buffer zone –

  Distance from borehole – >400 m

  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.
- Strict and frequent groundwater monitoring requirements to serve as early warning system

Marine environment

It was assumed that existing buffer zones between mono disposal sites and the marine environment would protect the marine receptor. However, the same buffer zones are recommended as for other receptors. This include:

Distance from surf zone – >400 m

Depth to aquifer – >5 m

A run-off interception measure should be introduced down slope of the disposal area

The marine environment will be discussed in the section 2.6.4 on “Marine disposal”.

Grazing animals

It is assumed that no grazing animals will be allowed at sludge disposal sites and therefore the impact of constituents present in sludge on grazing animals were not included for sludge disposal sites.

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). However, endangered species would have to be protected and therefore an EIA would be needed where sludge disposal is practiced.

2.2.4.2 DLD

General public

The general public in close proximity to DLD 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 of these constituents could have an impact on human health but the probability would be low (1:10 000) with a risk rating of 9 (No risk) and the probability of recovery would be high. 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 to protect the general public against the potential negative impacts of sludge:

- Access restrictions – Public access must be restricted at all sludge disposal sites while the site is in operation and 3 years after closure until it has been ascertained that the contaminants no longer pose a threat to human health. 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.
- Restrictions on grazing animals – the owner/operator should ensure that no animals are allowed to graze on the site. Regular ploughing of the area is required to minimise the possibility of plant growth that could serve as fodder for animals.
- 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 zones –

  Depth to aquifer – >5 m (to protect groundwater)

  Distance from surface water/borehole – >400 m (to protect surface water)

  Distance from dwellings – >500 m (to protect public from odours and vectors) unless a health or odour buffer assessment determines otherwise.

Soil and sediment

Soil would be the most vulnerable receptor during sludge disposal since it's the first line of defence. Due to the continuous high application rates of sludge at DLD sites, the metals and organic pollutants present in sludge will cause chemical soil degradation. Intervention would be required to remediate the soil and the risk ranking is 18 (high risk). Due to the elevated concentrations of metals, pathogens and organic pollutants that may be present in the soil after closure of the disposal site these soils cannot be considered for agricultural or residential use unless remediation has taken place.

The implementation of maximum permissible levels (MPL) for metals is proposed for soils receiving sludge at high application rates. These MPL 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 disposal site and surface water bodies is recommended (>400 m) to mitigate surface water contamination which could result in sediment contamination.

Crops

It is assumed that the cultivation of agricultural crops will not be allowed at DLD sites and therefore the impact of constituents present in sludge on crops was not included for DLD sites.

Vegetation

The natural vegetation at DLD 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 at a probability of 1:1000 (risk rating 16 – medium to high risk). DLD sites should be considered as "sacrificial" land where biodiversity would be compromised. Disposal sites should not be situated near areas where it could affect endangered plant species or its critical habitat.

Air

Sludge disposal will affect air quality before, during and after disposal. The odour associated with sludge disposal will regularly (1:100) have a severe influence on air quality which will affect the surrounding community (risk rating 20 – high risk). This is dependant on the how far away the community is.

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 regular ploughing
- Buffer zones – Distance from dwellings – >500 m (to protect public from odours, vectors and volatile pollutants) unless a health or odour buffer assessment determines otherwise.
- Areas immediately upwind of a residential area in the prevailing wind direction(s) should not be considered for sludge disposal.

Surface water

Surface water sources in close proximity to sludge disposal 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 nutrients 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 – >400 m

  Depth to aquifer – >5 m (to protect groundwater)
- Bund walls or cut-off trenches should be erected around/down slope of DLD 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). The probability for groundwater contamination will be even higher for DLD sites receiving liquid sludge.

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
- the soil has a low clay content (<20%)
- liquid sludge is 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 m

  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 existing buffer zones between DLD sites and the marine environment would protect the marine receptor. However, the same buffer zones are recommended as for other receptors. This include:

Distance from surf zone – >400 m

Depth to aquifer – >5 m

A run-off interception measure should be introduced down slope of the disposal area

The marine environment will be discussed in the section 2.6.4 on "Marine disposal".

Grazing animals

It is assumed that no grazing animals will be allowed at sludge disposal sites and therefore the impact of constituents present in sludge on grazing animals was not included for sludge disposal sites.

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). However, endangered species would have to be protected and therefore an EIA would be needed where sludge disposal is practiced.

2.2.4.3 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 of these constituents could have an impact on human health but the probability would be low (1:10 000) with a risk rating of 9 (No risk) and the probability of recovery would be high. The most critical pathways as 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) or any update thereto 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 to protect the general public against the potential negative impacts of sludge:

- Access restrictions – Public access is restricted by the Minimum Requirements (latest edition) and should be adhered to while the site is in operation and 3 years after closure until monitoring has ascertained that the contaminants no longer pose a human health hazard, except if the site is capped 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. At many landfills the public is allowed at the working face. If sludge is accepted this should not be allowed, except if the sludge is disposed of in trenches removed from the working face. Waste reclaimers can also come into contact with the sludge.
- 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 m (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.

Soil and sediment

It is assumed that the landfill owner/operator complies with the legislative requirements including the Minimum Requirements (latest edition) and Section 20 permit conditions. 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.

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 their critical habitat.

Air quality

Sludge co-disposal will affect air quality before, during and after disposal. 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 impact (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 daily cover
- 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 in place.

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 in place.

Marine environment

It was assumed that existing buffer zones between landfill sites and the marine environment would protect the marine receptor. The marine environment will be discussed in the section 2.6.4 on "Marine disposal".

Grazing animals

It is assumed that no grazing animals will be allowed at landfill sites and therefore the impact of constituents present in sludge on grazing animals were not included for the landfill site disposal option.

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 impacts 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). However, endangered species would have to be protected and therefore an EIA would be needed where sludge co-disposal is practiced.

2.2.4.4 Marine disposal

General public

There are three main pathways through which sludge may impact on human receptors in the marine environment:

- Sludge → dermal contact with toxic constituents

- Sludge → ingestion of toxic constituents
- Sludge → marine environment → bioaccumulation in sea-food → human

The pathogens, metals and organic pollutants present in the sludge are the constituents of concern for marine disposal of sludge. The consequence of these constituents to the general public are moderate (recoverable conditions) but the probability is low (1: 1000) resulting in a risk ranking of 12 (low to medium risk). The following management practices could be implemented to protect the general public:

- Ensure that disposal practices minimise the possibility of human contact through appropriate outfall location and design,
- Design the outfall to maximise dispersion,
- Monitor fisheries that might be at risk, and
- Monitor the water for certain indicator species.

<u>Soil</u>

Not applicable to marine disposal.

<u>Crops</u>

Not applicable to marine disposal.

<u>Vegetation</u>

Not applicable to marine disposal.

<u>Air</u>

Not applicable to marine disposal.

<u>Surface water</u>

Not applicable to marine disposal.

<u>Groundwater</u>

Not applicable to marine disposal.

<u>Marine ecosystems</u>

The two pathways with the most potential for ecological impact on the marine environment are:

- Sludge → water column

- Sludge → water column → sea bed → deposition centre

The water column could be contaminated by pathogens, metals, nutrients and organic pollutants that may be present in the sludge. The consequences are moderate (intervention required to maintain ecosystem) but the probability is frequent (1:10) resulting in a risk ranking of 18 (high risk). The probability of impact on the sea bed is lower (1:100) resulting in a risk ranking of 15 (medium to high risk). The risk would tend to be higher where there are active depocentres. The consequences might include biodiversity reduction, community disturbances and disruptions in ecological functioning. The following management practices are recommended to mitigate the risks:

- Ensure that location and mode of discharge are conducive to rapid dilution and dispersion so as to minimise ecological impacts
- Avoid sludge discharge in high risk areas where there is likely to be cumulative deposition and consequent ecological impacts
- Compliance to the Operational Policy and the Environmental Quality Objectives described in the document.

Grazing animals

Not applicable to marine disposal.

Fauna

There is a moderate risk of aquatic fauna being directly affected by toxic components of sludge such as trace metals and organic pollutants, particularly where these are concentrated at depocentres. . These effects would largely be localised and recoverable (risk rating 12; low to medium risk).

3 SLUDGE CLASSIFICATION FOR LAND DISPOSAL

The sludge classification system remains the same as defined in Volume 1 (Table 3.a), 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).

Table 3.a:Classification system for sludge

Use Quality	Unrestricted use	General use	Limited use
Pathogen class	A	B	C
Stability class	1	2	3
Pollution class	a	b	c

3.1 Microbiological class

The Microbiological class classification system of Volumes 1 and 2 have been adopted for sludge disposal as well (Table 3.b). Sludge producers should however be encouraged to increase the Microbiological class of their sludge.

Table 3.b: 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

3.2 Stability class

The same vector attraction reduction options are recommended for disposal as for agricultural use (Volume 2). Options 1 – 8 will be applicable for all disposal options. These vector attraction reduction criteria were adopted from the USEPA 503 Sludge rule (USEPA, 1993; USEPA 1994). These criteria (or very similar) have been adopted by many other countries including Australia. Options 9 and 10 will be applicable for land disposal options only and an additional option was added for co-disposal on landfill which requires daily cover (Table 3.c). Most landfill operations are based on a series of trenches or cells which are prepared to receive waste. The waste is deposited in trenches or cells, spread, compacted and covered to isolate the waste from the environment. Under certain circumstances (small or remote sites with limited cover material) this requirement may be relaxed (Minimum Requirements, latest edition). The material to be used as cover material may be soil, builder's rubble or ash.

Table 3.c: Determination of the Stability class

Stability class	1	2	3
	Comply with one of the options listed below on a 90 percentile basis.	Compy with one of the options listed below on a 75 percentile basis.	No stabilisation or vector attraction reduction options

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 temperatures 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 (like primary treatment)
Option 9	Applicable to Dedicated disposal and other land disposal options. Inject sludge beneath the soil surface within a specified time, depending on the level of pathogen treatment
Option 10	Applicable to Dedicated disposal and other land disposal options. Incorporate sludge disposed on the land surface within a specified time after disposal.
Option 11	Applicable to landfill option only. The sludge should be covered on a daily basis.

Note: Vector attraction reduction options 1-8 are applicable to all on-site and off-site disposal options, options 9 and 10 are applicable to all land disposal options and option 11 is applicable to co-disposal on landfill only.

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 is recommended that the Pollutant class for disposal purposes be based on the leachable metal fraction in the sludge.

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 reference to this, South Africa has adopted the Expected Environmental Concentration (EEC), which is a method whereby the exposure of aquatic 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). The recommended Pollutant class classification for sludge destined for land disposal is detailed in Table 3.d.

Table 3.d: Pollutant class classification for sludge destined for disposal

TCLP extractable metals	Pollutant class		
	a	b	c
	<AE mg/l	≥AE and ≤ 10*AE mg/l	>10*AE mg/l
Arsenic (As)	<0.38	0.38 - 3.8	>3.8
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)	<0.13	0.13 - 1.3	>1.3
Lead (Pb)	<0.12	0.12 - 1.2	>1.2
Mercury (Hg)	<0.022	0.022 - 0.22	>0.22
Nickel (Ni)	<0.75	0.75 - 7.5	>7.5
Zinc (Zn)	<0.7	0.7 - 7	>7

AE : Acceptable exposure

Pollutant class a sludge (TCLP metal concentration ≤ AE) could be disposed on land without restrictions, but with monitoring requirements. When the analytical results of the TCLP test indicate Pollutant class b sludge, the sludge should be limed at a recommended dosage of 25 mg_{lime}/kg_{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 disposed on land 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 disposal 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 disposal site owner/operator should provide the authority with the analytical results.

Land disposal of Pollutant class c sludge would only be allowed on properly engineered lined disposal facilities with stringent management and monitoring requirements. Specific liming tests are recommended to achieve at least a Pollutant class b classification.

4 RESTRICTIONS AND REQUIREMENTS FOR LAND DISPOSAL OF SLUDGE

Several general restrictions and requirements are applicable to all land disposal options considered in Volume 3 of the Sludge Guidelines. These restrictions and requirements include legal requirements and operational and management requirements and are discussed in the sections that follow.

4.1 Legal requirements

Collectively a hierarchy of policies and legislation, which include South Africa's international commitments, the Constitution, applicable Acts of Parliament, Provincial Legislation and Local Government Bylaws, govern environmental management in South Africa. The legislative framework of governance in South Africa consists of several levels (DWAF, 2004), as depicted in Figure 4.a below. Amongst these the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA), National Water Act (Act No. 36 of 1998) (NWA) and the Environment Conservation Act (Act No. 73 of 1989) (ECA) serve as the primary legislation that guide waste management and pollution control and accordingly are the key statutes guiding sludge disposal. These statutes together with other media specific environmental legislation all reflect and pursue the common goal of sustainable development, the fundamental principle in South African society today that aims to secure a "better quality of life for all South Africans." The 'sustainable development hierarchy' in terms of South African legislative context is depicted in Figure 4.a. The existing legislative framework within South Africa now promotes more environmental responsibility and duty, while at the same time supporting much needed social and economic growth.

Due to the diverse and fragmented nature of environmental law, waste management and pollution laws in South Africa arise from various sources, from the pure environmental to safety and health, planning, nature and conservation and natural resources, to name but a few. This fragmentation of legislation requires that different regulatory authorities implement these legislative requirements in terms of their mandates and obligations, which creates an administratively cumbersome, fragmented, complex, time-consuming and non-integrated regulatory system. While these challenges exist, waste management and water use, including pollution control, are very well regulated within a sound legal framework. The Sludge Guidelines are another tool that can be used to support these legislative requirements.

The South African Sludge Guidelines series can be categorised as a Best Practice Guideline. However the guidelines can be considered regulatory if contained within specifications of a water use authorisation/waste permit, which can be considered to be the case for the on-site and off-site disposal of sludge (Volume 3).

A comprehensive assessment of the South African legislative environment has indicated that a wide range of legal measures could be applicable to the management options identified for the on-site and off-site disposal of sludge (Refer to Section 7.1 in Legal Review Report). With respect to the management options that the guidelines provide, an increased level of responsibility and onus is placed on the wastewater sludge producer and user, in terms of the national, provincial and local environmental legislation and policies that govern the protection of the environment to ensure that sludge disposal is carried out in a sustainable manner, with the least amount of impact to the receiving environment.

Although from the review it appears that the legislative environment is South Africa is complex, requiring various legal aspects to be met, the burden placed on the sludge producer/user is not as onerous as perceived. What the legal review has identified is the suite of legal measures that *could apply* and does not necessarily mean that each has to be met for every option. The aim has been to highlight those legal aspects that must be considered for the disposal of sludge, and in most cases this relates primarily to either an authorisation that is required to ensure the activity is lawful, or to pollution prevention contraventions that have to be rectified should the sludge producer/user not meet the authorisation conditions and management measures stipulated therein. The authorisation would include the necessary guidelines, regulations and policies that must be adhered to, and should the sludge producer comply with this, the basic legal requirements should be met. The legal measures are aimed at ensuring that sludge producers/users manage their sludge in a responsible manner.

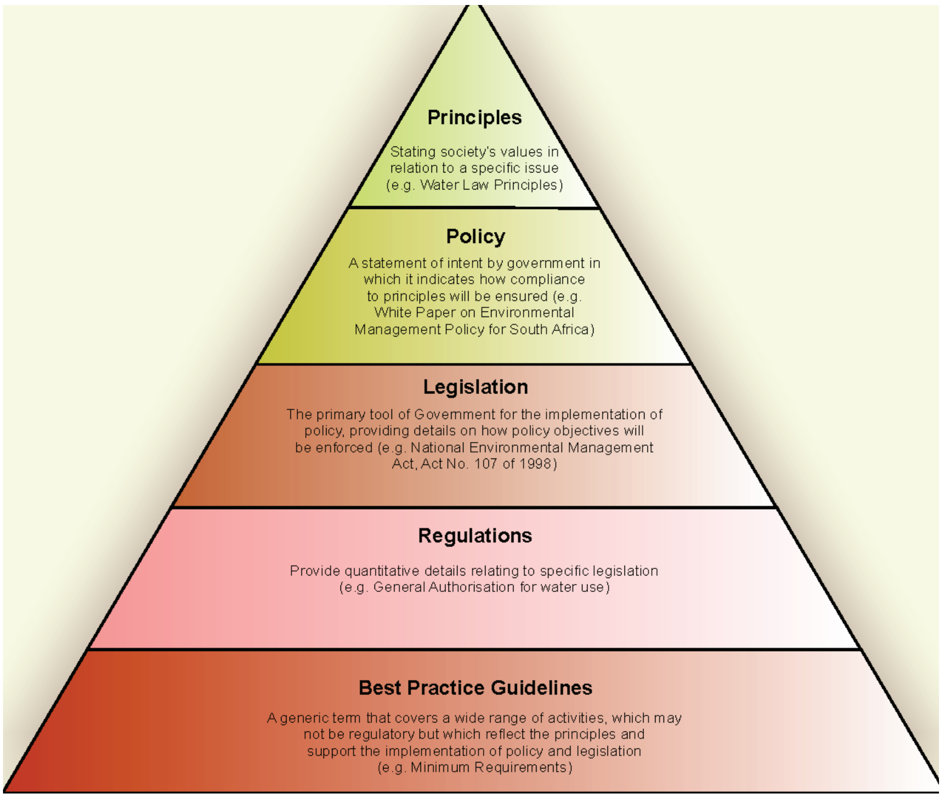

Figure 4.a: The hierarchy of the legislative framework in South Africa (DWAF, 2004)

The Volume 3 Sludge Guidelines are meant to serve as a management tool in support of an authorisation, and are developed to include guidelines and management practices that minimise the impact to the environment and prevent pollution of the environment.

The disposal of sludge (with respect to the disposal management options identified) is regulated through either the NWA or the ECA:

- In terms of the NWA the following sections apply:
  - Section 21 (e) – Engaging in a **controlled activity** – activities which impact detrimentally on a water resource (identified in section 37 (1) or declared as such under section 38 (1) *viz*.:
    - **Irrigation of any land with waste** or water containing waste which is generated through an industrial activity or a waterworks;
    - An activity aimed at the modification of atmospheric pollution;
    - A power generation activity which alters the flow regime of a water resource; and
    - Intentional recharging of an aquifer with any waste or water containing waste.
  - Section 21 (f) – **discharging waste** or water containing waste into a water resource through a pipe canal, sewer, **sea outfall** or other conduit
  - Section 21 (g) – **disposing of waste** in a manner which may detrimentally impact on a water resource
- In terms of the ECA the following sections apply:
  - Section 20 (1) – No person may, **establish, provide or operate** a disposal site **without a permit** issued by the Minister of Environmental Affairs and Tourism
  - Section 20 (6) – No person shall **discard waste or dispose of waste** in any other manner, except (a) at a disposal site for which a **permit has been issued** in terms of section 20 (1); or (b) in a manner or by a means of a facility or method and subject to such conditions as the Minister may prescribe

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

a waste. In addition, the Minimum Requirements also identifies sewage sludge as a **hazardous waste**, which requires that it should be classified to determine its hazard rating. The rating would then determine the minimum requirements for disposal, which could include its delisting.

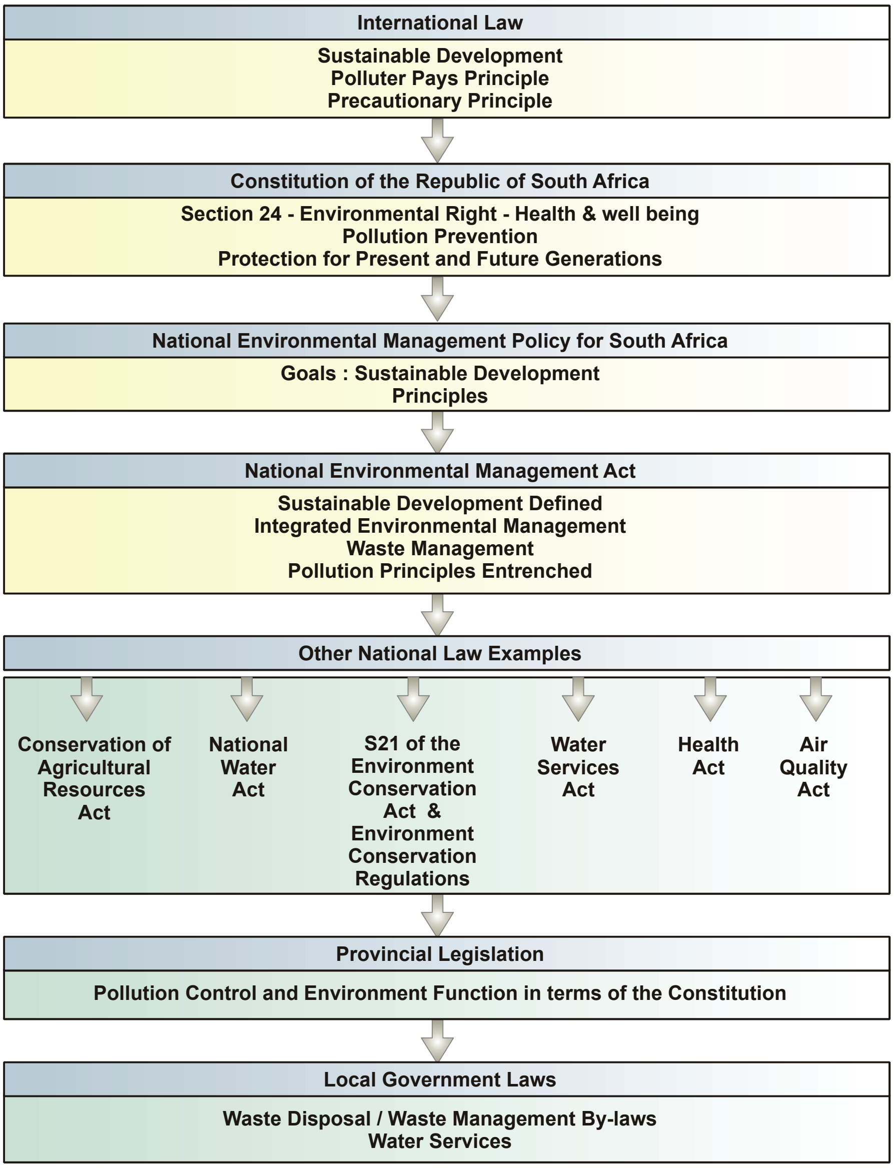

Figure 4.b: Sustainable development hierarchy

The Minimum Requirements documents are currently under review, with a third edition to be published in the near future. The 3rd edition of the Minimum Requirements is of relevance to the SA Sludge Guidelines Series as it includes the aspect of 'co-disposal' of sewage sludge at General Waste Sites. In addition sewage sludge is now defined as a waste **if it is to be disposed of at a site other than the sewage works itself**. Since January 2006 the DEAT is now the custodian of the Minimum Requirements and of its implementation.

The Department of Water Affairs and Forestry (DWAF) and Department of Environmental Affairs and Tourism (DEAT) have been identified as the key regulatory authorities in the regulation of the disposal of sludge, having the mandates for water use and waste management respectively.

In terms of defining the legal requirements for the on-site and off-site disposal of sludge these two key role players were thus engaged to provide direction in terms of what the sludge producer needs to comply with, taking into account the wide range of legal considerations listed above. In addition to the function for the administration of waste disposal sites having been transferred to the Minister of Environmental Affairs and Tourism (Section 1 of the Environmental Conservation Amendment Act, (Act No. 50 of 2003) through a Presidential Proclamation on 3 January 2006), the Section 20 ECA disposal site permit function and competency has also been transferred from DWAF to DEAT. It was thus important to identify the lead authorities for the authorisation processes.

In this regard a workshop between the responsible individuals of DWAF and DEAT was convened on 12 May 2006, at the offices of Golder Associates in Midrand at which the legal requirements and responsibilities for the on-site and off-site disposal of sludge were clarified. The decisions/outcomes of the workshop were the following:

- That the definition of an on-site and off-site disposal site relative to the WWTP would be used as the determining factor for the type of authorisation required.
- Clear definitions of on-site and off-site disposal sites were agreed upon.
- That the applicable regulatory instrument would be dependent on whether the disposal option was on-site and off-site (as per definition)
- That the lead regulatory authority would be determined by the regulatory instrument required (and the role of the supporting regulatory authority)
- That the 'Operational Policy for the disposal of land-derived water containing waste to the marine environment of South Africa' would be used as the guiding policy for the marine disposal option.
- That the lead agent with regard to the delisting of sludge would be DEAT, however DWAF would be responsible for the technical analysis and the approval of the delisting. DEAT would be responsible for the administration of the process.
- That a Memorandum of Understanding (MoU) would be drawn up between DWAF and DEAT to facilitate co-operative governance and to improve inter-department communication and co-ordination with regard to waste management and issues related herewith.

4.1.1 Definitions of on-site and off-site disposal:

- **On-site disposal** is the disposal of sludge within the boundaries of the wastewater treatment plant (WWTP) *i.e.* within the co-ordinates of the WWTP as defined in the water use authorisation for the treatment plant. On-site disposal includes:
    - Mono disposal (mono-fill, waste piles, lagoons)

- Dedicated land disposal (DLD) where the disposal sites are within the boundaries of the WWTP

- **Off-site land disposal** is the disposal of sludge outside the boundaries of the WWTP *i.e.* outside the co-ordinates of the WWTP as defined in the water use authorisation for the treatment plant. Off-site disposal includes:
    - Dedicated land disposal (DLD) where the disposal site is outside the boundaries of the WWTP
    - Co-disposal on landfill
    - Mono disposal (mono-fill, waste piles, lagoons)
- **Off-site marine disposal** is the disposal of sludge to the marine environment *i.e.* outside the co-ordinates of the WWTP as defined in the water use authorisation for the treatment plant.

4.1.2 Legal requirements for sludge producers (individual/entity producing sludge)

- For on-site disposal of dewatered sludge or liquid sludge the producer must have an authorisation for such a water use (*i.e.* a general authorisation, existing lawful use or water use licence) which would include a condition to comply with the latest sludge guidelines, in this case Volume 3.
- For off-site DLD the producer/user must have authorisation for such an activity (i.e. waste permit). However, should the activity involve irrigation of liquid sludge, a waste use authorisation may apply. Either authorisation will include the requirement to comply with the latest Sludge Guideline (Vol 3) edition and the latest version of the Minimum Requirements.
- For off-site co-disposal at a general or hazardous landfill site the producer and landfill owner/operator must comply with Volume 3 of the Sludge Guidelines and the latest version of Minimum Requirements (Waste Management Series). The disposal site must be authorised (i.e. must have a waste permit)
- For marine disposal the producer must comply with Volume 3 of the Sludge Guidelines and the Operational Policy for the disposal of land-derived water containing waste to the marine environment of South Africa. Disposal to the marine environment will require a water use authorisation.

Table 4.a: Summary of Legal Requirements applicable to sludge disposal

DISPOSAL OPTION	On-site disposal Within co-ordinates of WWTP	Off-site land disposal Outside co-ordinates of WWTP	Off-site marine disposal Outside co-ordinates of WWTP
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	National Water Act (Act No. 36 of 1998)
AUTHORISATION REQUIRED	Water Use Authorisation	Waste Permit – dewatered sludge disposal Water Use Authorisation – irrigation of liquid sludge	Water Use Authorisation
LEAD AUTHORITY	DWAF	DEAT – Disposal site permit DWAF – Water use authorisation	DWAF
REGULATORY INSTRUMENT	Water use licence (or general authorisation or existing lawful water use)	Disposal site Permit – dewatered sludge disposal Water Use Authorisation – irrigation of liquid sludge	Water use licence
REGULATORY GUIDELINES	Sludge Guidelines (Volume 3) and Minimum Requirements (latest edition)		Operational Policy for the disposal of land-derived water containing waste to the marine environment of South Africa

4.1.3 Integrated Environmental Management

For all new sludge disposal sites, changes to existing operations or applications for authorisations at existing sites/WWTPs, an Environmental Impact Assessment (EIA) may be requested by the permitting authority (DWAF/DEAT) before a Record of Decision (RoD)/authorisation will be granted. With regard to the issuing and enforcement of a disposal 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 disposal 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 a disposal site (Figure 4.c). The same process may apply for changes to existing operations at disposal sites in respect to application for authorisation for these. The objectives of the assessment of potential environmental impacts are:

- To identify the various ways in which an existing, proposed or closed disposal 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.

The Environmental Impact Assessment involves the process of identification of impacts, assessing the impacts of a site, determining the significance of each impact on the environment and formulating mitigating measures that are relevant to the consideration of an application for a disposal site activity. Based on this, the design, operation and monitoring of the disposal site are optimised, while taking social and 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 was until recently stipulated in the New Environmental Impact Assessment Regulations (EIAR) as promulgated by the Department of Environmental Affairs and Tourism (Government Gazette, No.28753, 21April 2006, GN R385, 386 and 387]. However, the DEAT has recently published the new EIA Regulations (Government Gazette No 28753, 21 April 2006, GNo R385, R386 and R387).

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.

4.2 Generic restrictions and requirements for land disposal

Some generic requirements apply irrespective of the classification or disposal option selected. These requirements include site selection, initial site investigation, areas where sludge disposal is not permitted and buffer zones.

4.2.1 Site selection

It is recognized that most existing on-site disposal sites are confined to the boundaries of the WWTP which were delineated some time ago. However, it must also be remembered that WWTPs were not developed in the most suitable areas for waste disposal (near rivers, dwellings etc). According to Section 24 of the Constitution: '**Everyone has the right to an environment that is not harmful to their health or well-being**'. The establishment and operation of a disposal site must therefore not violate the constitutional right of the communities living in the vicinity of the site (Minimum Requirements, latest edition).

The objectives of disposal site selection are as follows:

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

In the case of an operating landfill that is to be authorised, the Feasibility Study, which could include an EIA, will determine whether the site should be authorised for ongoing operation or for closure. The Interested and Affected Parties (IAPs) must be consulted during the study, to obtain their input regarding the future of the landfill.

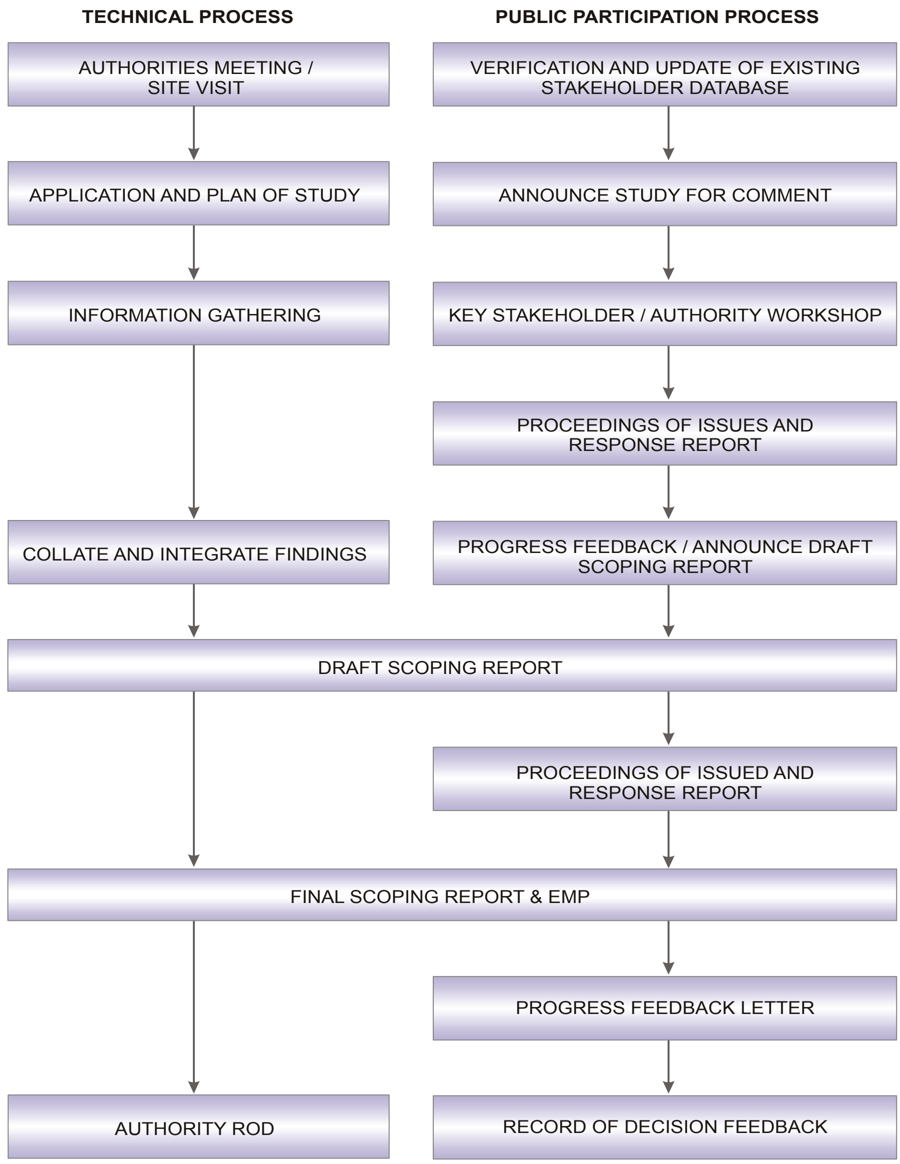

Figure 4.c: Environmental Impact Assessment process

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. The size of the site inevitably affects the size of the anticipated buffer zone. In addition the cumulative effect of the areas potentially impacted by the disposal site must be considered and adequate land area must be available beyond the site boundaries to accommodate the future buffer zone

- **General site location**. This is determined by the waste generation area(s) to be served. It is economically sound practice to establish the proposed facility as close to the generation area(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. Since the location of the site relative to the waste generation area(s) is an economic consideration rather than a Minimum Requirement, this is not addressed further. Existing and future land uses will, however, influence site location considerations, as incompatible land uses could prove to be a fatal flaw in the site selection process

For existing on-site sludge disposal sites the following site selection procedure is recommended:

- Ensure that the disposal site is not located in an area where disposal may not be allowed
- Ensure that the sludge disposal site is located as far as possible from the area where the final effluent is discharged to limit possible contamination of the final effluent or the receiving water resource
- Ensure that all buffer zones are adhered to

For new disposal sites the selection procedures described in the Minimum Requirements (latest edition) needs to be followed.

4.2.2 Initial site investigation

Initial site investigation is necessary to collect background/baseline data which could be used to assess the impact of the disposal option on the environment. The initial investigation should include:

4.2.2.1 Topography

The selection of a disposal site needs to include an evaluation of landscape topography along with the soil and underlying geologic layers. The landscape can be looked upon as a surface transport system for the applied 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 rate; soils on a 6-12% slope have medium run-off rate and soils on steeper slopes generally have a rapid run-off rate. The length and shape of slopes also influence the rate of runoff from a site. Rapid surface runoff can readily erode 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).

4.2.2.2 Soil properties

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

The soil structure, permeability and cation exchange capacity (CEC) will indicate whether the soil will act as a natural liner to minimise leaching of elements. **Texture**, defined as the relative proportions of various sized particles (sand, silt, clay) in a soil, can have a significant impact on the suitability of a soil for 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 far 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-textured 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 land disposal.

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

Soil chemical properties need to be evaluated in assessing the suitability of a site for the application of 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 for molybdenum and selenium, are more soluble at a low pH and their solubility decreases as the soil pH increases (Lue-Hing *et al*., 1992). It is recommended that soil pH >6.5 be maintained at all times to limit the mobility 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 USEPA 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 disposal on the soil.

4.2.2.3 Surface water

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

Background water quality monitoring is required to determine potential future impact of sludge disposal on surface water.

4.2.2.4 Groundwater

The depth to **groundwater**, the yield and the importance of the groundwater as a resource are important. The vulnerability of the aquifer and the risk of its possible pollution should be assessed to determine whether the site is suitable for sludge disposal. Generally, the greater the depth to the water table, the more desirable the site is for sludge disposal. 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 disposal sites. DEAT, in consultation with DWAF will not issue permits in terms of Section 20 of the Environment Conservation Act unless land has been zoned for waste disposal. For the purposes of permitting of waste disposal sites the Department will base its regulatory response upon the importance and vulnerability of the aquifer (Figure 4.a) which may be threatened by waste disposal activities.

Major aquifers and vulnerable sole-source aquifers: The Department will place a general ban on waste disposal and other polluting activities within 200 meters 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 disposal within the recharge zone of minor aquifers provided that adequate pollution control measures are implemented. Such measures as may be necessary for the most commonly practiced waste disposal 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 disposal 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).

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.

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

4.2.3 Areas where sludge disposal is not allowed

According to the Minimum Requirements (latest edition) the following areas are classified as areas with fatal flaws with regard to landfill. The land disposal of sludge 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 is also not suitable for land disposal. 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 land disposal of sludge at unlined facilities, i.e. areas where the soil clay content <20%. This recommendation is based on local research conducted by Herselman (2005) 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.

4.2.4 Buffer zones

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

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

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

The following buffer zones are suggested for sludge land disposal sites and were adopted from the Minimum Requirements (latest edition):

- Depth to aquifer – >5 m for dewatered sludge disposal and >10 m for liquid sludge disposal. The additional buffer zone of >10 m to the aquifer for liquid sludge disposal is suggested to protect groundwater from nitrogen contamination.

- Distance from surface water/borehole – >400 m

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

4.3 Restrictions based on Sludge classification

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

4.3.1 Restrictions based on Microbiological class

Microbiological class A

No restrictions apply for land disposal but sludge of such good quality should rather be used beneficially. Disinfection technologies are costly and disposal of the sludge represents wasting of potential resource recovery.

Microbiological class B

This sludge class could potentially be used beneficially as it is a partially disinfected product. Additional monitoring of faecal coliforms is recommended in surface and groundwater due to the sludge quality.

Microbiological class C

Additional monitoring of faecal coliforms and *E. coli* is recommended in surface and groundwater due to the high pathogen content of the sludge.

4.3.2 Restrictions based on Stability class

Stability class 1

No restrictions apply. Stable sludge should be considered for beneficial use.

Stability class 2

- **On-site mono disposal**
  - Depending on the reliability of the vector attraction reduction measures implemented, additional management systems may be required (liming and/or daily cover).
  - Sludge would need to be dewatered to at least 20% solids before it could be disposed on mono-fill or waste piles to ensure slope stability.
- **DLD** – Depending on the reliability of the vector attraction reduction measures implemented, additional management systems may be required (regular ploughing and/or liming).
- **Co-disposal on landfill** – Sludge would need to be dewatered to at least 20% solids before it can be co-disposed on landfill to ensure slope stability.

Stability class 3

Disposal of raw, primary sludge will not be allowed on any land disposal site, either on-site or off-site. At least 1 vector attraction reduction option should be implemented.

4.3.3 Restrictions based on Pollutant class

Pollutant class a

This is a high quality product and should rather be used beneficially. Although the metal content of the sludge is within acceptable levels, regular soil monitoring is required when disposed on land in high quantities to ensure no soil chemical degradation occurs.

Pollutant class b

It is recommended that the sludge is treated with lime (CaO) at an application rate of 25kg 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, the following restrictions will apply:

- **On-site mono disposal** – This product could potentially be used beneficially. When disposed on land the following restrictions apply:
  - Regular soil monitoring to determine soil quality
  - Disposal should cease when:
    - The MPL for soil is exceeded
    - Movement of metals in the soil profile is observed during monitoring
- **DLD** – DLD is allowed but restrictions should be implemented to protect the environment. The same restrictions apply as for on-site mono disposal.
- **Co-disposal on landfill –** Hazard rating and possible delisting according to the Minimum Requirements apply.

Pollutant class c

- **On-site mono disposal** – Disposal will only be allowed on properly engineered disposal sites with appropriate liners and leachate collection systems.
- **DLD** – DLD is allowed but restrictions should be implemented to protect the environment. Specific lime treatment tests, soil restrictions and frequent monitoring (soil and groundwater) are required. It should be noted that metals in liquid sludge are more mobile than metals in dewatered sludge and that metals in anaerobically digested sludge are more mobile than metals in waste activated sludge.

- **Co-disposal on landfill** – will only be allowed on H:H and H:h landfills according to the Minimum Requirements (latest edition).

4.4 Management requirements for land disposal

Sludge land disposal sites should be managed in a responsible way to protect the environment against the potential negative impact of sludge disposal at high application rates. These management practices could also serve as mitigating factors to protect the receptors against the potentially harmful substances present in the sludge.

4.4.1 Odour control

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 waste disposal facility. In extreme cases, odour suppressants such as spray curtains may be required. The application of soil or other suitable cover to compact waste also reduces litter and the risk of fire, but its main purpose is to eliminate odour. It also reduces scavenging and generally improves aesthetics. The sanitary landfill definition specifies daily cover, but, in certain instances, such as small or remote sites with a shortage of cover material, this minimum requirement might, with the proper motivation, be appropriately amended.

At least one of the vector attraction reduction options must be applied where sludge is disposed on land to minimise the production of odours.

4.4.2 Run-off collection

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.

The following management practices for run-off collection are required for:

- **On-site mono disposal** – where bund walls or cut-off trenches have been constructed around/down slope of mono-fills and waste piles, run-off should be collected, contained and treated/re-cycled/discharged depending on the water quality. The cut-off trenches should not pose a safety hazard.

- **DLD** – where bund walls or cut-off trenches have been constructed around/down slope of mono-fills and waste piles, run-off should be collected, contained and treated/re-cycled/discharged depending on the water quality. The cut-off trenches should not pose a safety hazard.

- **Co-disposal on landfill** – (Minimum Requirements, latest edition)

- Run-off and storm water must always be diverted around one or both sides of the waste body, by a system of berms and/or cut-off drains.
- Water contaminated by contact with waste, as well as leachate, must be contained within the site. If it is to be permitted to enter the environment, it must conform or be treated so as to conform to the water quality requirements as specified in terms of the Permit. Strictly speaking the water should comply with the catchment specific standards (such as for Holfontein for instance) or the provisions of Government Notice No 339 of 26 March 2004, Schedule 3.
- The sludge disposal must commence on the up gradient side of the cells or trenches in order to allow for drainage of surface water away from the disposed waste. Alternatively, cells must be so orientated as to facilitate drainage away from deposited waste. The resulting contaminated water, together with all other contaminated run-off arising from the landfill, must be stored in a sump or retention dam. It may be pumped from the dam and disposed of if it conforms to the water quality requirements/discharge standards stipulated in the Permit.
- A 0,5 m freeboard, designed for the 1 in 100 year flood event, must always be maintained in the case of contaminated water impoundments and drainage trenches.
- All temporarily and finally covered areas must be graded and maintained to promote run-off without excessive erosion and to eliminate ponding or standing water.
- Clean, uncontaminated water, which has not been in contact with the waste, must be allowed to flow off the site into the natural drainage system, under controlled conditions.

4.4.3 Leachate collection

Leachate is liquid originating from excess moisture in the sludge or from rainwater percolating through the waste body within the disposal site. If the disposal site has a liner and a leachate collection system the following additional management practices apply (USEPA, 1994):

- The leachate collection system should be operated and maintained according to design requirements and engineering recommendations. The owner/operator of the sludge disposal site is responsible for ensuring that the system is always operating to specifications and routinely maintained.
- The leachate should be collected and disposed in accordance with the permit requirements. Leachate should be pumped out by a system placed immediately above the liner. If leachate is discharged to surface water as a point source there would be specific monitoring and water quality requirements as part of the permit.

These management practices help to prevent the pollutants present in the sludge from entering the environment. If the leachate is not collected regularly the liner could be damaged and the leachate could leak into the groundwater. This requirement applies for a minimum of 3 years after closure of the disposal site.

Disposal sites without liners are regulated through the maximum permissible levels (MPL) of metals for soil at disposal sites (see Section 4.4.7).

4.4.4 Liner requirements

A liner is a layer of low permeability placed beneath a land disposal site, designed to direct leachate to a collection drain or sump, or to contain leachate. It may comprise natural materials, synthetic materials, or a combination thereof (Minimum Requirements, latest edition).

The compacted clay liner provides some attenuation capacity for escaped solutes, whilst the leakage detection layer provides a monitoring layer for volatile organic compounds in the solutes, as well as a collection system for leachate leakage through the composite liner. Leachate management is necessary in the case of $\mathbf{B}^{+}$ and hazardous waste disposal sites, where significant leachate is anticipated. The design includes a liner underlying the site, as well as leachate collection and treatment measures. It must make provision for the control of significant seasonal or continuous leachate generation, predicted by means of the Climatic Water Balance, or the Site Water Balance (Minimum Requirements, latest edition).

Appropriate liners will be required under the following circumstances:

- Soil clay content <20%. Soils with lower clay content may not be able to adsorb metals and therefore metals may leach from the soil profile.
- Co-disposal on general landfills – these landfills should be engineered as B^{+} sites with the appropriate liners and leachate collection systems due to the potential for co-disposal of sludge to generate leachate.
- Pollutant class c sludge is disposed, due to the high metal content of the sludge and the high risk to the receiving environment.

For more information on the design of a lining system and the appropriate liners needed for different types of landfills, see the *Minimum Requirements for Waste Disposal by Landfill* (latest edition).

4.4.5 Surface water protection

Surface water resources near the disposal sites need to be protected against contamination by constituents from the disposal site. This could be achieved by:

- Erecting cut-off trenches or bund walls to intercept run-off from the disposal site. Other appropriate water interception techniques could also be implemented and would be reviewed on a site specific basis.
- Increasing the buffer zone between the waste disposal site and the water body to ensure no run-off will reach the water body.
- Planting crops/plants/trees with a high water demand that will intercept run-off. However, these crops may not be used for animal feed or human consumption.

4.4.6 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. For this reason there are certain areas such as the subterranean government water control areas as set out in Table 4 of Schedule 4 of Government Notice 399 of 26 March 2004 where sludge disposal may not be allowed.

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 ranges from less than 1 m to a few meters per day. In karst and jointed aquifers flow rates are much higher, up to a few kilometers per day. With increasing depth groundwater becomes ever older and originates from percolation areas progressively farther upstream (USEPA, 1998).

Water applied to the soil surface through rainfall and irrigation events subsequently enters the soil through the process of infiltration. If the supply rate of water to the soil surface is greater than the soil's ability to allow the water to enter, excess water will either accumulate on the soil's surface or become runoff. The distribution of water during the infiltration process under ponded conditions is illustrated in Figure 4.d. In this idealized profile for soil water distribution for a homogeneous soil, five zones are illustrated for the infiltration process.

- Saturated zone: The pore space in this zone is filled with water, or saturated. Depending on the length of time elapsed from the initial application of the water, this zone will generally extend only to a depth of a few millimeters.
- Transition zone: This zone is characterized by a rapid decrease in water content with depth, and will extend approximately a few centimeters.
- Transmission zone: This zone is characterized by a small change in water content with depth. In general, the transmission zone is a lengthening unsaturated zone with uniform water content. The hydraulic gradient in this zone is primarily driven by gravitational forces.
- Wetting zone: In this zone, the water content sharply decreases with depth from the water content of the transmission zone to near the initial water content of the soil.
- Wetting front: This zone is characterized by a steep hydraulic gradient and forms a sharp boundary between the wet and dry soil. The hydraulic gradient is characterized primarily by metric potentials. Beyond the wetting front, there is no visible penetration of water (USEPA, 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 permeability (Figure 4.d). On the other hand, if water is applied slowly, the infiltration rate may be smaller than the soil permeability, 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 permeability 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 leaches 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.

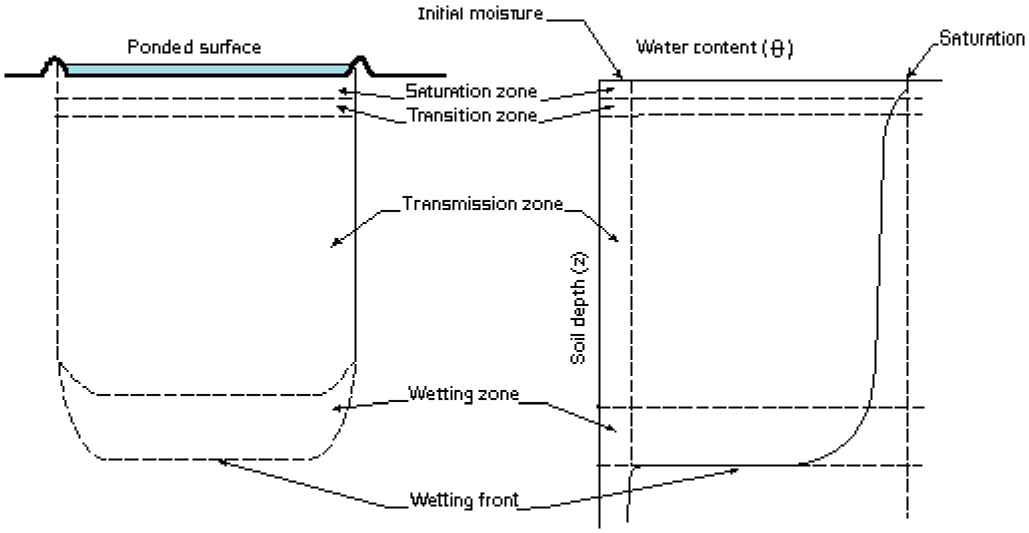

Figure 4.d: Zone of the infiltration process for the water content profile under ponded conditions (USEPA, 1998)

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 fertilizer 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. Due to the continuous stream of sludge production and the limited land available for waste disposal, it is difficult to set maximum load restrictions for sludge disposal to protect groundwater from nitrogen contamination. The following are recommended:

- the buffer zone between the soil surface and the aquifer be increased to >10 m in the case of liquid sludge disposal
- soils with clay content <20% should not be considered for sludge disposal
- sludge irrigation should 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 (USEPA, 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 owner/operator should provide proof that groundwater is not contaminated by:

- Implementation of a groundwater monitoring programme developed by a qualified person
- Certification by a qualified person that the groundwater would not be contaminated either because of the depth of the water table or by the amount of sludge disposed. This certification is generally unfeasible for sites without liners unless the depth to groundwater is considerable and there is a natural clay layer under the soil (USEPA, 1994). This would still be subject to a monitoring programme being put in place.

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

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

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**. However, if is any possibility that the groundwater may be used for **drinking purposes**, the maximum acceptable level of **10 mg/l NO_3-N** must not be exceeded.

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

4.4.7 Soil quality

The major impact of pollutants during sludge disposal is on surface and groundwater. This impact is due to nutrients present in the sludge, which will leach from the soil profile, and not the metal content of the sludge. Results of research by Herselman *et al*. (2005) indicated that even after long periods of sludge disposal to land at high application rates, the metals remain in the 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 disposal 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 applies specifically to disposal sites that receive Pollutant class b and c sludge.

In Australia guidelines for reuse of sludge on soils are published for New South Wales (NSW EPA, 1997) and for Southern Australia (SA EPA, 1996). These guidelines contain maximum permitted concentrations for metals in soils receiving sludge (Table 4.e). 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 soils 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 Waste 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 at preventing metal accumulation in the food chain.

The USEPA developed soil screening levels (SSL) above which further study or investigation is warranted (USEPA, 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.

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, it can be assumed that dedicated 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 maximum permissible concentrations (MPC) of Australia for non-agricultural land receiving sludge were adopted as maximum permissible levels (MPL) for South African soils at dedicated sludge disposal sites. Since the Australian values for Cr and Ni are much lower than the total maximum threshold (TMT) for South African soils, the USEPA 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 TMT limits as described in Volume 2 of the Sludge Guidelines will serve as a trigger value in Volume 3. In this Volume these metal limits will be referred to as the total trigger value (TTV) (Table 4.e). When the total metal content (*aqua regia* digestion) of the soil exceeds the TTV, stringent and frequent monitoring should be conducted to ensure that the metals stay immobile in the soil profile, especially at existing disposal sites where the pH<6.5 and the soil clay content <20%.

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

Additional management practices should also be implemented (liming) to ensure the immobility of the metals. 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 cease. 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 should be developed and implemented.

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

Metals	Total trigger value (TTV)	Maximum permissible level (MPL)
As	2	20
Cd	3	5
Cr	350	450
Cu	120	375
Pb	100	150
Hg	1	9
Ni	150	200
Zn	200	700

4.4.8 Methane gas

Waste decomposition goes through a series of stages from aerobic to anaerobic which result in the generation of methane gas in the final stage. The production of significant amounts of methane gas can occur within the first 3 months of disposal and can continue for more than 20 years. Where methane concentrations reach between 5% and 15% by volume in air, landfill gas represents an explosion hazard, as well as a potential health risk.

The US EPA Part 503 Rule (US EPA, 1994) includes a management practice that limits concentrations of methane gas in air because of its explosive potential where methane gas reaches concentrations of between 5% and 15% by volume of atmospheric gas composition. Methane is an odourless and highly combustible gas generated at disposal sites when sludge is covered by soil or other material. To protect site personnel and the public from risks of explosions, air must be continuously monitored for methane gas both on site and at the property line of the disposal site (Table 4.f). If monitoring indicates that there is any safety risk on account of methane gas accumulation and/or migration, controls must be considered in consultation with the Competent Authority (Minimum Requirements, latest edition).

Apart from the explosion potential, however, gas from disposal sites (landfill gas included) also contains a wide range of volatile organic compounds that are classified as hazardous air pollutants. Where significant gas is present, therefore, samples must be taken at various positions at the disposal site, and characterized for volatile organic compounds. The volatile organic compound compositions of the gas must then be subjected to occupational and environmental health risk assessments. This must be done at the discretion of the Competent Authority to ensure against unacceptable health risks to workers or communities (Minimum Requirements, latest edition).

Table 4.f: Recommended methane limits at disposal sites

	Methane level	Mitigation required
Inside buildings	0,1-1% in air (i.e. 2-20% of the LEL)	Regular monitoring must be instituted
	> 1% in air (i.e. 20% of LEL)	Building must be evacuated and trained personnel consulted
Disposal site property line	0,5-5% in air (i.e. 10% of LEL)	Regular monitoring of the boundary must be instituted
	> 5% in air (i.e. the LEL)	Monitoring should be initiated and an investigation to determine lateral migration undertaken
LEL = Lower explosive limit – the lowest % (by volume) of methane gas in air that supports a flame @ 25°C and atmospheric pressure.		

Volatile substances include organic and inorganic substances. These may be released as constituents in the landfill gas, or through mass transfer from the liquid or solid phases of the waste to the gas phase. There are four basic approaches for assessing emission rates of hazardous substances from landfill sites, namely:

- Direct measurement technologies
- Indirect measurement technologies
- Fence line monitoring and modeling technologies

- Predictive emission modeling

Direct measurement using a surface emission isolation flux chamber is the preferred technique in the USA for characterizing area source facilities with hazardous fugitive emissions. It is also recommended for use in South Africa. It can be used on any liquid or solid surfaces that are accessible for testing. The location and number of test points must be adequate to enable calculation of the emission rates of substances from the total area. Sampling and analysis must cover the complete range of substances that are relevant to the source. The data must then be used in a mathematical dispersion model to predict exposure levels for quantifying occupational and environmental health risks (Minimum Requirements, latest edition).

The frequency of sampling and analysis would depend on the level of identified risk, but must be at least once per year when activities and waste profiles do not change. After changes that could influence the emissions profiles, measurements must be made to establish the new profiles and associated occupational and environmental health risks. Gas monitoring should continue after landfill closure, until the Competent Authority is satisfied that landfill gas no longer presents a risk.

4.4.9 Restrictions on crop production

To protect human health, no crops may be grown on disposal sites unless the owner/operator at the disposal site can demonstrate to the permitting authority that public health and the environment are protected from reasonably anticipated adverse effects of certain pollutants present in the sludge (US EPA, 1994). If the owner/operator wishes to grow crops on the site, “Volume 4: Requirements for the beneficial use of sludge” will apply.

Especially at DLD sites the owner/operator should ensure that no edible, wild or cultivated crops grow on the site that could serve as a food source to the general public. Regular ploughing of the area is required and adequate signposts should be erected to warn the public that no crops may be harvested at the DLD site.

4.4.10 Restrictions on grazing animals

No grazing animals allowed on disposal sites unless the owner/operator at the disposal site can demonstrate to the permitting authority that public health, that of animals and the environment are protected from reasonably anticipated adverse effects of certain pollutants present in the sludge (US EPA, 1994). If the owner/operator wishes to graze animals on the site, “Volume 4: Requirements for the beneficial use of sludge” will apply.

The DLD site owner/operator should especially ensure that no animals are allowed to graze on the site. Regular ploughing of the area is required to minimise the possibility of plant growth that could serve as fodder for animals. Adequate signposts should be erected to warn the public that no grazing animals are allowed on the DLD site.

4.4.11 Public access restrictions

Public access must be restricted at all disposal sites while the site is in operation and for at least 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 (USEPA, 1994; Minimum Requirements, latest edition).

Due to the potentially high pathogen and metal content of the sludge and its' instability, public access to the disposal site should be restricted. Adequate signposts should be erected to warn the public that the DLD site might be hazardous.

4.5 Monitoring requirements for land disposal

Monitoring programmes should be implemented to protect the different receptors. Certain monitoring requirements are applicable for all types of sludge disposal on land. The number of samples taken and the frequency of monitoring would be influenced by the sludge class that is disposed, site specific conditions and the vulnerability of the receptors. These requirements will be discussed in the sections that follow.

4.5.1 Sludge monitoring

Sludge monitoring is recommended to determine whether sludge should rather be beneficially used, instead of being disposed. The sludge monitoring programme detailed in the EPA 503 Rule was adopted for Volume 2 of the Sludge Guidelines and remains applicable for Volume 3.

Table 4.g indicates the frequency of sampling and analyses needed for the sludge monitoring purposes.

4.5.2 Groundwater monitoring

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

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

Table 4.g: 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 of each time		
When to sample?	Before disposal		
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	
	Mechanically dewatered	Collect from discharge point	
	Dewatered by drying beds	Divide bed into quarters, sample from each quarter and combine samples	
Sample size	At least 500g $_{dry\ mass}$		
Analyses methods	See Volume 1 – Appendix 2 (Faecal coliforms), Volume 3 – Appendix 1 (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 boreholes will at least extend through the weathered zone, the aquifer below and 5 m into the non-water-yielding formation deeper down. The latter is intended to act as a sump, where material that falls down the borehole will accumulate, without affecting the performance of the monitoring system.

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

- The transmission zone below the disposal site must be monitored every 3 years to serve as an early warning system for groundwater pollution. The transmission zone is the zone between recharge and discharge.

- The frequency of sampling will depend on the disposal option and type of sludge (liquid or dewatered). Research results by Herselman *et al*. (2005) indicated that liquid sludge disposal pose a bigger threat to groundwater than dewatered sludge disposal. 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 prescribed procedures described in *Minimum Requirements for Water monitoring at waste management facilities* (latest edition) (Table 4.h)
- A closure and rehabilitation plan will be needed once groundwater contamination is observed.

Table 4.h: Groundwater 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	
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?	See Volume 3 – Appendix 3 (Groundwater sampling procedures)	
How 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 borehole, 1 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 for each sample would be needed	
Analytical methods	See Volume 3 – Appendix 1 (Standard analytical methods)	

The following **specific monitoring requirements** for groundwater monitoring apply for:

- **On-site mono disposal** –

  Groundwater chemistry should be monitored as follows:

  - Lined mono fills and waste piles – yearly groundwater monitoring will suffice since the liner should protect the groundwater from contamination.

- Unlined mono fills and waste piles – since dewatered sludge is disposed and leaching in the soil profile would be very slow, 6-monthly groundwater monitoring intervals would be adequate. At existing sites where the water table <5 m the monitoring frequency should increase to 3-monthly monitoring.
- Lined lagoons – a 6-monthly groundwater monitoring interval is recommended. Although the disposal site is lined, the risk of groundwater contamination is higher due to liquid sludge disposal. Regular monitoring will serve as an early warning system for possible leaks in the liner.
- Unlined lagoons – since liquid sludge is disposed, leaching in the soil profile would be faster than for dewatered sludge disposal and a 3 monthly (quarterly) groundwater monitoring interval are recommended. At existing sites where the water table <10 m the monitoring frequency should increase to monthly monitoring.
- Groundwater 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. 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).
- The monitoring frequency could be relaxed when:
  - Water table >10 m (mono-fills and waste piles) or >20 m (lagoons) because the aquifer will be protected by the overlying soil.
  - Soil clay content >35%. Soil with high clay content has a high metal attenuation capacity that will protect the groundwater.

- **DLD –**
  - Dewatered sludge disposal – since dewatered sludge is disposed and leaching in the soil profile would be very slow, 6 monthly groundwater monitoring intervals would be adequate. At existing sites where the water table <5 m the monitoring frequency should increase to 3-monthly monitoring.
  - Liquid sludge disposal – since liquid sludge is disposed, leaching in the soil profile would be faster than for dewatered sludge disposal and 3 monthly (quarterly) groundwater monitoring intervals are recommended. At existing sites where the water table <10 m the monitoring frequency should increase to monthly monitoring.
  - Groundwater microbiology should be monitored when Microbiological class B and C sludge are disposed.
  - The monitoring frequency could be relaxed when:
    - Water table >10 m (mono-fills and waste piles) or >20 m (lagoons) because the aquifer will be protected by the overlying soil.

- Soil clay content >35%. Soil with high clay content has a high metal attenuation capacity that will protect the groundwater.

- **Co-disposal on landfill** – the monitoring requirements as described in the *Minimum Requirements for Water monitoring at waste management facilities* (latest edition) apply for a permitted landfill site. Groundwater chemistry should be monitored as specified for the class of landfill site used for the disposal of the sludge.

4.5.3 Surface water monitoring

Surface water should be monitored to ensure that surface water bodies are not contaminated by sludge disposal. Surface water chemistry may change within minutes, depending on controlled or uncontrolled discharges. Flow from fountains and streams should be estimated. If pollution occurs as a result of sludge disposal, continuous recording of flow and water quality should be done (Minimum Requirements, latest edition). Surface water monitoring includes run-off monitoring. The following surface water monitoring is required for all land disposal sites (Table 4.i):

- Samples should be taken **monthly** from water courses above and below the disposal site (20-50 m upstream and downstream) – the distance is dictated by a number of things – it is important that thorough in-stream mixing has occurred before samples are taken.
- Water sampling, preservation and analyses should be done according to the prescribed 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 on a daily basis and analysed before discharge.
- No analysis is needed when run-off is re-cycled into the wastewater treatment system.

Table 4.i: Surface water 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>How often should samples be taken?</td><td colspan="2">Monthly from streams above and below the disposal site (20-50 m downstream)</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">See Volume 3 – Appendix 3 (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 stream, 1 sample for pH, EC and PO_4 analyses and 1 sample for NH_4, NO_3 and COD analyses. An additional sample is 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">See Volume 3 – Appendix 1 (Standard methods)</td></tr>
</table>

4.5.4 Soil monitoring

Soil monitoring is only needed at unlined disposal sites or at lined sites where groundwater contamination has indicated a breach in the lining. 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 disposal option and the sludge type (liquid or dewatered). Research results by Herselman *et al*. (2005) indicated that metals added to soil with liquid sludge disposal pose a bigger threat to the environment than metals added with dewatered sludge disposal. 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 them less soluble and immobile. Anaerobically digested liquid sludge is 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 DLD 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 dispose on the 4ha DLD site. 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. Regular liming will also ensure that soil will not acidify to such an extent that metals will be mobilised.
- 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 include nutrients and the 8 metals specified in the classification of sludge (Table 4.j). Soils should be analysed for total metal content with the *aqua regia* method (described in Volume 1).
- A closure and rehabilitation plan will be needed once:
  - movement of the constituents is observed in the soil profile and/or
  - the MPL of metals in the top soil is exceeded

Table 4.j: Soil sampling and analyses for monitoring

What should be monitored?	pH, nutrients and 8 metals (total) specified in classification
How to sample?	Sample at 100 mm intervals to at least 500 mm See Volume 3 – Appendix 3 (sampling procedures)
How many samples?	At least 4 composite samples of each disposal area
Sample sizes	At least 1kg
Analytical methods	See Volume 1 – Appendix 2

The following specific requirements for soil monitoring apply for:

- **On-site mono disposal –**
  - Unlined mono-fills and waste piles –
    - Yearly monitoring intervals are recommended.
    - Increase the sample frequency when the soil pH<6.5 and/or soil clay content <20%
    - Sample the footprint of disposal area
    - Sample the topsoil (0-100 mm) and 300 mm (3 replicates of each)
    - Analyse samples for nutrients and metals and determine pH
  - Unlined lagoons –

- 6-monthly monitoring intervals are recommended. Constituents are more mobile in the soil profile when liquid sludge is disposed on land. More frequent monitoring will be necessary to serve as an early warning system to protect the environment.
- Increase the sample frequency when the soil pH<6.5 and/or soil clay content <20%
- Sample down slope and as near as possible to the lagoon
- Sample the topsoil (0-100 mm), 300 mm and 500 mm (3 replicates of each). Deeper soil samples are needed because constituents move further with liquid sludge application.
- Analyse samples for pH, nutrients and metals. Analytical methods are described in Volume 1 and 2.

- **DLD** –
  - Recommended monitoring intervals are yearly for dewatered sludge disposal and every 6 months for liquid sludge disposal.
  - Increase the sampling frequency when the soil pH<6.5 and/or soil clay content <20%
  - Sample the footprint of disposal area
  - Sample the topsoil (0-100 mm) and 300 mm for dewatered sludge disposal. At liquid sludge disposal sites an additional soil sample at 500 mm is recommended.
  - Collect numerous samples, mix well and submit at least one composite sample for every 2 ha of the DLD site
  - Analyse samples for nutrients and metals. Analytical methods are described in Volume 1 and 2.
- **Co-disposal on landfill** – soil monitoring is not applicable for landfill sites.

4.5.5 Methane Gas monitoring

A methane gas monitoring system must be implemented at disposal sites where sludge is covered with soil or other material. The monitoring device must be installed so that methane concentrations in the air inside the property are continuously measured and the measurement can be read by any individual entering the premises. The prevailing wind direction should be considered when installing the measurement device (US EPA, 1994). Methane gas monitoring should continue throughout the operation of the disposal site, and post closure monitoring should continue until levels of methane specified in this document (Table 4.f) are reached for at least a 24 month period (Minimum Requirements, latest edition).

4.5.6 Air quality monitoring

Apart from the explosion potential landfill gas also contains a wide range of volatile organic compounds, of which some are classified as hazardous air pollutants. Where significant landfill gas is present, therefore, samples must be taken at various positions at the landfill site, and analysed for volatile organic compounds. The volatile organic compound compositions of the landfill gas must be subjected to occupational and environmental health risk assessments.

Direct measurement using a surface emission isolation flux chamber is the preferred technique in the USA for characterizing area source facilities with hazardous fugitive emissions. It is also recommended for use in South Africa. It can be used on any liquid or solid surfaces that are accessible for testing. The location and number of test points must be adequate to enable calculation of the emission rates of substances from the total area. Sampling and analysis must cover the complete range of substances that are relevant to the source. The data must then be used in a mathematical dispersion model to predict exposure levels for quantifying occupational and environmental health risks.

Sampling and analytical techniques that are used to monitor emission rates of hazardous substances must satisfy data quality objectives, i.e. the technologies must be applicable for testing area source emission rates, and must account for the key factors that influence the variability in the area source estimate. The frequency of sampling and analysis would depend on the level of identified risk, but must be at least once per year when activities and waste profiles do not change. After changes that could influence the emissions profiles, measurements must be made to establish the new profiles and associated occupational and environmental health risks (Minimum Requirements, latest edition).

4.6 Closure and remediation plans for land disposal

Remediation and closure design should account for site-specific considerations. DWAF is in a process of formulating a remediation strategy, which will provide further guidance on site- specific remediation. Closure is the final step in the operation of a disposal site. In order to close a disposal site properly, however, closure must be preceded by remediation, to ensure that the site is environmentally acceptable. The site must also be rendered suitable for its proposed end-use (Minimum Requirements, latest edition). Once the operation has ceased, aftercare is necessary to ensure sustained acceptability. A rehabilitation and closure plan for all disposal sites is required and should be developed by a responsible person. It has been assumed that the future land-use of sludge disposal sites will remain non-agricultural or industrial.

Aspects that should be addressed include:

- Remedial design to address identified problem areas
- Final landscaping and revegetation
- Permanent storm water diversion measures, run-off control and anti-erosion measures

Where it is intended to close a landfill, the Permit Holder must inform the Competent Authority of this intention at least one year prior to closure. This is because certain procedures must be implemented and criteria met before closure.

If the site is authorized, 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 authorized with a view to closure. In this event, the emphasis of the Permit Application is on closure design and remediation.

Regardless of whether a landfill is authorized 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).

4.6.1 Remediation

The remediation of a disposal 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, gas, 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 disposal site (localised waste pile or large area irrigated with sludge)
- Extent of pollution – sites where metals in the soil profile have not moved will require a less complicated rehabilitation plan than sites where groundwater contamination has already occurred
- Future land-use – it is assumed that the land-use will be non-agricultural or industrial.

A site rehabilitation plan should be developed by a responsible person when:

- Groundwater contamination occurs due to sludge disposal
- Surface water contamination occurs due to sludge disposal
- The total soil metal content exceeds the MPL
- Mobility of metals and nitrogen in the soil profile is observed

4.7 Record keeping for land disposal

Once the applicable permits or licences have been granted sludge disposal essentially become self-regulatory. This implies that certain records must be kept by the sludge producer and disposal site owner/operator. Table 4.k summarises the general record keeping requirements for the producer (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. These data could be used to obtain insight into the environmental degradation due to sludge disposal and to determine whether the mitigating factors implemented in this Guideline were sufficient to protect all receptors.

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

Description of records to be kept	
1	Report on the consideration of alternative, beneficial use options and feasibility studies
2	A copy of the applicable permits and licences
Sludge records	
3	Mass, solids content and volume of each sludge stream produced and a supporting wastewater treatment plants mass balance
4	Detailed description of sludge management process
5	Classification of each sludge stream that leaves the plant
6	Results supporting initial classification of sludge in terms of the: ▫ Microbiological class ▫ Stability class ▫ Pollutant class (total and TCLP)
7	The original or certified copy of the contract between the sludge producer and the disposal site owner/operator (if applicable)
8	Operational problem register
9	Complaints register
Initial site investigation records	
10	Groundwater data including: ▫ Aquifer classification (yield, depth, strategic value) ▫ Hydraulic gradient ▫ Groundwater quality (up gradient and down gradient)
11	Surface water quality data
12	Soil data including: ▫ Soil structure, clay content, permeability and cation exchange capacity (CEC) ▫ Soil pH ▫ Concentration of nutrients, trace elements and metals (total)
Monitoring records	
13	Sludge data pertaining to the: ▫ Microbiological class ▫ Stability class ▫ Pollutant class
14	Groundwater data including: ▫ Borehole yield ▫ Groundwater levels ▫ Groundwater chemistry
15	Surface water data including: ▫ Run-off volumes and quality (if applicable) ▫ Water quality from nearby streams
16	Soil data including: ▫ Nutrient status with depth ▫ Metal content of the soil with depth (total)
17	Methane gas data

5 SPECIFIC RESTRICTIONS AND REQUIREMENTS FOR SLUDGE CO-DISPOSAL ON LANDFILL

An important finding from research conducted in South Africa on sludge co-disposal (Dollar, 2005) was that a conventional water balance is unable to model the complexity introduced by sewage sludge co-disposal. The sewage sludge increased moisture storage per unit of dry solids (similar results were presented by Stamm and Walsh, 1998), and in the field, reduced the leachate volumes compared to unamended MSW, while also increasing the compaction density achieved.

Further, despite metal levels in the sludges being much higher than in the MSW, in general, their mobility was lower in co-disposal cells (a finding also reported in Stamm and Walsh, 1988). By mixing sewage sludge with MSW, methanogenic conditions were more rapidly attained than in unamended MSW tests. This resulted in reduced COD removal, increased pH, and therefore, in precipitation of metals. This is an important consideration not addressed by TCLP tests undertaken for delisting of sewage sludge. Metal removal during lysimeter tests was less than 0.15% of the initial metal levels in the lysimeters.

Co-disposal of sludge on landfill is an off-site disposal practice and is regulated by the Minimum Requirements (latest edition). Thus, most of the requirements for co-disposal should be adhered to by the landfill owner/operator. However, there are certain requirements that should be fulfilled before co-disposal can become a disposal option. These requirements are discussed in the sections that follow.

5.1 Specific water balance study

Sludge co-disposal affects the classification of proposed landfills, and may only be practiced at B+ sites provided that the site is equipped with an appropriate leachate management system. It is a requirement (Minimum Requirements, latest edition) that a site specific water balance be undertaken for sites for which co-disposal is proposed although it may only take place on M and L sites that are denoted B^+. Even sites that may have a negative water balance based on the climatic or site specific water balance would have to be designed as B^+ sites if co-disposal is proposed.

GMB^+ and GLB^+ sites are equipped with leachate collection systems and it is therefore implied in the requirements that leachate production will be increased by sludge co-disposal or that the leachate quality would be adversely impacted, and would thus pose a greater risk to water resources than general waste leachate. A site specific water balance is required for both co-disposal and no co-disposal cases to show the difference.

5.2 Site stability assessments

The construction of landfills usually involves excavating into natural soils. This can be unsafe, particularly with trench systems. It is therefore necessary to analyse the stability of these cut slopes to ensure that they are safe against shear failure.

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

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

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

5.3 Hazard rating

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

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

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

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

5.3.1 Estimated environmental concentration (EEC)

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

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

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

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

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

5.3.2 Acceptable exposure (AE)

The EEC is always compared to **acceptable exposure (AE)** calculated for the following three risk-based scenarios:

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

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

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

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

Dose-response curves (Figure 5.a) can be used to plot the results of LD_{50} experiments and concentration-response curves can be used to plot the results from LC_{50} experiments. The X-axis plots concentration of the chemical and the Y-axis plots mortality. Figure 5.a illustrates a dose-response curve for a toxic substance. The **dose-response curve** normally takes the form of a sigmoid curve. It conforms to a smooth curve as close as possible to the individual data points. For most effects, small doses are not toxic. The point at which toxicity first appears is known as the **threshold** dose level. From that point, the curve increases with higher dose levels.

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

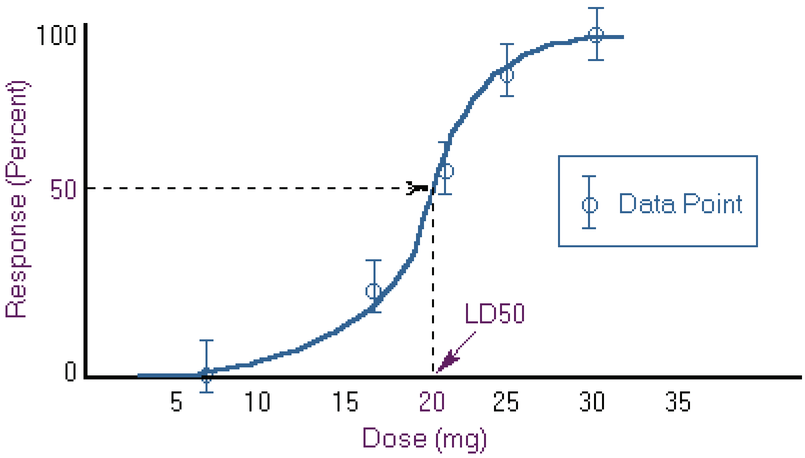

Figure 5.a: Example of a dose-response curve for a toxic substance

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

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

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

The objectives of Hazard Rating are to indicate:

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

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

- Hazard Rating 1 (Extreme Hazard): Is waste of first priority concern, containing significant concentrations of extremely toxic substances, including certain carcinogens, teratogens and infectious wastes.
- Hazard Rating 2 (High Hazard): Is waste of second priority concern with highly toxic characteristics or extremely toxic substances, which are not persistent, including certain carcinogens.

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

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

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

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

5.4 Minimum solids content

Experimental work conducted by Dollar (2006), on which the co-disposal ratios were based, was conducted using sludge from the Goudkoppies Waste Water Treatment Works. At the time the sludge was collected, the solids content varied between 16% and 20%, but the actual samples used had solids contents of 19%, 84.5% (after sun-drying) and 19.2%. Since leachate volumes were less than those predicted by a conventional water balance due to storage of moisture bound by the sewage sludge, it is evident that the limits of 20% solids and a co-disposal ratio of 1:10 were based on a precautionary approach (USEPA 1978 suggest a co-disposal ratios of 1:4 to 7 for sludge at 20% solids and Blakey, 1991 considers a ratio of 1:4 the highest likely in operations).

It is expected that as the solids content of sludge is reduced, the amount of capillary water and, particularly, free water increases. The moisture retention characteristics of the sludge would thus not be the same as at the higher solids content, and at very low solids content, the sewage sludge could be considered a liquid. Since the co-disposal ratio for liquids is based on a maximum permissible leachate volume, it could be argued that sewage sludge should be treated in a similar manner.

An aspect not accounted for in the calculation of co-disposal ratios for liquids or sewage sludge is that the liquids or sludge would increase the compaction density of the landfill. This occurs because the liquids and sludge fill the voids in the municipal solid waste (MSW), and some of the moisture is absorbed directly into the refuse at the working face, making the waste easier to compact. The increase in density is thus not just an increase reflected in the bulk density, but also an increase in the dry density achieved. As the density of waste is increased, the volume of voids is reduced and therefore the moisture-holding capacity at 35% saturation is reduced. The bulk density value used in the calculations should thus be chosen after careful consideration.

Sewage sludge with low solids content sometimes leads to a delay in the onset of methanogenesis (Barlaz *et al*, 1987; Stegmann and Spendlin, 1987; Barlaz *et al*, 1990; Novella, 1992). This is because of the high rate of moisture addition, which may stimulate the rate of hydrolysis of waste leading to a build up of volatile fatty acids and therefore a slow transition to methanogenesis. Also, as the density of waste increases due to moisture addition, the optimum moisture content required for decay decreases (Barlaz *et al*, 1990).

It is therefore recommended that the limit of a minimum of 20% solids for sewage sludge could be waived on a case-specific basis (Dollar, 2005). However, achieving the higher solids content should be encouraged, although the maximum sludge co-disposal ratio of 1:10 is retained. A possible alternative would be to limit the maximum leachate allowed for sludge with lower solids concentrations to that estimated for a co-disposal ratio of 1:10 and solids content of 20%, or at a site where the maximum leachate volume of 200 mm/year/unit area is expected, this limit would apply. Using the procedure for determining co-disposal ratios as given in the Minimum Requirements (latest edition), a leachate volume can be calculated. This value would then be used together with the expected moisture content of the lower solids content sludge to determine the new co-disposal ratio. Since sludge co-disposal is only permitted at GMB^+ and GLB^+ sites, leachate management systems would be required. However, the amount of water entering the site should not be increased above the limits set by the Minimum Requirements (latest edition), since stability of the landfill could become a concern (although at site with liquid co-disposal, the 200 mm/year/unit area applies and it is assumed that stability issues have been considered in setting this limit, but regular stability assessments are still required).

5.5 Delisting

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

The LC_{50} or acute eco-toxicity is the concentration at which a substance would kill 50 per cent of organisms if it were disposed of directly into a body of water. If the concentration of the hazardous substance does not exceed 10% of the LC_{50}, it represents an Acceptable 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 the 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 (Table 5.a). With regard to acute toxicity values, in terms of the LD_{50}, a Reference Dose (RfD) or Tolerance Daily Intake (TDI) of a non-carcinogenic substance is a daily exposure normally derived from tests involving surrogates such as rodents, and extrapolated to the human species, and which is considered not likely to be of appreciable adverse consequence during a lifetime exposure. It is therefore termed the **Acceptable Exposure to human health**, and is expressed in mg/kg body weight/day. The **Acceptable Exposure** for human health of a substance which displays **carcinogenic properties**, is the exposure derived from the Slope Factor (SF) of a dose-response curve in which excess risk is linearly related to dose, and which could result in an additional cancer incidence in a population of 10 000. The EEC is always compared to Acceptable Exposure, to indicate whether either the aquatic environment or human health will be at risk.

Table 5.a: Acceptable exposure levels, LD_{50} and LC_{50} values

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

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

5.6 Co-disposal ratio

The co-disposal ratio of 1:10 is the maximum permitted under the Minimum Requirements (latest edition), but depending on the metal levels in the sludge this ratio might need to be reduced (the other reason for a reduction in the amount of sewage sludge allowed would be the limit on the amount of leachate permitted from co-disposal sites; Appendix 2). The metal concentrations to be considered are Cd, Cu, Pb and Zn. If the total concentration of these were used in the calculations, the allowable limits for sewage sludge would be very low. It is accepted that only a fraction of these metals are available for leaching and therefore the results from a TCLP test may be used. Once the leachable concentrations of these metals (and any others of concern) have been determined, then the Acceptable Exposure (AE) and EEC must be calculated. The co-disposal ratio is limited to EEC ≤ AE.

Once the co-disposal ratio has been determined, the Total Load, described in Minimum Requirements (latest edition) must also be considered (Appendix 2). This limits the total load of any compound to be disposed of on a landfill over its design life. The delisting procedure, together with the EEC/AE approach, severely limits the amounts of sewage sludge that can be disposed of on general waste sites. This is considered too conservative and comments have been forwarded to DWAF in this regard. It is recommended that sludge not be classed as a hazardous waste, and that the limits on the co-disposal ratio and solids content as given in the Minimum Requirements (latest edition) are adequate. This recommendation is made in the light of the limits on leachate volumes permitted from co-disposal sites, preferential flow paths that develop in the landfill, rapid onset of methanogenesis due to sludge co-disposal and the precipitation of metals under these conditions.

5.6.1 Calculation of a co-disposal ratio, based on maximum permissible leachate volumes

A limit of 200 mm per year per unit area is given for leachate release from sites where co-disposal of liquid waste occurs with general waste. It is assumed that this also applies to sites where sewage sludge co-disposal occurs. For sludge co-disposal, the mass of solids in the sludge must be included in the calculation. It is assumed that the overall degree of saturation of the mixture at which leachate is produced will remain at 35%. In fact, sludge and refuse mixtures retain more moisture per unit mass of solids than refuse alone. In sludge, the moisture forms part of the organic material and further moisture is bound by the organics and flocculants (Dollar, 2005). It is therefore a conservative assumption to retain the degree of saturation at 35% in line with the precautionary principle used in the Minimum Requirements (latest edition).

Equation 1 can be used to determine the co-disposal ratio explicitly. It was derived by writing all parameters in terms of a co-disposal ratio in the form of 1:*x* (ratio of sludge to municipal solid waste (MSW) by wet weight) and solving for *x*. This enables multiple scenarios to be generated and compared with ease (Dollar, 2005).

Equation 1:

$$x = \frac{\sum R - \sum E_A - y - 1000 S_R H + 1000 H \rho_b (w_S / \rho_w + S_R / G_{SS})/(1 + w_S)}{\sum E_A - \sum R + y + 1000 S_R H - 1000 H \rho_b (w_M / \rho_w + S_R / G_{SM})/(1 + w_M)}$$

Where:

y = allowable depth of leachate in mm;

S_R = degree of saturation at which leachate is released, expressed as a proportion;

H = rate of rise per year at the landfill;

ρ_b = bulk density, expressed in kg/m^3;

ρ_w = density of water, expressed in kg/m^3;
G_{SM} = solids density of MSW, expressed in kg/m^3;
G_{SS} = solids density of sewage sludge, expressed in kg/m^3;
w_M = gravimetric moisture content of MSW, expressed as a proportion;
w_S = gravimetric moisture content of sewage sludge, expressed as a proportion;
(if the percent solids, %S, is known, then w_S = (1-%S/100)/(%S/100));
ΣE_A = $0.4(\overline{E}_A - 1.6\ \sigma_E)$, expressed in mm; and
ΣR = $\overline{R} + 1.6\sigma_R$, expressed in mm.

It is recommended that the limit of a minimum of 20% solids for sewage sludge could be waived on a case-specific basis. However, achieving the higher solids content should be encouraged, although the maximum sludge co-disposal ratio of 1:10 is retained. A possible alternative would be to limit the maximum leachate allowed for sludge with lower solids concentrations to that estimated for a co-disposal ratio of 1:10 and solids content of 20%, or at a site where the maximum leachate volume of 200 mm/year/unit area is expected, this limit would apply. Using the procedure for determining co-disposal ratios as given in Examples 1 and 2 (Appendix 2), a leachate volume can be calculated. This value would then be used as *y* in Equation 1 together with the expected moisture content of the lower solids content sludge to determine the new co-disposal ratio. For a landfill where no leachate would be expected at the limit in the Minimum Requirements (latest edition), *y* should be set as zero. Since sewage sludge co-disposal is only permitted at GMB^+ and GLB^+ sites, leachate management systems would be required. However, the amount of water entering the site should not be increased above the limits set by the Minimum Requirements (latest edition), since stability of the landfill could become a concern (although at site with liquid co-disposal, the 200 mm/year/unit area applies and it is assumed that stability issues have been considered in setting this limit, but regular stability assessments are still required) (Dollar, 2005).

5.6.2 Using the EEC to determine the loading rate at which sewage sludge may be co-disposed at a General waste site

As a consequence of industrial activities within their catchments, many WWTP produce sludge that has elevated concentrations of certain potentially toxic metals and elements (Snyman *et al*., 2004). It is the potential leaching of these elements into the subsurface below a landfill that is of concern and the reason that the loading rate (or co-disposal ratio) may have to be restricted.

To calculate the allowable loading rate it is necessary to determine the leachable fraction of the following heavy metals: cadmium, copper, lead and zinc. However, since an ICP scan provides for 33 elements at no extra cost, it is suggested that a full ICP scan is done on the leachate fraction to cover all 33 elements.

The Acceptable Exposure, AE must be compared with the Estimated Environmental Concentration (EEC). For the purposes of calculating allowable loading rates (or co-disposal ratios) the EEC should be based on leaching tests carried out using the TCLP method, with the results expressed as $mg/kg_{dry\ sludge}$. If the EEC calculated in this manner exceeds the AE, the loading rate must be reduced until the EEC = AE (Example 3, Appendix 2).

5.7 Management requirements for sludge co-disposal at landfill

All the management requirements as specified in the *Minimum Requirements (latest edition) Section 10: Landfill Operation* should be adhered to. Only the requirements specific to sludge co-disposal are discussed in this section.

5.7.1 Methods for co-disposal

According to the Minimum Requirements there are 3 acceptable methods for sludge co-disposal in landfill:

- Area method – Spread sludge as a thin layer on waste body, cover with a relatively thin layer of waste and compact with landfill compactor to achieve reasonable mixing.
- Toe method – Spread the sludge in a layer at the toe of an advancing cell. Waste is placed at the top of the slope and compacted down the slope to cover the sludge.
- Trench method – Sludge is deposited in trenches and filled over with waste immediately after filling.

For the area and the toe disposal methods appropriate measures must be implemented to manage odour problems and fly infestations. For the trenching method the following precautions should be considered:

- The spacing and orientation of trenches must be considered in 6-monthly stability assessments. As a precautionary principle the shear strength of sludge should be assumed to be zero.
- As a general rule, trench orientation should be perpendicular to the crest of a landfill and no trenching should occur within 30 m of the crest.
- In calculating an acceptable co-disposal ratio in terms of leachate generation the effective degree of mixing that is achieved with trenching should be taken into account.
- It must be ensured that trenches in successive lifts of waste do not coincide in plan with any trench in the previous lift.

5.7.2 Alternative method for sludge co-disposal

There is an alternative method of achieving co-disposal at the landfill working face to those described in the current draft of the Minimum Requirements (latest edition). The method is shown in Figure 5.b. A pile of refuse is placed at the toe of the slope. A pile of sludge is then placed against this. A second pile of refuse is then placed against the sludge (*i.e.* the sludge is sandwiched between two piles of refuse). The compactor then moves these piles up the working face. The advantages of this method are that good mixing is achieved and the compactor does not slip on or sink into the sludge.

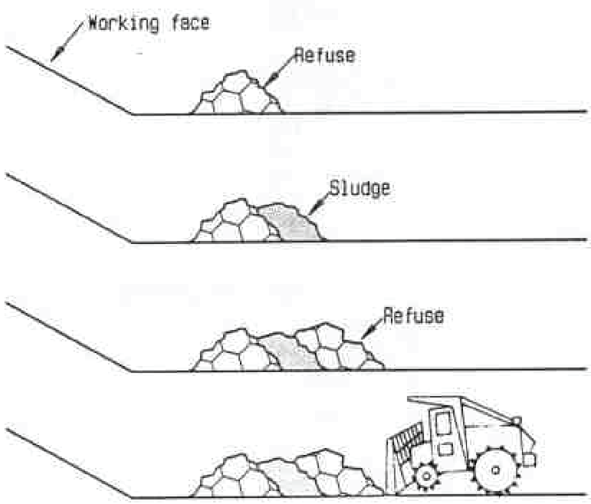

Figure 5.b: Proposed method of sewage sludge co-disposal (Röhrs, 2002).

Refuse trucks do not arrive at the landfill site in a steady stream throughout the day. There is often a busy period after the site opens, followed by a lull and then another busy period prior to the end of the working day. At some sites the amount of refuse arriving on various days of the week is also not constant (Mondays are often busiest). If co-disposal is to be undertaken at any site, the frequency of arrival of refuse trucks should be monitored so that sewage sludge delivery can coincide with the arrival of high volumes of refuse. This will ensure that good mixing occurs, that sufficient waste is present to cover the sewage sludge, and that no zones of weakness develop on the working face as a result of deposition of sludge with limited volumes of MSW. If cognisance is not taken of this, a lower overall co-disposal ratio than permitted will be achieved, as machine manoeuvrability will be lost (and slope stability is compromised) when the amounts of sludge are too high for the volumes of waste arriving.

Sludge that has undergone stabilization procedures such as digestion or lime-stabilisation need not cause problems at the landfill site if appropriately managed. If adequate mixing occurs, such as in the Area method, then standard operational procedures at the landfill are considered adequate. Daily cover over cells is required. For the Toe method, no further action is required since the pile of sewage sludge is immediately covered over with refuse and little or no mixing occurs. Sewage sludge in trenches should be covered immediately with a layer of MSW to limit odours and vector attraction.

5.7.3 Public access restrictions

At present, both uncontrolled and controlled salvaging takes place at many landfills. While the ethic of salvaging from the waste stream is supported, salvaging at landfills can endanger the health and safety of the salvagers. On account of the risks to health and safety, therefore, the Competent Authority discourages uncontrolled waste salvaging at landfill sites and wishes to see salvaging at disposal sites gradually brought to an end. In the interim, however, the Competent Authority wishes to professionalize salvaging to ensure the dignity and protection of salvagers. **No salvaging is permitted**

at any hazardous waste site or general site where co-disposal of sewage sludge is practiced (Minimum Requirements, latest edition).

5.7.4 Run-off collection and management

The following are Minimum Requirements for landfills (Minimum Requirements, latest edition):

- Run-off and storm water must always be diverted around one or both sides of the waste body, by a system of berms and/or cut-off drains.

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

- The bases of trenches and cells must be so designed that water drains away from the deposited waste. Alternatively, cells must be so orientated as to facilitate drainage away from deposited waste. The resulting contaminated water, together with all other contaminated run-off arising from the landfill, must be stored in a sump or retention dam. It may be pumped from the dam and disposed of if it conforms to the water quality values/limits stipulated in the Permit.

- A 0,5 m freeboard (the vertical distance between the maximum design water surface of a channel and the top of bank provided to account for differences between predicted and actual water surface elevations and/or to provide an allowance for protection), designed for the 1 in 100 year flood event, must always be maintained in the case of contaminated water impoundments and drainage trenches.

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

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

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

5.7.5 Transportation

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.

6 RESTRICTIONS AND REQUIREMENTS FOR DISPOSAL OF WASTEWATER CONTAINING SLUDGE TO THE MARINE ENVIRONMENT

While the sea is the ultimate natural sink for many of the wastes generated on land it is becoming increasingly evident, and more widely recognised, that it has limitations in its assimilative capacity. Careful management is required to ensure that this capacity is not exceeded and that the vital resources of the sea are not compromised. At the same time it may well be prudent to make use of the ocean’s capacity to assimilate wastes in situations where this represents the best practicable environmental option. Achieving a sensible compromise is an ongoing challenge for scientists and coastal managers.

South Africa has never seriously considered this route for sludge disposal and it is unlikely that it presents an economically viable or environmentally acceptable option. The recently published *"Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa"* (DWAF, 2004), which was drawn up using wide consultation amongst competent authorities and stakeholders, and with detailed reference to global experience, outlines DWAF and DEAT's thinking around discharges to sea. This document presents a revised set of basic principles, stipulates a set of ground rules and presents a detailed management framework. A major shift in approach is signalled by the change from an effluent standards approach (i.e. enforcing compliance with effluent standards) to an approach which focuses on receiving water quality objectives which support the maintenance of fitness for use.

It should be noted that, where municipal wastewater receive **preliminary treatment**, sludge is not yet separated from the effluent and may be discharged according to the discharge standards prescribed in the licence. In instances where the receiving environment can absorb such inputs, sludge disposal is essentially taken care of. However, where municipal wastewater receives **primary (partly separated) or higher treatment**, sludge is separated from the effluent and needs to be dealt with separately. Sludge removed from the wastewater during primary or higher treatment must be disposed of on land according to the minimum requirements for waste disposal (Minimum Requirements, latest edition).

Note that an application to dispose of wastewater to the marine environment must demonstrate that all reasonable efforts have been made, firstly to prevent waste, and secondly to minimize it. Only thereafter will minimum wastewater standards or standards based on the Receiving Water Quality Objective approach, whichever is strictest, be considered.

Alternative options of managing wastewater must therefore be investigated. Disposal to the marine environment is NOT the 'default' option in coastal areas. However, in evaluating wastewater disposal in coastal areas it should be considered. For example:

- Coastal real estate tends to be highly valued which may have implications in terms of setting large surface areas aside for treatment plants (e.g. maturation and oxidation ponds)
- The marine environment, including the surf zone and estuaries, tends to be particularly sensitive to the negative effects of poor water quality in terms of economic, social and ecological impact.
- Coastal areas are popular holiday and tourist destinations that particularly require that water should be of a high quality to support, for example, recreational use.

6.1 Basic principles

Basic Principles provide the broad reference framework or direction within which to develop ground rules for the disposal of land-derived wastewater to the marine environment, as well as the management thereof. These principles were distilled from the broader international and national legislative context (refer to Appendix B in *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Appendices*). The basic principles pertaining to the Operational policy for the disposal of land-derived wastewater to the marine environment of South Africa are listed below:

6.1.1 Principle 1: Pollution prevention, waste minimisation and precautionary approach

- **Pollution prevention**. This aims at preventing waste production and pollution wherever possible.
- **Minimisation of pollution and waste at source**. This aims at minimising unavoidable wastes through technical interventions including:
  - Recycling
  - Detoxification
  - Neutralisation
  - Treatment and re-use of waste streams
  - Cleaner technologies and best management practices.
- **Responsible disposal.** This aims at minimising environmental impact through applying the precautionary approach in terms of:
  - Applying wastewater standards as a minimum requirement
  - Ensuring that if wastewater discharge standards are not sufficient, fitness for use of the receiving water body is maintained in accordance with the Receiving Water Quality Objective approach
  - Ensuring that exemption from compliance with wastewater discharge standards is considered only in exceptional circumstances provided that the receiving water body remains fit for use in accordance with the Receiving Water Quality Objective approach.

6.1.2 Principle 2: Receiving water quality objectives approach

The requirements of the aquatic ecosystem, as well as the requirements of the beneficial uses of the water resource, will determine the objectives to be met (rather than following a uniform effluent standard approach as was the case with the General and Special Standard under the previous Water Act 54 of 1956). This principle applies to the marine environment as well.

6.1.3 Principle 3: Integrated assessment approach

The operational policy will adhere to the principles of Integrated Environmental Management, taking cognizance of concepts such as Strategic Environmental Assessment, and Environmental Impact Assessment and supporting the following underpinning principles:

- ‘Cradle-to-grave’ – Responsibility for the environmental and health and safety consequences of a policy, programme, project, product, process, service or activity exists throughout its life cycle. It starts with conceptualization and planning and runs through all stages of implementation to reuse, recycling and ultimate disposal of products and waste or decommissioning of installations.
- Strategic adaptive management – ‘improving-by-learning’ and ‘thinking strategically whilst implementing locally’.

- Best Practice – to be developed by a regulator and, as a matter of obligation, implemented by the regulated community as a minimum for responsible source management.
- Consistent Performance – all water users/impactors within the regulated community are required to ensure and strive for the same water quality goals at the same risk level.
- Flexibility in approach – the regulator has the flexibility to consider the application of different alternatives and approaches, provided each of these is capable of meeting the desired objectives and requirements of the Source Management Strategy.
- Continuous improvement – encouraging continuous improvement in the actions and practices of both government and the regulated community.

6.1.4 Principle 4: Polluter pays principle

The responsibility for environmental costs incurred for rehabilitation of environmental damage and the costs of preventive measures to reduce or prevent such damage will be shifted to the impactors through, for example, the implementation of a waste discharge charge system. Those responsible for environmental damage must pay the repair costs both to the environment and human health, and the costs of preventive measures to reduce or prevent further pollution and environmental damage.

6.1.5 Principle 5: Participatory approach

Transparent stakeholder participation will be required, not only as part of the decision-making process (e.g. Environmental Impact Assessment process and setting of common environmental quality objectives), but also through ongoing transparent and open communication on the *status quo* during design, construction and operations. Local management institutions (e.g. pipeline or catchment forums), for example, can be used for transparent stakeholder involvement throughout the process from application through to report back on monitoring results.

6.2 Ground rules related to municipal wastewater

Ground Rules are derived within the broader context of the Basic Principles and provide more specific rules that will be applied by Government when considering license applications to dispose of land-derived wastewater to the marine environment. For this operational policy, the Ground Rules are addressed under specific themes considered to be of particular importance in the disposal of land derived wastewater to the marine environment (in alignment with the key components of the management framework), namely:

- Legislative Framework
- Management institutions and Administrative Responsibilities
- Environmental Quality Objectives
- Activities and Associated Waste Loads
- Scientific and Engineering Assessment
- Monitoring and Contingency Plans.

The ground rules concerning marine disposal of wastewater and wastewater sludge will be discussed in the following sections.

6.2.1 Ground Rule No. 14

South Africa is a water scarce country. Marine disposal of land-derived municipal wastewater (particularly freshwater) will therefore only be considered where it has been evaluated in terms of the Water Services Development Plan for a particular municipal area (required under the Water Services Act 108 of 1997), and which, in turn, forms part of the Integrated Development Plans required in terms of the Local Government Transition Act 209 of 1993. This requirement supports the concept of a 'Master Plan for water supply/demand and wastewater treatment'.

Principles supported: Pollution Prevention, Waste Minimisation & Precautionary Approach, and Integrated Assessment Approach.

It is crucial that wastewater disposal be managed within a 'Master Plan' for water, taking into account, for example:

- Water supply and future water demand
- Reserve requirements for rivers and estuaries (under the NWA)
- Groundwater resources
- Surface water resources
- Sanitation (including reticulation systems)
- Wastewater treatment and disposal
- Trade effluents
- Storm water reticulation and disposal.

It is crucial that the upgrading of WWTP also be addressed as part of the holistic 'Master Plan' for water.

6.2.2 Ground Rule No. 15

Municipal WWTP receiving industrial effluent (also referred to as trade effluent) will be subject to the Ground Rules for Industrial Wastewater (refer to Ground Rules 19 to 22 in the Policy Document). Service Providers or Local Authorities operating such treatment works will be required to prepare Industrial wastewater management plans (as part of the 'Master Plan'). It is also the responsibility of the Service Provider or Local Authority to investigate possible synergistic and/or cumulative effects which may occur as a result of the interaction between different (industrial) wastewater inputs.

Principles supported: Pollution Prevention, Waste Minimisation & Precautionary Approach, and Integrated Assessment Approach.

6.2.3 Ground Rule No. 17

The new DWAF policy regarding municipal wastewater disposal to sea is clearly stated in their Ground Rule No. 17. For marine outfalls "primary treatment will be required as a minimum for disposal of municipal wastewater to the offshore marine environment". This minimum requirement will apply to:

- All marine outfalls to be authorised after 31 May 2004
- For marine outfalls that were already authorised by 31 May 2004,
  - preliminary treatment will be accepted as a minimum requirement, provided that the receiving environment is suitable for this marine disposal and that the environmental (or resource) quality objectives are met.
  - future expansions or upgrades to such existing marine outfalls will require primary treatment of the wastewater prior to discharge unless it can be proven that key socio-economic factors require otherwise. Nevertheless, environmental (or resource) quality objectives must still be met.
- With regard to discharges to the surf zone and estuaries the policy calls for a minimum of secondary treatment with disinfection for all existing and future discharges.

Given their imperatives around pollution prevention, waste minimisation and responsible disposal, together with the practical need for efficient waste disposal in highly variable physical and socio-economic environments, DWAF has devised a policy which is strict yet retains a measure of pragmatic flexibility. Sea disposal is not the default option for coastal communities. It will only be allowed where thorough screening has demonstrated that it is the best practicable option. The new policy strongly supports global trends in encouraging sludge beneficiation.

6.2.4 Ground Rule No. 18

The disposal of sludge arising from wastewater treatment facilities (e.g. primary, secondary and tertiary) must be in accordance with the Minimum Requirements for Waste Disposal by Landfill (DWAF, 2006) and the newest edition of the 'Sludge Guidelines' or any future updates of such policies or guidelines.

Principles supported: Pollution Prevention, Waste Minimisation & Precautionary Approach Integrated Assessment Approach.

6.2.5 Ground Rule No. 20

An industry, discharging wastewater to a municipal WWTP or directly to the marine environment (or applying for a licence or permit in the case of the first case, to do so), will be required to provide a detailed description of the waste stream in terms of both volume (quantity) and quality (*i.e.* listing all substances present and their concentrations and loads). Where industries discharge wastewater to a WWTP, the water services provider is responsible for obtaining this information from the industry concerned and for issuing an authorization (e.g. trade effluent permit) to discharge to sewer. DWAF or local authority may also require a detailed inventory of the raw materials, as well as process material, used by an industry.

Principle supported: Pollution Prevention, Waste Minimisation & Precautionary Approach.

It will be the responsibility of an industry to supply a detailed description of their effluent to DWAF. Such information is crucial to the licence authorisation process both in terms of evaluating potential impacts appropriately, and of evaluating alternative wastewater treatment options.

Toxicity testing will not be considered as a substitute where detailed description of the composition of the wastewater is not available. However, these tests are valuable techniques to be used as supplementary tools, for verifying impact assessment studies based on the detailed wastewater composition.

6.2.6 Ground Rule No. 21

Industrial wastewater discharged to a municipal WWTP disposing to the marine environment will be subject to appropriate pre-treatment. It is the responsibility of the local authority operating the WWTP to ensure compliance in this regard.

Principle supported: Pollution Prevention, Waste Minimisation & Precautionary Approach.

Appropriate pre-treatment is required to ensure that the:

- WWTP and associated equipment are not damaged
- Operation of the WWTP and the treatment or re-use of sludge are not impeded
- Discharge from the WWTP does not adversely affect the marine environment.

6.3 Management framework

The **Management Framework** provides the generic and structured approach within which the management and control of disposal of land-derived wastewater to the marine environment of South Africa needs to be conducted.

6.3.1 Management institutions and administrative responsibilities

The disposal of land-derived wastewater to the marine environment is currently governed by DWAF under the National Water Act 36 of 1998. DWAF works in consultation with other government departments. In the context of this operational policy, a water use authorisation, under section 21 of the NWA will be required for:

- New applications to dispose of land-derived wastewater to the marine environment

- Existing discharges of land-derived wastewater to the marine environment that are not considered to be existing lawful water uses in terms of Section 32 of the NWA
- Upgrades, extensions of existing WWTP or industries discharging to the marine environment that were not approved in terms of the original authorisation
- Change in effluent volume or composition (a licence is issued based on a specific effluent volume and composition, therefore if these change, the discharger legally must re-apply).

Although DWAF is responsible for the overarching management and administration of the disposal of land-derived wastewater to the marine environment, a key element in the successful implementation of this operational policy is the establishment of local management institutions, representing all the role players in a designated area, and which fulfill the role of 'local watchdogs' or 'custodians'. Local management institutions will play a leading role in identifying non-compliance (i.e. they will become the local 'watchdogs'), based on information provided by scientifically sound monitoring programmes. In the case of non-compliance, this information will provide the local management institution with an informed, scientific base from which to challenge the responsible authority (e.g. DWAF) to respond appropriately (e.g. prosecuting the offender) where such authorities are reluctant to do so. However, water services providers (operating WWTP) and industries are ultimately responsible in terms of their individual licence agreements with DWAF.

Where multiple developments and activities occur in a study area, it is usually extremely difficult and financially uneconomical to manage marine environmental issues in isolation because of, for example, their potential cumulative or synergistic effect on the receiving environment. Collaboration is often best achieved through a joint local management institution. Local management institutions are also considered the appropriate platform for facilitating the joint funding of studies (such as impact assessments and monitoring) where two or more developments/activities may be responsible for pollution in a particular area. It is essential that the local management institution include all relevant interested and affected parties or stakeholders in order to facilitate a participatory approach in decision-making. These stakeholders include, for example, representatives from:

- Department of Water Affairs and Forestry
- Department of Environmental Affairs and Tourism
- Department of Health (where applicable)
- Department of Minerals and Energy (where applicable)
- Department of Transport (where applicable)
- National Ports Authorities (where applicable)
- Provincial Department of Environmental Affairs
- Nature Conservation Board
- Local authorities (municipalities)
- Industries

- Tourism Board and recreation clubs
- Local residents, e.g. ratepayers association
- Non-government organizations.

Institutions that are already partly fulfilling the role envisaged for the local management institutions include:

- Catchment management forums
- Pipeline monitoring committees
- Pipeline advisory committees
- Pipeline forums (e.g. KZN coastline)
- Water quality forums (e.g. Saldanha Bay and False Bay/Table Bay)
- Pipeline technical steering committees (e.g. Hout Bay).

Although such institutions could be initiated from local level it is, however, crucial that these be coordinated from a national (or regional) level by the responsible government authorities, such as DEAT and DWAF. It is therefore recommended that the responsible government departments jointly investigate a legal route whereby local management institutions can be formally constituted to assist in the integrated management and control quality of marine water resources in South Africa. Towards enforcing the involvement of local role players, DWAF already requires the establishment of a local monitoring committee, as a licence condition for the disposal of land-derived wastewater to the marine environment.

Information compiled from: *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Guidance on Implementation, Section 3*.

6.3.2 Environmental quality objectives

The area within which this management framework is applied must be determined, taking into account the anticipated influence of the proposed discharge, both in the near and far fields (e.g. an entire bay or ecosystem). The purpose of the environmental quality objectives is:

- To define the extent of the study areas (*i.e.* study area boundaries)
- To produce a map (preferably a geo-referenced map) indicating important ecological and conservation areas and the location of the beneficial use areas in the study areas
- To determine site-specific environmental quality objectives for the identified beneficial uses, as well as the ecosystem’s requirements. For environmental quality objectives to be practical and effective management tools from a water quality point of view, they need to be set in terms of measurable target values or target ranges for specific chemical or microbiological constituents in the water column, sediment and/or biological tissue.

Definition of the extent of the area within which this management framework should be applied is very important. The extent of the anticipated influence of the proposed discharge, both in the near and far field, must be taken into account. The selection of study area boundaries is site specific, depending on the physical and biogeochemical processes, as well as the quantity and quality of waste inputs to the area. Important issues that need to be taken into account in the selection of the study boundaries include:

- Proximity of depositional areas that could result in cumulative effects associated with waste inputs to the area
- Possible synergistic effects in which the negative impact from a wastewater discharge could be aggravated through interactions with other waste inputs to the area, or even with natural processes.

The identification and mapping of key marine ecosystems and beneficial uses in a particular area provide the basis for the determination of the site specific environmental quality objectives. In addition to identifying sensitive marine ecosystems, it is also important that designated beneficial uses be identified. The following activities are defined as beneficial uses of marine waters in South Africa (RSA, DWAF, 1995):

- recreation
- marine culture (and fisheries)
- industrial uses (e.g. abstraction of seawater for cooling and fish processing).

Environmental quality objectives can be based on:

- National and international legal requirements e.g. target values for toxic substances in sediments in terms of the *London Convention* (refer to Appendix B in *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Appendices*)
- Generic target values, e.g. as recommended in the *'South African Water Quality Guidelines for Coastal Marine Waters'* (to assist managers in setting environmental quality objectives, this set of documents was published in 1995)
- Site-specific conditions (e.g. obtained through site-specific field measurements and numerical modeling outputs).

Guidance on procedures to be followed to determine the area boundaries, important ecosystems, beneficial uses and associated environmental quality objectives is provided in *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Guidance on Implementation, Section 4*).

6.3.3 Activities and associated waste loads

To ensure that possible cumulative and synergistic effects are taken into account, the waste loads of the marine disposal activities, as well as those of existing waste inputs to the study area (both in terms of quantity and quality), need to be defined. Information typically needed to define wastewater characteristics includes:

- Description of treatment processes
- Density, viscosity and temperature of the wastewater stream (average, maximum, minimum – specify if diurnal/seasonal variations occur)
- Flow rates (average, maximum, minimum and diurnal/seasonal variations) for present and future scenarios
- Composition of the wastewater – in terms of all relevant constituents (average, maximum, minimum and diurnal/seasonal variations) for present and future scenarios.

Guidance on determining the specification for different types of wastewater is provided in *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Guidance on Implementation, Section 5*).

6.3.4 Scientific and engineering assessment

The objective of this component of the management framework is to refine the environmental quality objectives for a particular marine receiving environment and to establish whether a waste disposal practice can be designed that will comply with such environmental quality objectives.

Guidance on the procedures to be followed in the scientific and engineering assessment of land derived wastewater disposal to the marine environment is provided in *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Guidance on Implementation, Section 6*). Where appropriate, a distinction is made between requirements for a pre-assessment and a detailed investigation as specified within the licence authorisation process, discussed in detail in Section 3 of that document.

6.3.5 Monitoring and contingency plans

Long-term monitoring plans need to be designed and implemented to enable the continuous evaluation of:

- The effectiveness of management strategies and actions to comply with the licence conditions and design criteria (Compliance monitoring and System Performance monitoring)
- The trends and status of changes in the environment in terms of the health of important ecosystems and designated beneficial uses in order to respond to and also to evaluate if the environmental responses that were predicted during the assessment process match the actual responses (Environmental monitoring).

Monitoring programmes typically become part of the license issued by DWAF for a particular discharge under Section 21 of the NWA. These monitoring programmes are designed and implemented at the cost of the licensee (following the Polluter Pays Principle). To be useful from a management perspective, monitoring data must be evaluated against predetermined objectives. Results need to be presented in clear format, providing the appointed management institution/s with the scientific and engineering information needed for effective decision making (*i.e.* facilitating effective adaptive management).

6.3.5.1 Compliance monitoring

Parameters to be monitored include:

- *Flow*: The sampling frequency needs to be sufficient to resolve the actual *variability* in the wastewater volume.
- *Composition of wastewater*: The list of constituents to be monitored will depend on the composition of the wastewater, while the frequency of monitoring needs to reflect the actual *variability* in wastewater composition. Urban/Municipal wastewater discharges, consisting mainly of domestic sewage have a characteristic wastewater composition. Key constituents that need to be included in the monitoring programme of discharges to the marine environment are:
  - Biochemical oxygen demand/Chemical oxygen demand (more commonly used)
  - Total suspended solids
  - Particulate organic carbon and nitrogen
  - Inorganic nitrate and nitrite
  - Total ammonia
  - Dissolved reactive phosphate.

  In the case of industrial wastewater discharges, or where industrial wastewater discharges enter a municipal WWTP, the constituents included in the monitoring programme will depend on the constituents present in the wastewater and their potential to impact negatively on the receiving marine environment and its designated beneficial uses.

  An industry, discharging to a WWTP or directly to the marine environment (or if applying for a licence to do so), will be required to provide a detailed description of the waste stream both in terms of volume (quantity) and quality (*i.e.* listing all substances present and their concentrations). Where industries discharge into a WWTP, the WWTP authority is responsible for obtaining this information from the industry concerned (in accordance with Ground Rule 20 in the *Operational Policy for the treatment and disposal of land-derived water containing waste to the marine environment of South Africa*).

  The sampling frequency of the composition of the wastewater will depend on the actual *variability* in wastewater composition. Sample analyses must be conducted by an accredited analytical laboratory.

- *Toxicity testing:* It is imperative that wastewater streams are routinely subject to toxicity testing. Such tests have been routinely used in South Africa for the past 15 years for monitoring the performance of wastewater discharges to the offshore marine environment. The frequency of toxicity testing of the wastewater will depend on the actual *variability* in the wastewater composition.

6.3.5.2 System performance monitoring

Monitoring of the performance of the wastewater disposal system comprises two main components:

- Physical inspections of the outfall system (for marine outfalls)

  Head works and land line. The Standard Operating Procedure for the head works and treatment plant should include specified and scheduled monitoring procedures. These include daily routine observations and longer-term mechanical, electrical and hydraulic testing. These records form an integral part of the maintenance programmes and service contracts for the plant and specific components.

  Underwater section. The stability of the pipeline and the diffuser of a wastewater discharge system should be checked regularly, especially after major storms, to ascertain that no undesired displacements or damage have occurred.

- Hydraulic performance (this typically applies to marine outfalls, *i.e*. wastewater discharges to the offshore marine environment). This field test(s) should include:

  - Controlled injection of a conservative tracer material, such as Rhodamine-B dye, into the wastewater at the head works
  - Continuous sampling downstream of the injection point and at one or more of the ports (depending on the length of the diffuser)
  - Spatial sampling in the initial mixing zone ('boil')
  - Accurate recording of wastewater flow and physical conditions at the discharge location (currents and seawater density throughout the water column)
  - Sample analysis (e.g. by using a calibrated Turner Design Fluorometer or similar device)
  - Statistical analysis of the distribution of concentrations in the boil to determine the achievable dilutions
  - Comparison of measured achievable dilution with the theoretically predicted dilutions.

  The performance test should also be conducted at any stage during the lifetime of the outfall when physical changes or alterations, which may have an effect on the hydraulic characteristics, are introduced or when there is a substantial change to the wastewater quantity or composition. During this performance test, the sampling can be extended to the far field to confirm the estimated achievable secondary dilutions.

Information obtained from: *Operational Policy for the treatment and disposal of land-derived water containing waste to the marine environment of South Africa, Section 7.2*).

6.3.5.3 Environmental monitoring

In the context of this operational policy, the purpose of establishing monitoring programmes in the receiving marine environment is to continuously provide data for the evaluation of the status of the receiving environment in terms of the health of important ecosystems and designated beneficial uses.

This evaluation enables a response, where appropriate, in good time to potentially negative impacts, including cumulative effects. The requirements for monitoring in the receiving environment are usually site-specific and depend on the type of wastewater discharge and the variability in its waste loads, as well as the site-specific physical, biogeochemical and ecological characteristics of the receiving environment and the variability thereof. As a result, this section is not intended to be prescriptive, but rather sets out the approach to follow when formulating long-term monitoring programmes associated with wastewater disposal activities to the marine environment.

Key elements of a successful monitoring programme include:

- Setting clear monitoring objectives – Measurable site-specific monitoring objectives are a key component of a sound monitoring programme. Such clear objectives make it possible to design a focused and cost-effective monitoring programme. These objectives can also be translated into hypotheses that could be proved statistically. The monitoring objectives are distilled from the environmental quality objectives previously specified for the study area and, in turn, are based on the requirements of the important marine ecosystems and the designated beneficial uses. Monitoring objectives for a discharge from a municipal WWTP typically aim to:
    - Determine whether *E. coli* levels measured at designated recreational beaches exceed the recommended target values for contact recreation, as set out in the *South African Water Quality Guidelines for Coastal Marine Waters*
    - Determine whether particulate organic matter discharged from the WWTP accumulates at depositional areas, thus creating a 'sink' for toxins such as trace metals
    - Determine whether trace metals present in the wastewater discharged from the WWTP accumulate at depositional areas and whether these exceed the limits set for such constituents under the London Convention
    - Determine whether toxins are accumulating in biological tissue (e.g. that of filter feeders such as mussels and oysters) at concentrations exceeding the environmental quality objectives set, for example, for human consumption of these organisms or the protection of organism health
    - Determine whether the composition of the biotic community in the study area is being altered as a result of the wastewater discharge.
- Design and implementation of a cost-effective programme – A key component of the design of a focused and cost-effective monitoring programme is an understanding of dominant physical, biogeochemical and ecological processes that govern the 'cause and- effect' linkages between the receiving environment and the wastewater discharge. This design should also take into account modifications to such processes resulting from existing human activities.

It is also important to remember that any long-term monitoring programme is a dynamic, iterative process that needs to be adjusted continuously to incorporate new knowledge, thereby supporting the principle of adaptive management.

Guidance on procedures to be followed in the design and implementation of monitoring programmes is provided in *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Guidance on Implementation in Section 7.3.2*).

6.3.6 Contingency plans and mitigating actions

Contingency plans and mitigating actions are required to minimise the risks to the environment in the event of malfunctioning, both during construction and operation of the marine outfall. Decommissioning of a wastewater disposal scheme is also addressed.

Contingency plans and mitigation measures for the operation of a marine outfall system relate mainly to accidental damage or failure of the system to perform to expected standards. Negative impacts resulting from the underperformance of the entire system and subsequent failure to perform to expected standards, or negative feedback from the monitoring programme can be the result of:

- Deviations from specifications, such as:
  - Increased loads (flow or quality) resulting from unexpected population increase
  - Extreme or abnormal physical conditions (meteorological or oceanographic) which were not anticipated in the data set used for the design.
- The malfunctioning/underperformance or breakdown of plant/equipment, as a result of:
  - Equipment/plant or outfall breakdown
  - Electrical power failures (local network or national power supply)
  - Overloading (flow conditions or wastewater composition which exceed design standards) that will result in the underperformance of the system due to one or more of the following:
    - ineffective screening;
    - sedimentation in the main pipeline and diffuser section;
    - blocking of ports;
    - insufficient initial dilution;
    - process failure and malfunctioning due to insufficient maintenance (corrosion, sliming in the pipeline, damaged ports, etc.);
    - operational problems due to deviation from standard operational procedures, insufficient control or incompetent staff; and
    - operational problems related to strikes (staff or suppliers).

- Incidents and disasters, such as:
  - Accidents related to ships (dragging or dropping anchors, direct collision with pipeline)
  - Extreme conditions (wave forces on exposed sections of the pipeline or excessive scour)
  - Vandalism of onshore structures
  - Fires
  - Earthquakes

Guidance on procedures to be followed in the design and implementation of contingency plans is provided in *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Guidance on Implementation in Section 8*).

7 CONCLUSIONS

The principles of the Waste Management Series (DWAF, 2006; updated during the development of Volume 3 of the Sludge Guidelines) comprising of the *Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste, Minimum Requirements for Waste Disposal by Landfill* and *Minimum Requirements for the Monitoring of Water Quality at Waste Management Facilities* have been adopted for sludge disposal on land in the development of Volume 3 of the South African Sludge Guidelines. Since sludge is an industry specific waste, not all the requirements in the above mentioned documents are applicable to land disposal of sludge. Therefore, only the requirements relevant to sludge disposal were included in this document.

Disposal of sludge to the marine environment is still debated nationally and internationally and the principles of the *Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa (DWAF, 2004)* have been adopted in Volume 3 for sludge disposal to the marine environment.

Volume 3 of the Sludge Guidelines informs the reader on the legal requirements for sludge disposal on land (both on-site and off-site), co-disposal on landfill and disposal to the marine environment. This document informs the reader on the scientific and technical foundations that Volume 3 was built upon. It also states clearly that beneficial use of sludge is encouraged and that sludge disposal would be considered as a last resort. Therefore, sludge producers would need to provide proof of the beneficial use options considered, feasibility studies to implement these options and efforts to improve the sludge quality should that be the limiting factor for beneficial use.

Should disposal be the only alternative management option for sludge, it becomes a ‘waste’ by definition and 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 disposal sites, where the necessary criteria for disposal sites are not met, the management and monitoring requirements increase substantially. The development of closure and remediation plans is introduced to ensure sustained acceptability.

References

Adriano, D.C. 2001. Trace elements in terrestrial environments: Biochemistry, bioavailability and risks of metals (2nd edn.) Springer-Verlag, New York.

Barlaz, M.A., Milke, M.W. and Ham, R.K. 1987. Gas production parameters in sanitary landfill simulators, *Waste Management and Research*, 5, 27-39.

Barlaz, M.A., Ham, R.K. and Schaefer, D.M. 1990. Methane production from municipal refuse: a review of enhancement techniques and microbial dynamics, *Critical reviews in environmental control*, 19, 6, 557-584.

Blakey, N.C. 1991. Enhanced landfill stabilization using sewage sludge, *Proc: Third International Landfill Symposium*, Sardinia, October 1991, 2, 1367-1380.

CEC (Commission of the European Communities). 1986. Council Directive (86/278/EEC) on the protection of the environment and in particular of the soil, when sewage sludge is used in agricultur. *Official Journal of the European Communities* 181, 6-12.

Dollar, L.H. 2005. Co-disposal of sewage sludge with refuse on sanitary landfills: Technical support document to Volume 3 of the South African Sludge Disposal Guidelines, WRC contract K5/1622.

Dollar, L.H. 2005. Moisture retention of municipal solid waste mixed with sewage sludge and ash in a semi-arid climate, *Waste Management and Research*, 23, 209-219.

DWAF, 1998. South African Water Quality Guidelines.

DWAF, 2000. Policy and strategy for groundwater quality management in South Africa.

DWAF, 2004. Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa. Sub-Series MS13.2.

DWAF, 2004. Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Guidance on Implementation. Sub-Series MS13.3.

DWAF, 2004. Operational policy for the disposal of land-derived water containing waste to the marine environment of South Africa: Appendices. Sub-Series MS13.4.

EPA (Environmental Protection Authority). 1996. Environmental Guidelines: Solid Waste Landfills. Environmental Protection Authority, Chatswood

EPA (Environmental Protection Authority). 1997. Sludge Management Guidelines South Australia. Department of Environment and Natural Resources. ARMCANZ/ANZECC/NHMRC

EPA (Environmental Protection Authority). 2002. Western Australian guidelines for direct land application of biosolids and biosolids products. Department of Environmental Protection, Water and Rivers Commission and Department of Health.

European Commission. 2001. Disposal and recycling routes for sewage sludge: Executive summary and main conclusions. http://europa.eu.int/comm/environment/waste/sludge/sludge_disposal2_xsum.pdf

European Commission. 2001. Disposal and recycling routes for sewage sludge: Part 2 – Regulatory report. http://europa.eu.int/comm/environment/waste/sludge/sludge_disposal2a.pdf.

European Commission. 2001. Disposal and recycling routes for sewage sludge: Part 3 – Scientific and technical report. (http://europa.eu.int/comm/environment/waste/sludge/sludge_disposal3.pdf)

European Commission. 2001. Disposal and recycling routes for sewage sludge: Chapter 5: Synthesis of the Stakeholders positions, motivations and constraints. (http://europa.eu.int/comm/environment/waste/sludge/sludge_disposal1a.pdf).

European Commission. 2002. Disposal and recycling routes for sewage sludge: Synthesis Report. (http://europa.eu.int/comm/environment/waste/sludge/synthesisreport020222.pdf)

European Commission. 2004. Urban wastewater treatment. (http://europa.eu.int/comm/environment/water/water-urbanwaste/index_en.html).

European Commission. 2005. Summaries of Legislation: Waste incineration. (http://europa.eu.int/scadplus/leg/en/lvb/l28072.htm)

European Union, 2001. Heavy metals and organic compounds from wastes used as organic fertilizers *ENV.A.2./ETU/2001/0024*

Federal Office for the Environment. 2004. Waste Management: Other facilities and methods: Cement works. (http://www.umwelt-schweiz.ch/buwal/eng/fachgebiete/fg_abfall/anlagen/andere/zw/index.html).

Herselman, J.E., Wade, P.W., Steyn, C.E. & Snyman, H.G. 2005. An evaluation of dedicated land disposal practices for sewage sludge. WRC Report No. 1209/1/05.

Hillel, D. 1982. Introduction to soil physics. New York: Academic Press

Kabata-Pendias, A. & Pendias, H. 2001. Trace elements in soils and plants. 3rd edn. CRC Press, London.

Lue-Hing, C., Zenz, D.R. & Kuchenrither, R. 1992. Municipal sewage sludge management: Processing, utilization and disposal. Technomic Publishing, Lancaster.

Metcalf & Eddy Inc. 1991. Wastewater Engineering, Treatment, Disposal, Reuse, 3 rd edition, New York, Mc Graw Hill International Editions, Civil Engineering Series.

Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste. Waste Management Series. Latest Edition.

Minimum Requirements for Waste Disposal by Landfill. Waste Management Series. Latest Edition.

Minimum Requirements for the Monitoring of Water Quality at Waste Management Facilities. Waste Management Series. Latest Edition.

Murray, K., du Preez, M., Taylor, M.B., Meyer, R., Parsons, R., van Wyk, E., Kuhn, A., van Niekerk, H. and Ehlers, M.M. 2004. National microbial monitoring programme for groundwater. WRC Report no. 1277/1/04.

Novella, P.H. 1992. The codisposal of sewage sludge with refuse, *Proc: Third Southern Africa Anaerobic Digestion Symposium*, Pietermaritzburg.

NSW EPA. 1997. Environmental Guidelines: Use and disposal of biosolids products. New South Wales Environmental Protection Authority, Sydney.

NZDoH. 1992. Public health guidelines for the safe use of sewage effluent and sewage sludge on land. New Zealand Department of Health, Wellington.

NZWWA. 1999. New Zealand guidelines for the beneficial use of biosolids. Draft No 2. New Zealand Water and Waste Association, Woodward-Clyde (NZ) Ltd., Auckland.

Rőhrs, L.H., Fourie, A.B. & Blight, G.E. 1998. Effects of sewage sludge and refuse composition on the rate of degradation and leachate quality of co-disposed waste in a water deficient environment. Water SA Vol 24 (2), 137-146.

SA EPA. 1996. South Australian biosolids guidelines for the safe handling, reuse or disposal of biosolids. Department of Environment and Natural Resources, South Australian Environment Protection Authority, Adelaide.

Snyman, H.G., Herselman, J.E. and Kasselman, G. 2004. A metal content survey of South African sewage sludge and an evaluation of analytical methods for their determination in sludge. WRC Report 1283/1//04.

Stegmann, R. and Spendlin, H.H. 1987. Enhancement of Biochemical processes in sanitary landfills, *Proc: International Sanitary Landfill Symposium*, Sardinia, October 1987, II 28pp.

USEPA, 1994. A plain English Guide to the EPA Part 503 sludge rule. EPA/832/R-93/003. Washington, DC.

USEPA. 1996. Land application of biosolids – Process design manual. Technomic Publishing, Lancaster.

USEPA. 1999. *"Biosolids Generation,Use, and Disposal in the United States",* (USEPA 530-R-99-009)

USEPA, 2005: Ocean Dumping. (http://www.epa.gov/owow/oceans/regulatory/dumpdredged/oceandumping.html).

USEPA, 1998. Estimation of Infiltration Rate in the Vadose Zone: Compilation of Simple Mathematical Models Volume I. EPA/600/R-97/128a

Appendix 1: Risk assessments

On-site mono disposal (mono-fill, waste piles, lagoons)		
	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	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	3	9	Pathogens will cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at mono disposal sites
		Stability	2	3	6	Vectors and odours may cause self treatable conditions	Access restrictions for general public at mono disposal 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 mono disposal 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 mono disposal sites
		Stability	2	3	6	Vectors may cause self treatable conditions	Access restrictions for general public at mono disposal 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 mono disposal 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 mono disposal sites
		Other			0		
	2.3	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for general public at mono disposal sites, buffer zones between mono disposal sites and dwellings
		Stability	3	3	9	Odours may influence general public	Access restrictions for general public at mono disposal sites, buffer zones between mono disposal 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 mono disposal sites, buffer zones between mono disposal sites and dwellings
		Other			0		
	2.4	Microbiological	1	1	1	Inhalation of incinerator emissions not applicable to mono disposal 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 the	Access restrictions to general public
		Stability	1	1	1		

		Metal	1	1	1	mono disposals and that no plants grow on mono disposals	
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	2.6	Microbiological	1	1	1	Not applicable to mono disposals. It is assumed that no animals are allowed onto mono disposals	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	3	4	12	Drinking surface water contaminated with pathogens may cause recoverable conditions, probability is possible (1:1 000)	Buffer zones between mono disposals and surface water bodies
		Stability	2	2	4	Drinking surface water impacted by vectors may cause self treatable conditions, probability is rare (1:100 000)	Buffer zones between mono disposals and surface water bodies
		Metal	1	3	3	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 mono disposals and surface water bodies
		Nutrient	1	3	3	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 mono disposals and surface water bodies
		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	Buffer zones between mono disposals and surface water bodies
		Other			0		
	2.8	Microbiological	1	1	1	Pathway to long, no impact	Buffer zones between mono disposals and surface water bodies would protect the water
		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 stockpiles 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 stockpiles 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 stockpiles and the sea
		Other			0		
	2.10	Microbiological	2	3	6	Impact on general public bathing in surface water impacted by mono disposals is low, the probability is also low 1: 10 000	Buffer zones between mono disposals and surface water bodies
		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	2	2	4	Impact on general public bathing in surface water impacted by mono disposals is low, the probability is rare 1: 100 000	Buffer zones between mono disposals and surface water bodies
		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 mono disposals and groundwater (depth to aquifer)
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	Buffer zones between mono disposals and groundwater (depth to aquifer)
		Nutrient	2	4	8	Leaching of nitrate to groundwater at mono disposal sites 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 mono disposals 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 mono disposals 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 mono disposals 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	Buffer zones between mono disposals and groundwater (depth to aquifer)
		Nutrient	1	1	1	Leaching of nitrate to groundwater at mono disposal sites is probable (1:1 000; dewatered sludge) but the consequence to humans bathing in groundwater is low.	Buffer zones between mono disposals and groundwater (depth to aquifer)

		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	Buffer zones between mono disposals and groundwater (depth to aquifer)
		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 mono disposal sites
		Stability	2	3	6	Vectors may cause self treatable conditions	Access restrictions for general public at mono disposal 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 mono disposal 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 mono disposal sites
		Other			0		
	2.14	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for general public at mono disposal sites, buffer zones between mono disposal sites and dwellings
		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	Access restrictions for general public at mono disposal sites, buffer zones between mono disposal sites and dwellings
		Other			0		
	2.15	Microbiological	1	1	1	Assume no animals are allowed on mono disposals	Access restriction for grazing animals
		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	1	1	1	Mono disposal has no impact on soil physical structure since it is not incorporated into the soil	
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	3.2	Microbiological	1	1	1	NA	NA
		Stability	1	1	1	NA	NA
		Metal	3	6	18	Intervention needed to rehabilitate soil for use after mono disposal ito metal content	mono disposal sites could not be considered for public use after mono disposal
		Nutrient	1	6	6	Increase in soil fertility due to sludge application	None required
		Organic pollutants	3	6	18	Intervention needed to rehabilitate soil for use after mono disposal ito organic pollutants	mono disposal sites could not be considered for public use after mono disposal
		Other			0		
	3.3	Microbiological	1	1	1	Minimal threat of pathogenic effects in marine organisms	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 mono disposals and surface water
		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 mono disposals and surface water
		Nutrient	3	3	9	Impact of nutrients on sediments may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between mono disposals and surface water
		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	3	3	9	Impact of pathogens on wetlands may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between mono disposals and wetlands
		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 mono disposals and wetlands
		Nutrient	3	3	9	Impact of metals on wetlands may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between mono disposals and wetlands
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
Crops	4.1	Microbiological	1	1	1	Assumed that crop cultivation on mono disposals is not allowed	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	4.2	Microbiological	1	1	1		
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	4.3	Microbiological	1	1	1		
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
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	mono disposal 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 mono disposals 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 mono disposals 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	3	3	9	Volatile pollutants confined to working area, 1:10 000	Supply workers with PPE
		Stability	4	5	20	Odour nuisance to surrounding community	Vector attraction reduction options, Buffer zone between mono disposals and dwellings
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	3	9	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 mono disposal 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 mono disposals and surface water bodies
		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 mono disposals and surface water bodies
		Nutrient	3	3	9	Recoverable impact due to nutrients via soil, low probability	Buffer zone between mono disposals and surface water bodies
		Organic pollutants	3	3	9	Recoverable impact due to organic pollutants via soil, low probability	Buffer zone between mono disposals and surface water bodies
		Other			0		
	7.2	Microbiological	4	3	12	Long-term impairment of fitness of use due to pathogens, low probability	Buffer zone between mono disposals and surface water bodies
		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 mono disposals and surface water bodies
		Nutrient	4	3	12	Long-term impairment of fitness of use due to nutrients, low probability	Buffer zone between mono disposals and surface water bodies
		Organic pollutants	4	3	12	Long-term impairment of fitness of use due to organic pollutants, low probability	Buffer zone between mono disposals and surface water bodies
		Other			0		
	7.3	Microbiological	3	2	6	Recoverable impact due to airborne pathogens, rare probability	Buffer zone between mono disposals 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 mono disposals 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 mono disposals and surface water bodies
		Organic pollutants	3	2	6	Recoverable impact due to organic pollutants, rare probability	Buffer zone between mono disposals and surface water bodies
		Other			0		
	7.4	Microbiological	3	1	3	Recoverable impact due to airborne pathogens via soil, highly unlikely probability	Buffer zone between mono disposals and surface water bodies
		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	Buffer zone between mono disposals and surface water bodies
		Nutrient	2	1	2	Temporary impact on fitness for use of surface water due to airborne nutrients, highly unlikely probability	Buffer zone between mono disposals and surface water bodies
		Organic pollutants	3	1	3	Recoverable impact due to organic pollutants via soil, Highly unlikely probability	Buffer zone between mono disposals and surface water bodies
		Other			0		
	7.5	Microbiological			0		
		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 mono disposals 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 mono disposals and groundwater (depth to aquifer) will protect surface water as well
		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		
		Stability	4	2	8	Low pH mobilize metals, may cause long-term impairment of fitness for use, rare probability	Buffer zone between mono disposals 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 mono disposals 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 mono disposals and groundwater (depth to aquifer)
		Organic pollutants			0		
		Other			0		
	8.2	Microbiological			0		
		Stability	1	1	1	NA	NA
		Metal	4	3	12	Metals may cause long-term impairment of fitness for use, low likelihood of direct groundwater contamination	Buffer zone between mono disposals 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 mono disposals and groundwater (depth to aquifer)
		Organic pollutants			0		
		Other			0		
	8.3	Microbiological			0		
		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	Buffer zone between mono disposals 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 mono disposals and groundwater (depth to aquifer)
		Organic pollutants			0		
		Other			0		

	8.4	Microbiological	4	2	8	Long-term impairment of fitness of use due to pathogens, rare probability	Buffer zone between mono disposals and surface water bodies will also protect groundwater
		Stability	1	1	1	NA	
		Metal	3	2	6	Recoverable impact on fitness for use of surface water due to metals, rare probability	Buffer zone between mono disposals and surface water bodies will also protect groundwater
		Nutrient	4	2	8	Long-term impairment of fitness of use due to nutrients, rare probability	Buffer zone between mono disposals and surface water bodies will also protect groundwater
		Organic pollutants	4	2	8	Long-term impairment of fitness of use due to organic pollutants, rare probability	Buffer zone between mono disposals and surface water bodies will also protect groundwater
		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	NA	
		Metal	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
		Nutrient	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
		Organic pollutants	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
		Other			0	NA	
	9.2	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	NA	
		Metal	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
		Nutrient	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

		Organic pollutants	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
		Other			0	NA	
	9.3	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	NA	
		Metal	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
		Nutrient	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
		Organic pollutants	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
		Other			0	NA	
	9.4	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	NA	
		Metal	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
		Nutrient	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
		Organic pollutants	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
		Other			0	NA	

	9.5	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	NA	
		Metal	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
		Nutrient	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
		Organic pollutants	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
		Other			0	NA	
Grazing animals	10.1	Microbiological			0	Assume no grazing animals allowed on mono disposals	
		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 mono disposals, multiple barrier pathway	None required
		Nutrient	1	4	4	Low impact, very little vegetation on mono disposals, multiple barrier pathway	None required
		Organic pollutants	1	5	5	Low impact, multiple barrier pathway	None required
		Other			0		
	11.2	Microbiological	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Stability	1	1	1	NA	NA
		Metal	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Nutrient	1	4	4	No negative impact	None required
		Organic pollutants	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Other			0		
	11.3	Microbiological	2	2	4	Intervention may be required due to pathogens, low probability due to multiple barrier pathway	Buffer zone between mono disposals and surface water bodies will protect fauna
		Stability	1	1	1	NA	
		Metal	2	2	4	Intervention may be required due to metals, low probability due to multiple barrier pathway	Buffer zone between mono disposals and surface water bodies will protect fauna
		Nutrient	1	3	3	No impact due to nutrients, low probability due to multiple barrier pathway	Buffer zone between mono disposals and surface water bodies will protect fauna

		Organic pollutants	2	2	4	Intervention may be required due to organic pollutants, low probability due to multiple barrier pathway	Buffer zone between mono disposals and surface water bodies will protect fauna
		Other			0		
	11.4	Microbiological	2	2	4	Intervention may be required due to pathogens, low probability due to multiple barrier pathway	Buffer zone between mono disposals and groundwater will protect fauna
		Stability	1	1	1	NA	
		Metal	2	2	4	Intervention may be required due to metals, low probability due to multiple barrier pathway	Buffer zone between mono disposals and groundwater will protect fauna
		Nutrient	1	4	4	No impact due to nutrients, probable due to mobility of nutrients	Buffer zone between mono disposals and groundwater will protect fauna
		Organic pollutants	2	2	4	Intervention may be required due to organic pollutants, low probability due to multiple barrier pathway	Buffer zone between mono disposals and groundwater will protect fauna
		Other			0		
	11.5	Microbiological	2	2	4	Inhalation of airborne pathogens may need intervention to maintain biodiversity	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	None required
		Other			0		
	11.6	Microbiological	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Stability	1	1	1	NA	NA
		Metal	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Nutrient	1	4	4	No negative impact	None required
		Organic pollutants	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Other			0		
	11.7	Microbiological			0		
		Stability	1	1	1	NA	NA
		Metal	3	2	6	Biodiversity will recover after closure, metal contamination rare	Buffer Zones between mono disposals and surface water
		Nutrient	3	2	6	Biodiversity will recover after closure, metal contamination rare	Buffer Zones between mono disposals and surface water
		Organic pollutants			0		
		Other			0		

On-site sludge disposal: **Lagoons**	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: Conse-quence	Risk to receptor: Proba-bility	Risk to receptor: Risk rating	Notes	Mitigating factors
Workers	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	3	9	Pathogens will cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at lagoons
		Stability	2	3	6	Vectors and odours may cause self treatable conditions	Access restrictions for general public at lagoons
		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 it could occur (1:10 000)	Access restrictions for general public at lagoons
		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 lagoons
		Stability	2	3	6	Vectors may cause self treatable conditions	Access restrictions for general public at lagoons
		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 lagoons
		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 lagoons
		Other			0		
	2.3	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for general public at lagoons, buffer zones between lagoons and dwellings
		Stability	3	5	15	Odours may influence general public	Access restrictions for general public at lagoons, buffer zones between lagoons and dwellings
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for general public at lagoons, buffer zones between lagoons and dwellings
		Other			0		
	2.4	Microbiological	1	1	1	Inhalation of incinerator emissions not applicable to lagoons	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 near lagoons and that no plants grow on lagoons	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 lagoons. It is	None required

		Stability	1	1	1	assumed that no animals are allowed near lagoons	
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	2.7	Microbiological	3	3	9	Drinking surface water contaminated with pathogens may cause recoverable conditions, probability low (1:10 000) since lagoons are in trenches and run-off to surface water is limited	Buffer zones between lagoons and surface water bodies
		Stability	2	2	4	Drinking surface water impacted by vectors may cause self treatable conditions, probability is rare (1:100 000)	Buffer zones between lagoons and surface water bodies
		Metal	1	3	3	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. Since lagoons are in trenches, run-off to surface water is limited	Buffer zones between lagoons and surface water bodies
		Nutrient	1	3	3	The impact of nutrients on human health via drinking of impacted surface water is assumed to be very low. Since lagoons are in trenches, run-off to surface water is limited	Buffer zones between lagoons and surface water bodies
		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. Probability is low since lagoons are in trenches and run-off to surface water is limited	Buffer zones between lagoons and surface water bodies
		Other			0		
	2.8	Microbiological	1	1	1	Pathway to long, no impact	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	Maintain buffer zones between lagoons 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 lagoons 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 lagoons and the sea
		Other			0		
	2.10	Microbiological	2	3	6	Impact on general public bathing in surface water impacted by stockpiles is low, the probability is also low 1: 10 000	Buffer zones between lagoons and surface water bodies
		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	2	2	4	Impact on general public bathing in surface water impacted by stockpiles is low, the probability is rare 1: 100 000	Buffer zones between lagoons and surface water bodies
		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 lagoons and groundwater (depth to aquifer)
		Stability	1	1	1	NA	NA
		Metal	3	4	12	Although the mobility of metals in soil is very low, the sludge is in a liquid form and may leach in an acid environment	Buffer zones between lagoons and groundwater (depth to aquifer)
		Nutrient	2	5	10	Leaching of nitrate to groundwater at stockpiled sites is probable (1:100; liquid 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 lagoons 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 lagoons 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 lagoons and groundwater (depth to aquifer)
		Stability	1	1	1	NA	NA
		Metal	1	4	4	Mobility of metals in soil very low, bathing in groundwater will have no impact	Buffer zones between lagoons and groundwater (depth to aquifer)

		Nutrient	1	5	5	Leaching of nitrate to groundwater at stockpiled sites is probable (1:1 000; dewatered sludge) but the consequence to humans bathing in groundwater is low.	Buffer zones between lagoons and groundwater (depth to aquifer)
		Organic pollutants	1	2	2	Organic pollutants are insoluble and has low mobility in soil profile (1:100 000) and the impact to humans bathing in groundwater is low	Buffer zones between lagoons and groundwater (depth to aquifer)
		Other			0		
	2.13	Microbiological	3	2	6	Ingestion of pathogens may cause recoverable conditions but is rare (1:100 000)	Access restrictions for general public at lagoons
		Stability	2	2	4	Vectors may cause self treatable conditions	Access restrictions for general public at lagoons
		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 lagoons
		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 and could occur (1:10 000)	Access restrictions for general public at lagoons
		Other			0		
	2.14	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for general public at lagoons, buffer zones between lagoons and dwellings
		Stability	1	1	1	NA	NA
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	3	3	9	Inhalation of airborne organic pollutants may cause recoverable conditions	Access restrictions for general public at lagoons, buffer zones between lagoons and dwellings
		Other			0		
	2.15	Microbiological	1	1	1	Assume no animals are allowed near lagoons	Access restriction for grazing animals
		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, buffer zones between lagoons and dwellings
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction measures, buffer zones between lagoons and dwellings
		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	Lagoons has no impact on soil physical structure since it is not incorporated into the soil	
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	3.2	Microbiological	1	1	1	NA	NA
		Stability	1	1	1	NA	NA
		Metal	3	6	18	Intervention needed to rehabilitate soil for use after lagooning ito metal content	Sites could not be considered for public use after lagooning
		Nutrient	1	6	6	Increase in soil fertility due to sludge application	None required
		Organic pollutants	3	6	18	Intervention needed to rehabilitate soil for use after lagooning ito organic pollutants	Sites could not be considered for public use after lagooning
		Other			0		
	3.3	Microbiological	1	1	1	Minimal threat of pathogenic effects in marine organisms	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 lagoons and surface water
		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 lagoons and surface water
		Nutrient	3	3	9	Impact of nutrients on sediments may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between lagoons and surface water
		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	3	3	9	Impact of pathogens on wetlands may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between lagoons and wetlands
		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 lagoons and wetlands
		Nutrient	3	3	9	Impact of metals on wetlands may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between lagoons and wetlands
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
Crops	4.1	Microbiological	1	1	1	Assumed that crop cultivation on lagoons is not allowed	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	4.2	Microbiological	1	1	1		
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
	4.3	Microbiological	1	1	1		
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	1	1		
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	Lagoon 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 lagoons 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 lagoons 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	3	3	9	Volatile pollutants confined to working area, 1:10 000	Supply workers with PPE
		Stability	4	5	20	Odour nuisance to surrounding community	Vector attraction reduction options, Buffer zone between lagoons and dwellings
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	3	9	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 lagoons	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	1	3	Recoverable impact due to pathogens via soil, highly unlikely since lagoons are in trenches, limiting run-off to surface water	None required
		Stability	1	1	1	NA	NA
		Metal	2	1	2	Temporary impact on fitness for use of surface water due to metals via soil, low probability since lagoons are in trenches, limiting run-off to surface water	None required
		Nutrient	3	1	3	Recoverable impact due to nutrients via soil, highly unlikely since lagoons are in trenches, limiting run-off to surface water	None required

		Organic pollutants	3	1	3	Recoverable impact due to organic pollutants via soil, highly unlikely since lagoons are in trenches, limiting run-off to surface water	None required
		Other			0		
	7.2	Microbiological	4	1	4	Long-term impairment of fitness of use due to pathogens, highly unlikely since lagoons are in trenches, limiting run-off to surface water	None required
		Stability	1	1	1	NA	NA
		Metal	3	1	3	Recoverable impact on fitness for use of surface water due to metals, highly unlikely since lagoons are in trenches, limiting run-off to surface water	None required
		Nutrient	4	1	4	Long-term impairment of fitness of use due to nutrients, highly unlikely since lagoons are in trenches, limiting run-off to surface water	None required
		Organic pollutants	4	1	4	Long-term impairment of fitness of use due to organic pollutants, highly unlikely since lagoons are in trenches, limiting run-off to surface water	None required
		Other			0		
	7.3	Microbiological	3	2	6	Recoverable impact due to airborne pathogens, rare probability	Buffer zone between lagoons 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 lagoons 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 lagoons and surface water bodies
		Organic pollutants	3	2	6	Recoverable impact due to organic pollutants, rare probability	Buffer zone between lagoons and surface water bodies
		Other			0		
	7.4	Microbiological	3	1	3	Recoverable impact due to airborne pathogens via soil, highly unlikely probability, multiple barrier pathway	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, multiple barrier pathway	None required

		Nutrient	2	1	2	Temporary impact on fitness for use of surface water due to airborne nutrients, highly unlikely probability, multiple barrier pathway	None required
		Organic pollutants	3	1	3	Recoverable impact due to organic pollutants via soil, Highly unlikely probability, multiple barrier pathway	None required
		Other			0		
	7.5	Microbiological			0		
		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 to groundwater, it is a rare probability that surface water will be impacted, multiple barrier pathway	Buffer zone between lagoons 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, and due to the mobility of especially N, it could happen regularly that groundwater would be impacted but, due to the multiple barrier pathway the probability for surface to be impacted is low	Buffer zone between lagoons and groundwater (depth to aquifer) will protect surface water as well
		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		
		Stability	4	3	12	Low pH mobilize metals, may cause long-term impairment of fitness for use, low likelihood	Buffer zone between lagoons and groundwater (depth to aquifer)
		Metal	4	4	16	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a rare probability	Buffer zone between lagoons 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 lagoons and groundwater (depth to aquifer)
		Organic pollutants			0		
		Other			0		
	8.2	Microbiological			0		
		Stability	1	1	1	NA	NA
		Metal	4	3	12	Metals may cause long-term impairment of fitness for use, low likelihood of direct groundwater contamination	Buffer zone between lagoons 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 lagoons and groundwater (depth to aquifer)
		Organic pollutants			0		
		Other			0		
	8.3	Microbiological			0		
		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	Buffer zone between lagoons 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 lagoons and groundwater (depth to aquifer)
		Organic pollutants			0		
		Other			0		
	8.4	Microbiological	4	1	4	Long-term impairment of fitness of use due to pathogens, highly unlikely since lagoons are in trenches, limiting run-off to surface water and subsequently to groundwater	Buffer zone between lagoons and surface water bodies will also protect groundwater
		Stability	1	1	1	NA	
		Metal	3	1	3	Recoverable impact on fitness for use of surface water due to metals, highly unlikely since lagoons are in trenches, limiting run-off to surface water and subsequently to groundwater	Buffer zone between lagoons and surface water bodies will also protect groundwater
		Nutrient	4	1	4	Long-term impairment of fitness of use due to nutrients, highly unlikely since lagoons are in trenches, limiting run-off to surface water and subsequently to groundwater	Buffer zone between lagoons and surface water bodies will also protect groundwater

		Organic pollutants	4	1	4	Long-term impairment of fitness of use due to organic pollutants, highly unlikely since lagoons are in trenches, limiting run-off to surface water and subsequently to groundwater	Buffer zone between lagoons and surface water bodies will also protect groundwater
		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 at lagoons	
		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	4	4	Low impact, multiple barrier pathway	None required
		Stability	1	1	1	NA	NA
		Metal	1	3	3	Low impact, very little vegetation on lagoons, multiple barrier pathway	None required
		Nutrient	1	3	3	Low impact, very little vegetation on lagoons, multiple barrier pathway	None required
		Organic pollutants	1	4	4	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	2	2	4	Intervention may be required due to pathogens, low probability due to multiple barrier pathway	Buffer zone between lagoons and surface water bodies will protect fauna
		Stability	1	1	1	NA	
		Metal	2	2	4	Intervention may be required due to metals, low probability due to multiple barrier pathway	Buffer zone between lagoons and surface water bodies will protect fauna
		Nutrient	1	2	2	No impact due to nutrients, low probability due to multiple barrier pathway	Buffer zone between lagoons and surface water bodies will protect fauna
		Organic pollutants	2	2	4	Intervention may be required due to organic pollutants, low probability due to multiple barrier pathway	Buffer zone between lagoons and surface water bodies will protect fauna
		Other			0		
	11.4	Microbiological	2	2	4	Intervention may be required due to pathogens, low probability due to multiple barrier pathway	Buffer zone between lagoons and groundwater will protect fauna
		Stability	1	1	1	NA	
		Metal	2	3	6	Intervention may be required due to metals, low probability due to multiple barrier pathway	Buffer zone between lagoons and groundwater will protect fauna
		Nutrient	1	4	4	No impact due to nutrients, probable due to mobility of nutrients	Buffer zone between lagoons and groundwater will protect fauna
		Organic pollutants	2	2	4	Intervention may be required due to organic pollutants, low probability due to multiple barrier pathway	Buffer zone between lagoons and groundwater will protect fauna
		Other			0		
	11.5	Microbiological	2	2	4	Inhalation of airborne pathogens may need intervention to maintain biodiversity in 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	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Stability	1	1	1	NA	NA
		Metal	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Nutrient	1	4	4	No negative impact	None required
		Organic pollutants	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Other			0		
	11.7	Microbiological			0		
		Stability	1	1	1	NA	NA
		Metal	3	2	6	Biodiversity will recover after closure, metal contamination rare	Buffer Zones between lagoons and surface water
		Nutrient	3	2	6	Biodiversity will recover after closure, metal contamination rare	Buffer Zones between lagoons and surface water
		Organic pollutants			0		
		Other			0		

Dedicated land disposal (liquid and dewatered application)	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: Conse-quence	Proba-bility	Risk rating	Notes	Mitigating factors
Workers	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	3	9	Pathogens will cause recoverable conditions and thus could occur (1:10 000)	Access restrictions for general public at DLD sites
		Stability	2	3	6	Vectors and odours may cause self treatable conditions	Access restrictions for general public at DLD 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 DLD 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 DLD sites
		Stability	2	3	6	Vectors may cause self treatable conditions	Access restrictions for general public at DLD 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 DLD 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 DLD sites
		Other			0		
	2.3	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for general public at DLD sites, buffer zones between DLD sites and dwellings
		Stability	3	3	9	Odours may influence general public	Access restrictions for general public at DLD sites, buffer zones between DLD 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 DLD sites, buffer zones between DLD sites and dwellings
		Other			0		
	2.4	Microbiological	1	1	1	Inhalation of incinerator emissions not applicable to DLD sites	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	2.5	Microbiological	3	4	12	Ingestion of pathogens via plants grown on DLD sites may cause recoverable conditions and is possible (1:1 000)	Access restrictions for general public at DLD sites, crop restrictions at DLD sites
		Stability	1	1	1	NA	NA

		Metal	3	4	12	Ingestion of crops/plants with high metal concentrations may cause recoverable conditions and it is possible (1:1 000)	Access restrictions for general public at DLD sites, crop restrictions at DLD sites
		Nutrient	1	3	3	Nutrients have no negative impact although the probability is high	None required
		Organic pollutants	3	4	12	Organic pollutants may cause recoverable conditions and it is possible (1:1 000)	Access restrictions for general public at DLD sites, crop restrictions at DLD sites
		Other			0		
	2.6	Microbiological	1	1	1	No impact, Pathway too long	None required
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other			0		
	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 DLD sites and surface water bodies
		Stability	2	2	4	Drinking surface water impacted by vectors may cause self treatable conditions, probability is rare (1:100 000)	None required
		Metal	1	3	3	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 DLD sites and surface water bodies
		Nutrient	1	3	3	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 DLD sites and surface water bodies
		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	Buffer zones between DLD sites and surface water bodies
		Other			0		
	2.8	Microbiological			0	Pathway to long, no impact	Buffer zones between DLD sites and surface water bodies would protect the water & fish
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		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 DLDs 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 DLDs 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 DLDs and the sea
		Other			0	NA	
	2.10	Microbiological	2	3	6	Impact on general public bathing in surface water impacted by DLD is low, the probability is also low 1: 10 000	Buffer zones between DLD sites and surface water bodies
		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	2	2	4	Impact on general public bathing in surface water impacted by DLD sites is low, the probability is rare 1: 100 000	Buffer zones between DLD sites and surface water bodies
		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 DLD sites and groundwater (depth to aquifer)
		Stability	1	1	1	NA	NA
		Metal	1	1	1	Mobility of metals in soil very low	Buffer zones between DLD sites and groundwater (depth to aquifer)
		Nutrient	4	4	16	Leaching of nitrate to groundwater at DLD sites is high (1:100) especially in the case of liquid sludge application, and the consequence to humans consuming groundwater may result in negative health effects resulting in hospitalization. NO3 in groundwater can be as high as 900 mg/l at sites that receive liquid sludge	Buffer zones between DLD 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 DLD 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 DLD 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	Buffer zones between DLD sites and groundwater (depth to aquifer)
		Nutrient	1	1	1	Leaching of nitrate to groundwater at DLD sites is probable (1:1 000; dewatered sludge) but the consequence to humans bathing in groundwater is low.	Buffer zones between DLD sites and groundwater (depth to aquifer)
		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	Buffer zones between DLD sites and groundwater (depth to aquifer)
		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 DLD sites
		Stability	2	3	6	Vectors may cause self treatable conditions	Access restrictions for general public at DLD 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 DLD 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 DLD sites
		Other			0		
	2.14	Microbiological	3	3	9	Inhalation of airborne pathogens may cause recoverable conditions	Access restrictions for general public at DLD sites, buffer zones between DLD sites and dwellings
		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	Access restrictions for general public at DLD sites, buffer zones between DLD sites and dwellings
		Other			0		
	2.15	Microbiological	2	4	8	May cause self-treatable conditions in the general public that eat the animals, it may possibly happen	Grazing restrictions at DLD sites
		Stability	1	4	4	NA	NA
		Metal	3	4	12	Metals may accumulate in animals that eat sludge and may cause recoverable conditions in the general public that eat the animals, it may possibly happen	Grazing restrictions at DLD sites
		Nutrient	1	4	4	NA	NA

		Organic pollutants	2	4	8	May cause self-treatable conditions in the general public that eat the animals, it may possibly happen	Grazing restrictions at DLD sites
		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 options
		Stability	3	4	12	Vectors will occur if stability is not achieved, may cause recoverable conditions	Apply vector attraction reduction options
		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	
		Stability	1	1	1		
		Metal	1	1	1		
		Nutrient	1	1	1		
		Organic pollutants	1	1	1		
		Other	1	6	6	Organic material have positive impact on soil physical structure	None required
	3.2	Microbiological	1	1	1	NA	NA
		Stability	1	1	1	NA	NA
		Metal	3	6	18	Intervention needed to rehabilitate soil for use after DLD practices ito metal content	DLD sites could not be considered for commercial use
		Nutrient	1	6	6	Increase in soil fertility due to sludge application	None required
		Organic pollutants	3	6	18	Intervention needed to rehabilitate soil for use after DLD ito organic pollutants	DLD sites could not be considered for commercial use
		Other			0		
	3.3	Microbiological	1	1	1	Minimal threat of pathogenic effects in marine organisms	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	NA	NA
	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 DLD sites and surface water
		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 DLD sites and surface water
		Nutrient	3	3	9	Impact of nutrients on sediments may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between DLD sites and surface water
		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	3	3	9	Impact of pathogens on wetlands may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between DLD sites and wetlands
		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 DLD sites and wetlands
		Nutrient	3	3	9	Impact of metals on wetlands may need intervention to rehabilitate, probability is low (1: 10 000)	Buffer zones between DLD sites and wetlands
		Organic pollutants	1	1	1	NA (low solubility)	
		Other			0		
Crops	4.1	Microbiological			0	Assumed that crop cultivation on DLD sites is not allowed	None required
		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		

Vegetation		Other			0		
	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	DLD 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 DLD 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 DLD 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	3	3	9	Volatile pollutants confined to working area, 1:10 000	Supply workers with PPE
		Stability	4	5	20	Odour nuisance to surrounding community	Vector attraction reduction options, Buffer zone between DLD sites and dwellings
		Metal	1	1	1	NA	
		Nutrient	1	1	1	NA	
		Organic pollutants	3	3	9	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 DLD 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 DLD sites and surface water bodies
		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 DLD sites and surface water bodies
		Nutrient	3	3	9	Recoverable impact due to nutrients via soil, low probability	Buffer zone between DLD sites and surface water bodies
		Organic pollutants	3	3	9	Recoverable impact due to organic pollutants via soil, low probability	Buffer zone between DLD sites and surface water bodies
		Other			0		
	7.2	Microbiological	4	3	12	Long-term impairment of fitness of use due to pathogens, low probability	Buffer zone between DLD sites and surface water bodies
		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 DLD sites and surface water bodies
		Nutrient	4	3	12	Long-term impairment of fitness of use due to nutrients, low probability	Buffer zone between DLD sites and surface water bodies
		Organic pollutants	4	3	12	Long-term impairment of fitness of use due to organic pollutants, low probability	Buffer zone between DLD sites and surface water bodies
		Other			0		
	7.3	Microbiological	3	2	6	Recoverable impact due to airborne pathogens, rare probability	Buffer zone between DLD 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 DLD 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 DLD sites and surface water bodies
		Organic pollutants	3	2	6	Recoverable impact due to organic pollutants, rare probability	Buffer zone between DLD sites and surface water bodies
		Other			0		Buffer zone between DLD sites and surface water bodies
	7.4	Microbiological	3	1	3	Recoverable impact due to airborne pathogens via soil, highly unlikely probability, multiple barrier pathway	Buffer zone between DLD sites and surface water bodies
		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, multiple barrier pathway	Buffer zone between DLD sites and surface water bodies

		Nutrient	2	1	2	Temporary impact on fitness for use of surface water due to airborne nutrients, highly unlikely probability, multiple barrier pathway	Buffer zone between DLD sites and surface water bodies
		Organic pollutants	3	1	3	Recoverable impact due to organic pollutants via soil, Highly unlikely probability, multiple barrier pathway	Buffer zone between DLD sites and surface water bodies
		Other			0		
	7.5	Microbiological			0		
		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 DLD 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 DLD sites and groundwater (depth to aquifer) will protect surface water as well
		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	4	3	12	Pathogens may cause long-term impairment of fitness for use, but due to low mobility it is a low likelihood and would be higher for liquid sludge application than for dewatered sludge application	Buffer zone between DLD 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 DLD sites and groundwater (depth to aquifer)

		Metal	4	3	12	Metals may cause long-term impairment of fitness for use, but due to low mobility it is a low likelihood and would be higher for liquid sludge application than for dewatered sludge application	Buffer zone between DLD 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, especially in the case of liquid sludge application	Buffer zone between DLD sites and groundwater (depth to aquifer)
		Organic pollutants	3	2	6	Organic pollutant content of South Africa sludge is low.	None required
		Other			0		
	8.2	Microbiological			0		
		Stability	1	1	1	NA	NA
		Metal	4	3	12	Metals may cause long-term impairment of fitness for use, low likelihood of direct groundwater contamination	Buffer zone between DLD 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 DLD sites and groundwater (depth to aquifer)
		Organic pollutants			0		
		Other			0		
	8.3	Microbiological			0		
		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	Buffer zone between DLD 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 DLD sites and groundwater (depth to aquifer)
		Organic pollutants			0		
		Other			0		
	8.4	Microbiological	4	2	8	Long-term impairment of fitness of use due to pathogens, rare probability	Buffer zone between DLD sites and surface water bodies will also protect groundwater
		Stability	1	1	1	NA	
		Metal	3	2	6	Recoverable impact on fitness for use of surface water due to metals, rare probability	Buffer zone between DLD sites and surface water bodies will also protect groundwater
		Nutrient	4	2	8	Long-term impairment of fitness of use due to nutrients, rare probability	Buffer zone between DLD sites and surface water bodies will also protect groundwater
		Organic pollutants	4	2	8	Long-term impairment of fitness of use due to organic pollutants, rare probability	Buffer zone between DLD sites and surface water bodies will also protect groundwater
		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	NA	
		Metal	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
		Nutrient	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
		Organic pollutants	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
		Other			0	NA	
	9.2	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	NA	
		Metal	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
		Nutrient	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
		Organic pollutants	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
		Other			0	NA	
	9.3	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	NA	

		Metal	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
		Nutrient	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
		Organic pollutants	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
		Other			0	NA	
	9.4	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	NA	
		Metal	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
		Nutrient	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
		Organic pollutants	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
		Other			0	NA	
	9.5	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	NA	
		Metal	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
		Nutrient	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

		Organic pollutants	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
		Other			0	NA	
Grazing animals	10.1	Microbiological	3	4	12	Intervention may be needed to maintain viable animals due to pathogens, it is a possibility (1:1 000)	Restrictions on grazing animals at DLD sites
		Stability	1	1	1	NA	NA
		Metal	3	4	12	Intervention may be needed to maintain viable animals due to metals, it is a possibility (1:1 000)	Restrictions on grazing animals at DLD sites
		Nutrient	1	4	4	No negative impact due to nutrients	None required
		Organic pollutants	3	4	12	Intervention may be needed to maintain viable animals due to organic pollutants, it is a possibility (1:1 000)	Restrictions on grazing animals at DLD sites
		Other			0		
	10.2	Microbiological	3	5	15	Intervention may be needed to maintain viable animals due to pathogens, it can occur (1:10 000)	Restrictions on grazing animals at DLD sites
		Stability	1	1	1	NA	NA
		Metal	3	5	15	Intervention may be needed to maintain viable animals due to metals, it can occur (1:10 000)	Restrictions on grazing animals at DLD sites
		Nutrient	1	5	5	No negative impact due to nutrients	None required
		Organic pollutants	3	5	15	Intervention may be needed to maintain viable animals due to organic pollutants, it can occur (1:10 000)	Restrictions on grazing animals at DLD sites
		Other			0		
	10.3	Microbiological	3	4	12	Intervention may be needed to maintain viable animals due to pathogens, it is a possibility (1:1 000)	Buffer zones between DLD sites and surface water, Restrictions on grazing animals at DLD sites
		Stability	1	1	1	NA	NA
		Metal	3	4	12	Intervention may be needed to maintain viable animals due to metals, it is a possibility (1:1 000)	Buffer zones between DLD sites and surface water, Restrictions on grazing animals at DLD sites
		Nutrient	1	4	4	No negative impact due to nutrients	None required
		Organic pollutants	3	4	12	Intervention may be needed to maintain viable animals due to organic pollutants, it is a possibility (1:1 000)	Buffer zones between DLD sites and surface water, Restrictions on grazing animals at DLD sites
		Other			0		

	10.4	Microbiological	3	4	12	Intervention may be needed to maintain viable animals due to pathogens, it is a possibility (1:1 000)	Buffer zones between DLD sites and groundwater, Restrictions on grazing animals at DLD sites
		Stability	1	1	1	NA	NA
		Metal	3	1	3	Intervention may be needed to maintain viable animals due to metals, it is highly unlikely (1:1 000 000)	None required
		Nutrient	1	4	4	No negative impact due to nutrients	None required
		Organic pollutants	3	4	12	Intervention may be needed to maintain viable animals due to organic pollutants, it is a possibility (1:1 000)	Buffer zones between DLD sites and groundwater, Restrictions on grazing animals at DLD sites
		Other			0		
	10.5	Microbiological	2	2	4	Inhalation of airborne pathogens may cause recoverable effects	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 cause recoverable effects	None required
		Other			0		
	10.6	Microbiological	3	5	15	Intervention may be needed to maintain viable animals due to pathogens, it can occur (1:10 000)	Restrictions on grazing animals at DLD sites
		Stability	1	1	1	NA	NA
		Metal	3	5	15	Intervention may be needed to maintain viable animals due to metals, it can occur (1:10 000)	Restrictions on grazing animals at DLD sites
		Nutrient	1	5	5	No negative impact due to nutrients	None required
		Organic pollutants	3	5	15	Intervention may be needed to maintain viable animals due to organic pollutants, it can occur (1:10 000)	Restrictions on grazing animals at DLD sites
		Other			0		
	10.7	Microbiological	3	4	12	Intervention may be needed to maintain viable animals due to pathogens, it is a possibility (1:1 000)	Restrictions on grazing animals at DLD sites
		Stability	1	1	1	NA	NA
		Metal	3	4	12	Intervention may be needed to maintain viable animals due to metals, it is a possibility (1:1 000)	Restrictions on grazing animals at DLD sites
		Nutrient	1	4	4	No negative impact due to nutrients	None required
		Organic pollutants	3	4	12	Intervention may be needed to maintain viable animals due to organic pollutants, it is a possibility (1:1 000)	Restrictions on grazing animals at DLD sites

		Other			0		
	10.8	Microbiological	3	3	9	Intervention may be needed to maintain viable animals due to pathogens, it is a low likelihood (1:10 000)	Restrictions on grazing animals at DLD sites, implement vector attraction reduction options
		Stability	1	1	1	NA	NA
		Metal	1	1	1	NA	NA
		Nutrient	1	1	1	NA	NA
		Organic pollutants	3	3	9	Intervention may be needed to maintain viable animals due to organic pollutants, it is a low likelihood (1:10 000)	Restrictions on grazing animals at DLD sites, implement vector attraction reduction options
		Other			0		
Fauna	11.1	Microbiological	1	5	5	Low impact, multiple barrier pathway	None required
		Stability	1	1	1	NA	NA
		Metal	2	4	8	Low impact, multiple barrier pathway	None required
		Nutrient	1	4	4	Low impact, multiple barrier pathway	None required
		Organic pollutants	1	5	5	Low impact, multiple barrier pathway	None required
		Other			0		
	11.2	Microbiological	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Stability	1	1	1	NA	NA
		Metal	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Nutrient	1	4	4	No negative impact	None required
		Organic pollutants	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Other			0		
	11.3	Microbiological	2	2	4	Intervention may be required due to pathogens, low probability due to multiple barrier pathway	Buffer zone between DLD sites and surface water bodies will protect fauna
		Stability	1	1	1	NA	
		Metal	2	2	4	Intervention may be required due to metals, low probability due to multiple barrier pathway	Buffer zone between DLD sites and surface water bodies will protect fauna
		Nutrient	1	3	3	No impact due to nutrients, low probability due to multiple barrier pathway	Buffer zone between DLD sites and surface water bodies will protect fauna
		Organic pollutants	2	2	4	Intervention may be required due to organic pollutants, low probability due to multiple barrier pathway	Buffer zone between DLD sites and surface water bodies will protect fauna
		Other			0		
	11.4	Microbiological	2	2	4	Intervention may be required due to pathogens, low probability due to multiple barrier pathway	Buffer zone between DLD sites and groundwater will protect fauna
		Stability	1	1	1	NA	

		Metal	2	2	4	Intervention may be required due to metals, low probability due to multiple barrier pathway	Buffer zone between DLD sites and groundwater will protect fauna
		Nutrient	1	4	4	No impact due to nutrients, probable due to mobility of nutrients	Buffer zone between DLD sites and groundwater will protect fauna
		Organic pollutants	2	2	4	Intervention may be required due to organic pollutants, low probability due to multiple barrier pathway	Buffer zone between DLD sites and groundwater will protect fauna
		Other			0		
	11.5	Microbiological	2	2	4	Inhalation of airborne pathogens may need intervention to maintain biodiversity	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	None required
		Other			0		
	11.6	Microbiological	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Stability	1	1	1	NA	NA
		Metal	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Nutrient	1	4	4	No negative impact	None required
		Organic pollutants	2	4	8	Intervention may be required to maintain biodiversity, possible	None required
		Other			0		
	11.7	Microbiological	1	1	1		
		Stability	1	1	1	NA	NA
		Metal	3	2	6	Biodiversity will recover after closure, metal contamination rare	Buffer Zones between DLD sites and surface water
		Nutrient	3	2	6	Biodiversity will recover after closure, nutrient contamination rare	Buffer Zones between DLD sites and surface water
		Organic pollutants	3	2	6	Biodiversity will recover after closure, organic pollutant contamination rare	
		Other			0		

Sludge co-disposal on landfill	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	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	3	9	Pathogens will 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	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 it could occur (1:10 000)	Access restrictions for general public at landfill sites
		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 surface water	
		Stability	1	1	1		
		Metal	1	1	1		
		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	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.11	Microbiological			0	Assume liners will protect groundwater	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.12	Microbiological			0	Assume liners will protect groundwater	
		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		

Marine disposal			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	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	4	12	Possible chance of pathogenic effects in recreational users of the sea.	Ensure that disposal practices minimize the possibility of human contact through appropriate outfall location and design
		Stability	1	3	3	There might be odours from shore handling facilities	Take appropriate precautions in facility design
		Metal	1	3	3	Will generally be sufficient dilution and dispersion to not be of any consequence	Ensure appropriate location and design of outfall
		Nutrient	1	3	3	Will generally be sufficient dilution and dispersion to not be of any consequence	Ensure appropriate location and design of outfall
		Organic pollutants	1	3	3	Will generally be sufficient dilution and dispersion to not be of any consequence	Ensure appropriate location and design of outfall
		Other			0		
	2.2	Microbiological	3	4	12	Possible pathogenic effects particularly through contact aquatic recreation	Ensure that disposal practices minimize the possibility of human ingestion through appropriate outfall location and design
		Stability			0	N/A	
		Metal	3	1	3	Highly unlikely due to dilution and dispersion	Ensure appropriate location and design of outfall
		Nutrient	2	1	2	Highly unlikely due to dilution and dispersion	Ensure appropriate location and design of outfall
		Organic pollutants	3	1	3	Highly unlikely due to dilution and dispersion	Ensure appropriate location and design of outfall
		Other			0		
	2.3	Microbiological	3	1	3	Highly unlikely due to adsorption of pathogens/toxicants to particulates and entrainment in the water column. Rare chance of some uptake through aerosol.	
		Stability			0	N/A	
		Metal	3	1	3	Highly unlikely due to adsorption of pathogens/toxicants to particulates and entrainment in the water column. Rare chance of some uptake through aerosol.	
		Nutrient	2	1	2	Highly unlikely due to adsorption of pathogens/toxicants to particulates and entrainment in the water column. Rare chance of some uptake through aerosol.	
		Organic pollutants	3	1	3	Highly unlikely due to adsorption of pathogens/toxicants to particulates and entrainment in the water column. Rare chance of some uptake through aerosol.	

		Other			0	N/A	
	2.4	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.5	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.6	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.7	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.8	Microbiological	4	3	12	Low likelihood of pathogenic effects through eating the alimentary tracts of fish that have recently consumed contaminated sludge	Reduce likelihood by locating and designing the outfall to maximize dispersion. Monitor fisheries that might be at risk
		Stability			0	N/A	
		Metal	4	3	12	Toxic effects could happen through consumption of pollutants that have accumulated in edible tissues via the food web.	Reduce likelihood by locating and designing the outfall to maximize dispersion. Monitor fisheries that might be at risk
		Nutrient			0	N/A	
		Organic pollutants	4	3	12	Toxic effects could happen through consumption of pollutants that have accumulated in edible tissues via the food web.	Reduce likelihood by locating and designing the outfall to maximize dispersion. Monitor fisheries that might be at risk
		Other			0	N/A	

	2.9	Microbiological	4	3	12	Filter feeders such as mussels and oysters could accumulate particulates with attached pathogens	Reduce likelihood by locating and designing the outfall to maximize dispersion. Avoid dispersion in the intertidal zone. Monitor fisheries that might be at risk
		Stability			0	N/A	
		Metal	4	3	12	Filter feeders such as mussels and oysters could accumulate trace metals associated with sludge particulates	Reduce likelihood by locating and designing the outfall to maximize dispersion. Avoid dispersion in the intertidal zone. Monitor fisheries that might be at risk
		Nutrient			0	N/A	
		Organic pollutants	4	3	12	Filter feeders such as mussels and oysters could accumulate organic pollutants associated with sludge particulates	Reduce likelihood by locating and designing the outfall to maximize dispersion. Avoid dispersion in the intertidal zone. Monitor fisheries that might be at risk
		Other			0	N/A	
	2.10	Microbiological	4	3	12	Low likelihood of pathogens from poorly located disposal sites infecting recreational users of the sea.	Minimize risk by locating discharge points away from bathing beaches etc.
		Stability				N/A	
		Metal	1	1	1	Highly unlikely to be of any consequence. No impact.	
		Nutrient			0	N/A	
		Organic pollutants	1	1	1	Highly unlikely to be of any consequence. No impact.	
		Other			0	N/A	
	2.11	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.12	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.13	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		

		Organic pollutants			0		
		Other			0		
	2.14	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.15	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	2.16	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Soil	3.1	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	3.2	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	3.3	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	3.4	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		

	3.5	Microbiological	1	1	1	Highly unlikely chance of persistent pathogens remaining dormant in the sediments	
		Stability			0	N/A	
		Metal	4	3	12	Possible chance of trace metals contaminating sediments and impacting negatively on local benthic communities	
		Nutrient	4	3	12	Possible chance of excessive nutrient enrichment in sediments, with localized oxygen depletion and consequent negative effects on benthic communities	
		Organic pollutants	4	3	12	Possible chance of localized contamination and negative impacts on benthic communities	
		Other			0	N/A	
	3.6	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Crops	4.1	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	4.2	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	4.3	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Vegetation	5.1	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Air	6.1	Microbiological			0	Not applicable to marine	

		Stability			0	disposal	
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	6.2	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	6.3	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	6.4	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Surface water	7.1	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	7.2	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	7.3	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	7.4	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		

		Organic pollutants			0		
		Other			0		
	7.5	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	7.6	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	7.7	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Groundwater	8.1	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	8.2	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	8.3	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	8.4	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		

Marine environment	9.1	Microbiological	3	6	18	High likelihood of localized contamination near point of discharge	Ensure that location and mode of discharge are conducive to rapid dilution and dispersion so as to minimize human and ecological impacts
		Stability			0	N/A	
		Metal	3	6	18	High likelihood of localized contamination near point of discharge	Ensure that location and mode of discharge are conducive to rapid dilution and dispersion so as to minimize human and ecological impacts
		Nutrient	3	6	18	High likelihood of localized contamination near point of discharge	Ensure that location and mode of discharge are conducive to rapid dilution and dispersion so as to minimize human and ecological impacts
		Organic pollutants	3	6	18	High likelihood of localized contamination near point of discharge	Ensure that location and mode of discharge are conducive to rapid dilution and dispersion so as to minimize human and ecological impacts
		Other			0	N/A	
	9.2	Microbiological	2	1	2	Sludge, if present, likely to be sufficiently diffuse to be of no consequence	
		Stability			0	N/A	
		Metal	2	1	2	Sludge, if present, likely to be sufficiently diffuse to be of no consequence	
		Nutrient	2	1	2	Sludge, if present, likely to be sufficiently diffuse to be of no consequence	
		Organic pollutants	2	1	2	Sludge, if present, likely to be sufficiently diffuse to be of no consequence	
		Other			0	N/A	
	9.3	Microbiological	2	1	2	Sludge, if present, likely to be sufficiently diffuse to be of no consequence	
		Stability			0	N/A	
		Metal	2	1	2	Sludge, if present, likely to be sufficiently diffuse to be of no consequence	
		Nutrient	2	1	2	Sludge, if present, likely to be sufficiently diffuse to be of no consequence	
		Organic pollutants	2	1	2	Sludge, if present, likely to be sufficiently diffuse to be of no consequence	
		Other			0	N/A	

	9.4	Microbiological	2	5	10	Good probability of pathogens associating with particles and being transported to possible sediment "depocentres". Viability of pathogens will decrease with time.	Avoid sludge discharge in high risk areas where is likely to be cumulative deposition and consequent human and ecological impacts.
		Stability			0	N/A	
		Metal	3	5	15	Good probability of metals associating with particles and being transported to possible sediment "depocentres" where there could be cumulative effects.	Avoid sludge discharge in high risk areas where is likely to be cumulative deposition and consequent human and ecological impacts.
		Nutrient	3	5	15	Good probability of particulate nutrients being deposited at possible sediment "depocentres" where there could be cumulative effects.	Avoid sludge discharge in high risk areas where is likely to be cumulative deposition and consequent human and ecological impacts.
		Organic pollutants	3	5	15	Good probability of metals associating with particles and being transported to possible sediment "depocentres" where there could be cumulative effects.	Avoid sludge discharge in high risk areas where is likely to be cumulative deposition and consequent human and ecological impacts.
		Other			0	N/A	
	9.5	Microbiological	1	1	1	Highly unlikely and of no consequence	
		Stability			0	N/A	
		Metal	1	1	1	Highly unlikely and of no consequence	
		Nutrient	1	1	1	Highly unlikely and of no consequence	
		Organic pollutants	1	1	1	Highly unlikely and of no consequence	
		Other			0	N/A	
Grazing animals	10.1	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.2	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.3	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		

		Other			0		
	10.4	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.5	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.6	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.7	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	10.8	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
Fauna	11.1	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	11.2	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	11.3	Microbiological			0	Not applicable to marine disposal	
		Stability			0		

		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	11.4	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	11.5	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	11.6	Microbiological			0	Not applicable to marine disposal	
		Stability			0		
		Metal			0		
		Nutrient			0		
		Organic pollutants			0		
		Other			0		
	11.8	Microbiological	1	1	1	Note: The pathway considered here (renumbered 11.8) is one which was not adequately recognized at the Risk Assessment Workshop. It is best described as "marine ecological impacts" and would include biodiversity reduction, community disturbances and disruptions in ecological functioning. It is recognized that moderate risks are posed by metals, nutrients and organic pollutants associated with sludge disposal, particularly where there are active depocentres. The impacts would largely be localized and recoverable.	
		Stability			0		
		Metal	3	4	12		
		Nutrient	3	4	12		
		Organic pollutants	3	4	12		
		Other			0		

Appendix 2: Examples of calculations

Example 1: Calculating co-disposal ratio in terms of allowable leachate limit.

A landfill is being designed for co-disposal of sewage sludge with general waste. The following information is available for the waste characteristics:

- Average annual rainfall: $\overline{R}$ = 480 mm, σ_R = 120 mm
- Average annual A-pan evaporation: $\overline{E}_A$ = 2310 mm, σ_E = 155 mm
- Water content of incoming waste: 20%
- Sewage sludge solids content: 20% (therefore, w = 400%)
- Compacted bulk density: 800 kg/m^3
- Rate of rise: 2.5 m/y
- Assume that the runoff is zero during the operational phase of the landfill
- A maximum amount of leachate of 200 mm/y per unit area is permitted from co-disposal activities.

Assume an initial co-disposal ratio of 1:10 (wet mass of sludge: wet mass of MSW)

Then:

Vt = d x A
= 2.5 x 1 m^3
= 2.5 m^3

Mt = ρ_b x d x A (using 1 m^2)
= 800 x 2.5 x 1 kg
= 2000 kg

Mass MSW = 2000/11 x 10 kg
= 1818.2 kg

Mass SS = 2000 – 1818.2 kg
= 181.8 kg

For MSW:

Mass of water = Mt x w/(1+w)
= 1818.2 x 0.2/(1+0.2) kg
= 303.0 kg

Mass of solids = Mt / (1+w)
= 1818.2 / (1+0.2) kg
= 1515.2 kg

Volume of water = Mw/ρ_w
= 303.0 / 1000 m^3
= 0.303 m^3

Volume of solids = Ms/ρ_s (MRLF uses ρ_s as 2340 kg/m^3)
= 1515.2 / 2340 m^3
= 0.648 m^3

For SS:

Mass of water = Mt x w/(1+w)
= 181.8 x 4/(1+4) kg
= 145.5 kg

Mass of solids = Mt / (1+w)
= 181.8 / (1+4) kg
= 36.4 kg

Volume of water = Mw/ρ_w
= 145.5 / 1000 m^3
= 0.146 m^3
Volume of solids = Ms/ρ_s (ρ_s = 1500 kg/m^3, from Blight et al, 2000)
= 36.4 / 1500 m^3
= 0.024 m^3

Total:
Volume of solids = 0.146 + 0.024 m^3
= 0.672 m^3
Volume of voids = Vt – Vs
= 2.5 – 0.672 m^3
= 1.828 m^3

ΣE_A = $0.4 (\overline{E}_A - 1.6\ \sigma_E)$
= 0.4 (2310 -1.6 x155)
= 825 mm
Volume of evaporation = ΣE_A/1000 x A
= 0.825 m^3

ΣR = $\overline{R} + 1.6\sigma_R$
= 480 + 1.6 x 120 mm
= 672 mm
Volume of precipitation = ΣR/1000 x A
= 0.672 m^3

Allowable volume of leachate = 200/1000 x A
= 0.2 m^3

$\Sigma(L + S) = \Sigma W + \Sigma R - \Sigma E_A$

Right hand side
$\Sigma W + \Sigma R - \Sigma E_A$ = (0.303 + 0.146) + 0.672 – 0.825 m^3
= 0.296 m^3

Left hand side
S_R = 0.35
= Vw/(Vt – Vs)
Vw = 0.35 x 1.828 m^3
= 0.64 m^3
Σ(L + S) = 0.2 + 0.64 m^3
= 0.84 m^3

This is greater than the sum for the RHS (even without the allowable leachate), therefore the co-disposal of 1:10 does not use the full storage potential of the waste, but it is the maximum permissible.

This calculation of co-disposal ratios could also be done in mm, by dividing volumes of water in MSW, sludge and moisture storage by the area and converting the units.

Notes:
The bulk density in this example is relatively low, particularly for medium and large sites where compaction is common.
The solids density (2340 kg/m^3) for MSW is the one given in the MR for all general wastes, but this is very high. Expected values are 1700 – 1860 kg/m^3 for waste from high income areas and up to 2100 kg/m^3 for wastes with a large ash fraction. When these lower values are used the volume of solids increases and the corresponding storage potential of the waste is decreased.

Example 2: Calculating co-disposal ratio in terms of allowable leachate limit (higher moisture content).

The easiest method is to set up a spreadsheet and use a SOLVER function to solve or S_R with the mass (wet mass) of MSW or sewage sludge (SS) being the variable. The alternative is to assume a co-disposal ratio of 1:10 and check if this meets the requirements.

A landfill is being designed for co-disposal of sewage sludge with general waste. The following information is available for the waste characteristics:

- Average annual rainfall: $\overline{R}$ = 480 mm, σ_R = 120 mm
- Average annual A-pan evaporation: $\overline{E}_A$ = 2310 mm, σ_E = 155 mm
- Water content of incoming waste: 50%
- Sewage sludge solids content: 20% (therefore, w = 400%)
- Compacted bulk density: 1000 kg/m^3
- Rate of rise: 2.5 m/y
- Assume that the runoff is zero during the operational phase of the landfill
- A maximum amount of leachate of 200 mm/y per unit area is permitted from co-disposal activities.

Assume an initial co-disposal ratio of 1:10 (wet mass of sludge : wet mass of MSW)

Then:

Vt = d x A
= 2.5 x 1 m^3
= 2.5 m^3

Mt = ρ_b x d x A (using 1 m^2)
= 1000 x 2.5 x 1 kg
= 2500 kg

Mass MSW = 2500/11 x 10 kg
= 2272.7 kg

Mass SS = 2500 – 2272.7 kg
= 227.3 kg

For MSW:

Mass of water = Mt x w/(1+w)
= 2272.7 x 0.5/(1+0.5) kg
= 757.6 kg

Mass of solids = Mt / (1+w)
= 2272.7 / (1+0.5) kg
= 1515.2 kg

Volume of water = Mw/ρ_w
= 757.6 / 1000 m^3
= 0.758 m^3

Volume of solids = Ms/ρ_s (using ρ_s as 1800 kg/m^3, a more appropriate value)
= 1515.2 / 1800 m^3
= 0.842 m^3

For SS:

Mass of water = Mt x w/(1+w)
= 227.3 x 4/(1+4) kg
= 181.8 kg

Mass of solids = Mt / (1+w)
= 227.3 / (1+4) kg
= 45.5 kg

Volume of water = Mw/ρ_w
= 181.8 / 1000 m^3
= 0.182 m^3

Volume of solids = Ms/ρ_s (ρ_s = 1500 kg/m^3, from Blight et al, 2000)
= 45.5 / 1500 m^3
= 0.030 m^3

Total:

Volume of solids = 0.842 + 0.030 m^3
= 0.872 m^3

Volume of voids = Vt – Vs
= 2.5 – 0.872 m^3
= 1.628 m^3

ΣE_A = $0.4(\overline{E}_A - 1.6\ \sigma_E)$
= 0.4 (2310 -1.6 x155)
= 825 mm

Volume of evaporation = ΣE_A/1000 x A
= 0.825 m^3

ΣR = $\overline{R} + 1.6\sigma_R$
= 480 + 1.6 x 120 mm
= 672 mm

Volume of precipitation = ΣR/1000 x A
= 0.672 m^3

Allowable volume of leachate = 200/1000 x A
= 0.2 m^3

$\Sigma(L + S) = \Sigma W + \Sigma R - \Sigma E_A$

Right hand side

$\Sigma W + \Sigma R - \Sigma E_A$ = (0.758 + 0.182) + 0.672 – 0.825 m^3
= 0.787 m^3

Left hand side

S_R = 0.35
= Vw/(Vt – Vs)

Vw = 0.35 x 1.628 m^3
= 0.570 m^3

$\Sigma(L + S)$ = 0.2 + 0.570 m^3
= 0.770 m^3

The incoming moisture from the sewage sludge is too high, since the RHS is greater than the LHS. By iteration, the correct ratio is 1:12.6

The examples above can be solved by substituting the known values and solving for x. Writing all terms with respect to the ratio 1:*x* to solve for *x*:

$$LHS = \frac{y}{1000} + S_R H - \frac{S_R H \rho_b}{G_{SM}(1+w_M)} \frac{x}{(1+x)} - \frac{S_R H \rho_b}{G_{SS}(1+w_s)} \frac{1}{(1+x)}$$

$$RHS = \frac{H\rho_b}{\rho_w} \frac{w_M}{(1+w_m)} \frac{x}{(1+x)} + \frac{H\rho_b}{\rho_w} \frac{w_s}{(1+w_s)} \frac{1}{(1+x)} + \frac{\sum R}{1000} - \frac{\sum E_A}{1000}$$

Where:

y = allowable depth of leachate in mm;

S_R = degree of saturation at which leachate is released, expressed as a proportion;

H = rate of rise per year at the landfill;

ρ_b = bulk density, expressed in kg/m^3;

ρ_w = density of water, expressed in kg/m^3;

G_{SM} = solids density of MSW, expressed in kg/m^3;

G_{SS} = solids density of sewage sludge, expressed in kg/m^3;

w_M = gravimetric moisture content of MSW, expressed as a proportion;

w_S = gravimetric moisture content of sewage sludge, expressed as a proportion;

(if the percent solids, %S, is known, then w_S = (1-%S/100)/(%S/100));

ΣE_A = 0.4($\overline{E}_A$ – 1.6 σ_E), expressed in mm; and

ΣR = $\overline{R}$ + 1.6σ_R, expressed in mm.

Example 3: Using the EEC to determine the loading rate at which sewage sludge may be co-disposed at a General waste site

Consider dewatered sewage sludge at 20% solids that had a leachable zinc (Zn^{2+}) concentration determined from a TCLP test of 118.85 mg/kg $_{\text{dry sludge.}}$ If it were to be co-disposed with refuse at a 1 hectare general waste site at a ratio of 1:10 and the refuse deposition rate was 600 ton per day, the Loading Rate (LR) of the sludge would be:

LR = General waste deposition rate x co-disposal ratio x percent solids

= (600 $_{\text{tonnes/day}}$ x 30 $_{\text{days/month}}$) x (1 part sludge / 10 parts waste) x 0.2

= 360 $_{\text{tonnes/month}}$ = 360 000 $_{\text{kg/month}}$ of dry sewage sludge

Calculate the AE:

AE = $0.1xLC_{50}$

= 0.1x7.0 $_{\text{mg/l}}$

= 0.7 $_{\text{mg/l}}$ = 700_{ppb}

Calculate the EEC:

EEC = loading rate x leachable concentration x 0.66

= 360 000 $_{\text{kg/month}}$ x (118.85 m$_{\text{g/kg}}$ x 1g/1000 mg) x 0.66

= 28 238.6 ppb

Compare the AE and the EEC

EEC>AE, therefore the co-disposal ratio needs to decrease until the EEC equals the AE

Calculate the allowable co-disposal ratio

Allowable ratio = EEC/AE = 28 238.6 / 700 = 40.3

Therefore the allowable co-disposal ratio is 1:40.3.

Calculate the mass of sludge that can be co-disposed.

Mass of sludge that can be co-disposed = General deposition rate / co-disposal ratio

Mass of sludge that can be co-disposed = (600 $_{\text{tonnes/day}}$ / 40.3) = 14.9 $_{\text{tonnes / day.}}$

= 447 tons/month of wet sewage sludge

= 89.4 tons/month of dry sludge

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

TABLE 3A: 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.		

TABLE 3B: 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.

TABLE 3C: 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

TABLE 3D: 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 TTV 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.

Recommended new procedure to determine Helminth ova in wastewater sludge

Method for analyses of wet sludge

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 try to 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 your 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 put them into 4 x 50 ml test tubes. (If the solid content is high this should be sufficient sample. If it is low you may need to 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 about 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 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 1389 g (±3000 rpm) for 3 min. 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 $ZnSO_4$ and vortex well to mix. Keep adding more $ZnSO_4$ and mixing until the tube is almost full.

6. Centrifuge the tubes at 617 g (±2000 rpm) for 3 min. 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 964 g (±2500 rpm) for 3 min; remove & discard the supernatant fluid. The deposits can then be combined into one test tube, using water to rinse out all the eggs and then centrifuge again at 964 g for 3 min. to get one deposit.

9. Once you have the final deposit, remove all of it using a plastic Pasteur pipette and place it onto one or more microscope slides. Place a coverslip over the 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.

ERWAT Laboratory Services choose to examine the samples slightly differently from Step No. 7: 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.

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!

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.

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.

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

7. 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; 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 (%) = $\{(V_i – V_o)/ V_i – (V_i \text{ x } V_o)\}\text{x}100$

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.

<u>Option 8: Moisture Reduction of Sludge Containing Unstabilised Solids</u>

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.

<u>Option 9: Sludge Injection</u>

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.

<u>Option 10: Incorporation of Sludge into the Soil</u>

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.

<u>Option 11: Daily cover</u>

This option is applicable to landfill only. Most landfill operations are based on a series of trenches or cells which are prepared to receive waste. The waste is deposited in trenches or cells, spread, compacted and covered to isolate the waste from the environment. The material to be used as cover material may be soil, builder's rubble or ash.

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 (glass bottle needed)
  - Sealed container or cool box which can be kept cool (preferably with ice)
- Equipment to collect chemical and physical samples
  - Plastic bottles with plastic cap without liner / Glass bottles
  - Cooler box with ice (if necessary)

Special precautions

- Microbiological water samples
  - Keep sample bottle closed and in a clean condition up to the point where it has to be filled with the water to be sampled.
  - Do not rinse bottle with any water prior to sampling.
  - When samples for chemical and microbiological analysis are to be collected from the same location, the microbiological sample should be collected first to avoid the danger of microbiological contamination of the sampling point.
  - The sampler (person taking the sample) should wear gloves (if possible) or wash his/her hands thoroughly before taking each sample. Avoid hand contact with the neck of the sampling bottle.
- Chemical water samples
  - Some plastic caps or cap liners may cause metal contamination of the water sample. Please consult with the laboratory on the correct use of bottle caps.
  - Keep sample bottle closed and in a clean condition up to the point where it has to be filled with the water to be analysed.
  - Never leave the sample bottles (empty or filled with the water sample) unprotected in the sun.
  - After the sample has been collected the sample bottle should be placed directly in a cooled container (e.g. portable cooler box). Try and keep cooled container dust-free.

[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) and leave ample air space in the bottle (at least 2.5 cm) to facilitate mixing by shaking before examination.
- Label the sample
- Submit for analysis to a reputable analytical laboratory.

Composite Borehole Water Sampling

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

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

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

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

SOIL SAMPLING[2]

Sampling equipment needed

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

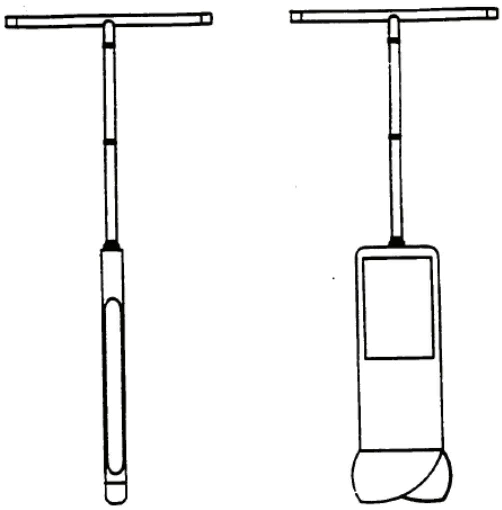

Figure 5A: Soil augers

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:

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.

---

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

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

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

5. Preserve the samples as recommended in the table below 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^{o}C	14 days
Ammonia	Plastic/Glass	Cool, 4^{o}C	28 days
Sulfate	Plastic/Glass	Cool, 4^{o}C	28 days
Nitrate	Plastic/Glass	Cool, 4^{o}C	48 hours
Organic Carbon	Plastic/Glass	Cool, 4^{o}C	28 days
Chromium VI	Plastic/Glass	Cool, 4^{o}C	48 hours
Mercury	Plastic/Glass	Cool, 4^{o}C	28 days
Other Metals	Plastic/Glass	Cool, 4^{o}C	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

AE	Acceptable Exposure
DEAT	Department of Environmental Affairs and Tourism
DLD	Dedicated land disposal
DWAF	Department of Water Affairs and Forestry
ECA	Environment Conservation Act 73 of 1989
EEC	Estimated Environmental Concentration
EIA	Environmental Impact Assessment
$G:B^+$	General landfill with leachate generation (rainfall exceeds evaporation)
$G:B^-$	General landfill without leachate generation (evaporation exceeds rainfall)
H:H	Hazardous landfill
MPL	Maximum Permissible Level
NEMA	National Environmental Act, No. 107 of 1998
NWA	National Water Act 36 of 1998
RoD	Record of Decision
TCLP	Toxicity Characteristic Leaching Procedure
TTV	Total Trigger Value
WWTP	Wastewater treatment plant

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 100kg 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).