GUIDELINES FOR DEEP ROW ENTRENCHMENT OF FAECAL SLUDGE AND SECONDARY WASTEWATER SLUDGE

Partners in Development

WATER RESEARCH COMMISSION

TT 880/22

GUIDELINES FOR DEEP ROW ENTRENCHMENT OF FAECAL SLUDGE AND SECONDARY WASTEWATER SLUDGE

Report
to
the Water Research Commission
by

Partners in Development

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LIST OF ABBREVIATIONS

CEC	Cation Exchange Capacity
COD	Chemical Oxygen Demand
DRE	Deep Row entrenchment
DWS	Department of Water and Sanitation
EAP	Environmental Assessment Practitioner
EIA	Environmental Impact Assessment
FSM	Faecal Sludge Management
MPL	Maximum Permissible Level
PAR	Permissible Application Rate
PPE	Personal Protective Equipment
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
TS	Total Solids
VIP	Ventilated Improved Pit
VFA	Volatile Fatty Acids
VSS	Volatile Suspended Solids
WWTP	Wastewater Treatment Plant
WWTW	Wastewater Treatment Works
WRC	Water Research Commission

KEY DEFINITIONS

Biosolids	Sludge generated from centralised or decentralised wastewater treatment works
Deep Row Entrenchment	Burial of sludge in a trench, with a minimum of 300mm soil cover
Faecal sludge	Sludge generated from on-site sanitation systems
Faecal Sludge Management	The full service chain for managing faecal sludge produced from on-site sanitation systems, including collection, emptying, transport, treatment, and use and/or disposal
Leachate	Liquid draining from a site where sludge has been buried. Leachate may carry pollutants from entrenched sludge, but it also receives a level of treatment as it moves through the soil.
Maximum Permissible Level	Maximum level of certain elements that can be present in soil without negative environmental impacts. Sludge applied to soil should not cause the level of these elements to exceed the maximum permissible levels.
Microbiological class	Classification of sludge based on presence of pathogens, which ranges from A (no pathogens, unrestricted use) to C (pathogens present, limited use)

On-site sanitation systems	Decentralised sanitation solutions that contain faecal sludge on the site where it is generated before it is emptied and disposed of. In South Africa, typical on-site sanitation systems include VIP toilets, pour flush toilets, urine-diverting dry toilets, and septic tanks with soakaways. The type of system (e.g. flush vs. dry or sealed vs. open-joint containment) will impact on the characteristics of faecal sludge produced from the on-site sanitation system.
Pathogens	Microorganisms that pose risks to human health. While microorganisms are present in very large numbers in the environment, certain organisms (e.g. *E. Coli* and Helminths) may lead to health problems if humans are exposed to them.
Permissible Application Rate	The calculated maximum amount of sludge that may be applied to land based on metals concentrations in the sludge and receiving soil
Pollutant class	Classification of sludge based on the full elemental analysis of the sludge, with emphasis on elements monitored for toxicity (e.g. heavy metals). Pollutant class ranges from a (low levels of toxic elements) to c (high levels of toxic elements).
Sludge	A mixture of solids and liquids, containing mostly excreta and water, in combination with sand, grit, metals, trash and/or various chemical compounds
Stability class	Classification of sludge based on the fraction of degradable organic matter it contains. This is determined by chemical oxygen demand (COD), with a lower COD representing a stability class of 1 and high COD representing stability class of 3. Sludge that is not stabilised can achieve a better stability class rating if one of 10 vector attraction reduction options is applied.

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INTRODUCTION

Deep row entrenchment of sludge can be used to safely dispose of untreated or partially treated faecal material while achieving several benefits:

- Improved soil fertility and increased agricultural productivity: enhanced growth of timber or other non-edible commercial crops
- Food security: improved nutrient value of fruit grown by households
- Environmental rehabilitation: restoration or enhancement of ecosystems through remediation of poor or disrupted soils and stabilisation of carbon in the soil, thus reducing greenhouse gas emissions

While further research on the benefits and risks associated with deep row entrenchment (DRE) is warranted to better understand the interaction of entrenched sludge with the environment and with the species of tree or other crop, it has been entrenched to benefit, sludge producers can begin to implement this method with proper management and monitoring. Deep row entrenchment of sewage sludge has been presented as a feasible option by the United States Environmental Protection Agency (US EPA) since at least 1975 (see *Trench Incorporation of Sewage Sludge in Marginal Agricultural Land*). Thus, while it is not yet a widely used and defined practice in the South African context, the practice has been used for many years elsewhere in the world.

Let's zoom out a bit

Entrenchment of sludge has potential to provide several benefits if done properly:

Short term benefits:
*Solution to an urgent waste management and public health problem
*Improved crop yields

Medium-term benefits:
*Improved crop yields over multiple crop cycles
*Improved soil health (e.g. increase in organic content)

Long-term benefits:
*Stabilisation of carbon, leading to reduced release of greenhouse gases

Is it HELPFUL for crops?

Does burial of sludge lead to increased crop yields? In short, yes. Buried sludge is a sustainable source of nutrients and carbon that are essential to the growth of crops. Taking timber for example, Abreu-Junior et al. (2020) found that buried sludge led to an increase of 7% in wood volume in a *Eucalyptus urograndis* plantation when comparing plots where nitrogen requirement was met by wastewater sludge and those using NPK fertiliser.

Similarly, Neethling and Still (2022) found that buried sludge led to an approximately 15% minimum increase in Eucalyptus yields over a single growing season, based on estimated conical volume. When examining the impact on a second growing season on the same plot, with no additional sludge applied, volume of timber in plots with sludge application showed increases of approximately 30% within the first 3 years of growth when compared to plots without sludge.

Is it HARMFUL to the environment?

Monitoring of boreholes downhill from the experimental plot at SAPPI in Howick showed negligible impact on nitrate and phosphate in groundwater. Additionally, an expert study on the stream downhill from SAPPI plot with entrenched sludge more than 10 years after entrenchment showed that the stream was in near natural condition. Other studies have been done to assess the impact of on-site sanitation systems on groundwater, and many have also found very limited impact, though the impact is dependent on the specific site characteristics (e.g. soil type). One study from 1979 found some evidence of nitrogen migration below entrenched sludge, but this study was conducted in sandy, well-drained soil and thus represented a worst-case scenario Sikora et al., (1979). This study did not detect any evidence of leaching of heavy metals from the sludge. Nyenje et al. (2014) investigated pollution of a shallow aquifer from a densely populated informal settlement with many pit latrines and found that although there was localised contamination of the groundwater, the shallow aquifer also acted as a sink of nutrients. No impact on the groundwater was observed 200 metres downslope from the settlement.

See the following sources:

Felton, G. K., & Kays, J. S. (2014). *Nitrogen Migration from Deep-Row Biosolids Incorporation on a Hybrid Poplar Tree Farm*. In *Water Environment Federation Residuals and Biosolids Meeting*. Austin, TX.

Nyenje, P. M. (2014). *Fate and Transport of Nutrients in Groundwater and Surface Water in an Urban Slum Catchment, Kampala, Uganda*. Delft University of Technology.

Sikora, L.J., Frankos, N.H., Murray, C.M., and Walker, J.M. (1979). *Effects of trenching undigested lime-stabilized sludge.* Water Pollution Control Federation, Vol. 51, No. 7.

Still, D., Salisbury, H., Lorentz, S., & Foxon, K.M. (2012). *Beneficial use of faecal sludge through deep row entrenchment.* WRC.

Wickham, B. N. (2014). *On-site sanitation impacts on water resources near Taylors Halt, KwaZulu-Natal, South Africa*. University of KwaZulu-Natal.

Is it HELPFUL for the environment?

Burial of sludge adds carbon to the soil, leading to increased organic matter in the soil. This has a positive impact on soil health and can improve structural aspects, such as water holding capacity. In the long run, burial of sludge allows it to decompose underground and be used by organisms in the soil. The alternative, landfill applicationand even surface application results in the decomposition of carbon to carbon dioxide, which is a greenhouse gas. Thus, burying sludge can provide some mitigation of climate change in the long run.

GUIDING LEGISLATION AND REGULATIONS

The South African *Neighbourhood Planning and Design Guide* (Red Book, Section K) states that faecal sludge from pit toilets can be disposed of by burial in trenches and provides a diagram for exactly how to do that. However, when discussing disposal of sludge/biosolids from wastewater treatment works (WWTW) and septic tanks, the *Red Book* refers readers to the South African *Guidelines for the Utilisation and Disposal of Wastewater Sludge* (*Guidelines*). The *Guidelines* are discussed in more detail below.

The disposal and beneficial use of sludge are addressed in the five volumes of the *Guidelines for the Utilisation and Disposal of Wastewater Sludge* published by the South African Department of Water Affairs in 2006-2009. These in turn draw on and interpret earlier guidelines and legislation with the aim of encouraging the beneficial use of sludge. These include the *National Water Act* (1998), the *National Environmental Management Act* (1998), the *Minimum requirements for the handling, classification, and disposal of hazardous waste* (1998), *A protocol to manage the potential of groundwater contamination from on-site sanitation* (2003) the *Waste Act* (2008) and the *Environmental Impact Assessment Regulation* (2010), among others.

The *Guidelines for the Utilisation and Disposal of Wastewater Sludge* introduce a classification system designed to maximise the beneficial use of sludge, which is based on three parameters: microbiological quality (presence of pathogens), stability and pollutant content. Sludge classified as ***A1a*** has the least restricted use while sludge classified as ***C3c*** has the most restricted use.

Microbiological class	A: Unrestricted use	B: General use	C: Limited use
Stability class	1: Stable	2: Partially stabilised	3: Unstable
Pollutant class	a: Minimal restriction	b: Moderate restriction	c: High restriction

Microbiological class
Criteria for microbiological classification are shown in Table 1. Pit sludge or faecal sludge, which has not undergone specific treatment to destroy pathogens, would fall into Microbiological Class ***C***.

Table 1: Descriptions of microbiological classes

Microbiological class	A: Unrestricted use	B: General use	C: Limited use
Criteria	All three samples comply with the following standard	Two of the three samples comply with the following standard	The sample that failed does not exceed the following standard
Faecal coliforms (CFU/g dry)	< 1 000	< 1 x 10^6	1 x 10^7
Helminth ova (Total viable ova/g dry)	< 0.25 (or one viable ova/4 g)	< 1	4

Stability class
The stability of sludge relates to the fraction of degradable organic matter it contains. As the organic components degrade into inorganic components, sludge eventually becomes stable. Unstable sludge attracts organisms such as rodents, flies and mosquitoes, which operate as vectors for disease transmission, and it also has a stronger odour, which impacts on public acceptance. Measuring the chemical oxygen demand (COD) of sludge provides an indication of how well stabilised it is. Fresh excreta would typically fall into class ***3*** with COD levels of 20,000-50,000 mg/litre; after treatment COD levels may have dropped to 500-2,500 mg/litre falling into class ***1***. Sludge from a pit latrine would typically include older layers of well-stabilised sludge but also fresher, unstable sludge, resulting in a classification of ***3***. Unstable sludge can be reclassified more favourably if one of the options for reducing the attraction of vectors can be applied.

Table 2: Vector reduction options for improving stability class (Guidelines for Sludge Utilisation and Disposal, Volume 1)

Stability class	**1**	**2**	**3**
Criteria	Plan/design to comply with one of the options listed below on a 90% basis.	Plan/design to comply with one of the options listed below on a 75% basis.	No stabilisation or vector attraction reduction options applied.
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% **Option 2**: Demonstrate vector attraction reduction with additional anaerobic digestion. If in a bench-scale unit, sludge digested for 40 days between 30° C and 37° C shows a reduction of volatile solids of less than 17%, the sludge has been adequately stabilised. **Option 3**: Demonstrate vector attraction reduction with additional aerobic digestion in a bench-scale unit **Option 4:** Meet a specific oxygen uptake rate for aerobically treated sludge **Option 5:** Use aerobic processes at a temperature greater than 40° C (average temperature 45° C) for 14 days or longer (e.g. during sludge composting) **Option 6:** Add alkaline material (typically lime) to raise the pH under specific conditions **Option 7:** Reduce moisture content of sludge that does not contain un-stabilised solids (from treatment processes other than primary treatment) to at least 75% solids **Option 9:** Inject sludge beneath the soil surface within a specified time, depending on the level of pathogen treatment **Option 10**: Incorporate sludge applied to or placed on the surface of the land within specified time periods after application to or placement on the surface of the land.			

Pollutant class

Pollutant class is determined from a full total elemental analysis of the sludge. The most common elements monitored for toxicity are listed in Table 3. Sludge, which comes exclusively from domestic sources, such as pit latrines, is considered class ***a***. Sludge that has been treated at a wastewater treatment works, however, must undergo a pollutant analysis to determine its classification.

Table 3: Pollutant class definitions

Pollutant class	a	b	c
Arsenic (As)	<40	40-75	>75
Cadmium (Cd)	<40	40-85	>85
Chromium (Cr)	<1200	1200-3000	>3000
Copper (Cu)	<1500	1500-4300	>4300
Lead (Pb)	<300	300-840	>840
Mercury (Hg)	<15	15-55	>55
Nickel (Ni)	<420	420	>420
Zinc (Zn)	<2800	2800-7500	>7500

These guidelines provide background and practical guidance on deep row entrenchment of sludge. While two of the applications addressed in the guidelines can be used for either VIP sludge or WWTW sludge, it is important to keep in mind that separate analyses of these different sludges should be made before application as they differ in several key respects:

- While VIP sludge can be expected to have a low pollutant content because it originates exclusively from domestic sources,[1] it is less stable than WWTW sludge and water-soluble elements have not yet been removed, with the result that greater movement of pollutants through the soil and water table might be seen[2].
- Because WWTW sludge originates from multiple domestic, commercial, and industrial sources where pollutant disposal may fluctuate widely over time and from one treatment works to another; the pollutant level of WWTW sludge can never be assumed and must always be assessed, along with the receiving soil, before application, to ensure that the combined loading of pollutants at the entrenchment site will not pose a threat to the environment.
- While processes at the WWTW may have reduced the presence of pathogens in WWTW sludge significantly, both WWTW sludge and VIP sludge can be assumed to have viable pathogens and should be treated as hazardous materials. However, because the odour of WWTW sludge has been reduced significantly through stabilisation, it will not attract vectors to the extent that VIP sludge would. In addition, as the smell of WWTW sludge is less offensive it can be applied at closer proximity to settlements than VIP sludge without creating a nuisance. Sludge from pits which have not been disturbed for some time (e.g. in twin pit systems) may also have stabilised to the point that it has no odour.
- Volume 4 of the *Guidelines* addresses two types of applications of wastewater sludge at higher than agronomic rates: once-off application of less than three times in a five-year period, or continuous high-rate sludge application, a method which requires less stringent planning and monitoring, which is more than three times in a five-year period. With deep row entrenchment, sludge is normally applied on a crop planting/harvest cycle, which is typically longer than five years, and thus could be categorised as “once-off” application. However, entrenching sludge in deep rows allows sludge to be applied at much higher rates, making it necessary to consider some of the implications addressed in the guidelines for “continuous high-rate sludge application.”

GUIDELINES FOR DEEP ROW ENTRENCHMENT OF FAECAL SLUDGE AND WASTEWATER TREATMENT SLUDGE

Aim

The purpose of these guidelines is to facilitate the viable and beneficial use of sludge through entrenchment within the leanest framework of restrictions and requirements that can adequately protect the environment and public health.

Scope

The guidelines presented here are intended to provide a practical framework for entrenchment of both biosolids (i.e. sludge from wastewater treatment works) and faecal sludge (i.e. sludge from on-site sanitation systems) which adequately protects the environment and public health while avoiding excessive measures which could prove prohibitive to the implementation of this method both in terms of costs and time. Volume 4 of the *Guidelines* forms the basis of many of the recommendations, in addition to the

[1] This assumption could, however, be questioned on the basis that pit sludge often contains solid waste, the more so if a solid waste collection service is not provided. Waste associated with home businesses could potentially contain pollutants. Sampling and testing of the waste may therefore be appropriate.
[2] Heidi Snyman, pers. comm.

experience gained with entrenchment in the trials conducted in this study as well as earlier trials conducted abroad. While these recommendations may prove over time to be overly conservative, they are intended to ensure that all variables are considered. As more experience is gained with this disposal method in practice, it is expected that these guidelines will continue to be revised until they reflect a solid understanding of the interactions between entrenched sludge and the surrounding environment.

The following guidelines provide options for the application of the deep row entrenchment method for both faecal sludge and biosolids:

❖ *Commercial entrenchment (faecal sludge or biosolids)*

This would involve a larger scale partnership between a municipal wastewater treatment works and a forestry company in which the sludge generated within a municipality is transferred to a forestry company through some mutually beneficial arrangement. Alternatively, the municipality might contract a forestry company to manage a timber crop on entrenched sludge on municipal land. This option may also apply to entrenchment of sludge for rehabilitation purposes or on lands supporting other crops (e.g. sugarcane). **Commercial entrenchment will require both Environment Impact Assessment and Water Use License processes to be followed.**

❖ *Decentralised entrenchment (pit latrine sludge or treatment works sludge)*

This option involves entrenchment of sludge on relatively small tracts of land, particularly in rural areas where utilising sludge close to its point of origin on smaller plots represents a significant saving compared with transporting sludge long distances for more centralised use/disposal. Trees or other non-edible crops would be grown on the sludge.

❖ *Burial of sludge on household premises (pit latrine sludge)*

This option provides for situations where there is space at the site where a pit is emptied for the sludge to be entrenched on site. The entrenchment of the sludge provides a protective barrier over the pathogens, and the planting of trees provides a means to derive some benefit from the nutrients in the sludge.

HOW TO USE THESE GUIDELINES

The *DRE Guidelines* complement the South African *Guidelines for the Utilisation and Disposal of Wastewater Sludge* and should be used in conjunction with those guidelines. Each chapter provides a description of the specific deep row entrenchment (DRE) application and details the various aspects to consider when planning for DRE. Users of these guidelines that are considering options for faecal sludge from on-site sanitation systems should also consult the *Guidelines for FSM Collection, Disposal, and Valorisation* (WRC, 2022).

To accompany this guide, a DRE Guideline Toolbox has been created using MS Excel. The Toolbox automates some of the calculations required in decision making and provides an overview of general options that sludge producers can consider when considering sustainable sludge disposal and recycling. Chapter 4 of this document provides an overview of how to use the DRE Guideline Toolbox.

1 COMMERCIAL DEEP ROW ENTRENCHMENT

Both faecal sludge and biosolids can be entrenched within a commercial site. If done in a commercial plantation, this option reduces the costs and problems associated with other disposal options and yields an economic benefit in terms of greater biomass of timber produced. While fruit trees and food crops with edible parts grown above the soil could benefit from the nutrient supply provided by entrenched sludge, the possibility of the covering layer of soil being disturbed by heavy rains or activities and thereby exposing pathogens in the sludge makes it an inappropriate option for commercial production of food. Class ***A*** sludge, which has been treated to destroy pathogens, may, however, be used to grow food commercially either through surface application, shallow incorporation, or deep row entrenchment. Commercial DRE can also be used for land rehabilitation, for example, where surface mines have been decommissioned.

1.1 LEGAL REQUIREMENTS

The sludge producer and sludge user must have a legal agreement/contract if the sludge is utilised by a third party.[3] Formal application must be made to the competent authority for authorisation of the proposed activity at the proposed site. Details for this process can be found in the Environmental Impact Assessment (EIA) Regulations (GN No. R. 660 of 30 July 2010). The applicant must appoint an Environmental Assessment Practitioner (EAP) to prepare the necessary basic assessment, scoping report or EIA, including handling the public participation process required for obtaining authorisation. A rejected application can be appealed; in addition, it is possible to apply for exemption from the process. Practical guidelines on this process can be found in the *EIA Guideline and Information Document Series* prepared by the Western Cape Department of Environmental Affairs & Development Planning (DEA&DP) (2013).

The costs and benefits to stakeholders in the local community must be assessed prior to commencing the activity, in addition to needs and rights. If an environmental impact assessment is required, a public participation process must be undertaken.

Licensing

Centralised DRE will require sludge producers and users to go through **EIA** and **WULA** processes. The results from this WRC study make a case for limited environmental impacts from DRE. However, the costs and time associated with these processes may make DRE impractical, especially for small municipalities. At a very large scale, the benefits may begin to outweigh the costs and inconvenience of these processes.

For guidance on the EIA process, check out *EIA Guideline and Information Document Series* prepared by the Western Cape Department of Environmental Affairs & Development Planning (DEA&DP) (2013). Click here.

For guidance on the WULA process, visit the DWS website. Click here.

A Water Use Licence (WULA) will likely be required for all commercial DRE applications. Firstly, only sites authorised for forestry with a WULA may practice forestry. Secondly, in terms of Section 21(g), a WULA may be required for "disposing of waste in a manner which may detrimentally impact on a water resource." Guidance on how to apply for a WULA can obtained from Department of Water and Sanitation.

[3] The conditions, which must be included, are provided in the Guidelines for the utilisation and disposal of wastewater sludge, Volume 4, Appendix 3.

Once the applicable permits and authorisations have been granted, management and monitoring of the entrenchment site becomes self-regulatory. The Department of Water and Sanitation (DWS) will provide a list of the records that must be kept by the sludge producer and disposal site owner/operator.

1.2 FINANCIAL VIABILITY

To determine whether deep row entrenchment of sludge on commercial land is a viable option for a sludge producer, a cost benefit analysis should be conducted to determine:

- The current expenditure on sludge disposal versus anticipated expenditure for disposal of sludge by entrenchment. Can expenses be reduced by simplifying or bypassing some stages of treatment at the works, which are not essential for sludge destined for entrenchment? The costs of testing sludge for pollutant levels before disposal must be added in.
- The current expenditure on transport to the disposal site versus anticipated expenditure for transport to a deep row entrenchment site (including worker and public safety measures and measures to address contamination of vehicles if sludge is currently not transported off site)
- Income, if any, generated by existing disposal alternatives versus anticipated income generated by deep row entrenchment
- Period for which this cost benefit analysis can be expected to apply: Can the designated site accommodate all the sludge generated at the works or will it reach capacity after a certain number of years? How often can sludge be entrenched, or will it be stockpiled at the works during the growing cycle?[4]

Similarly, a cost benefit analysis should be conducted by the commercial partner to determine:

- Increased / decreased costs of obtaining, developing, and operating a site for deep row entrenchment due to more stringent environmental impacts (limitations on site selection, preparation of trenches, entrenchment equipment, monitoring, savings on fertiliser, protective equipment, and training for personnel)
- Willingness (if any) to pay for the sludge supply
- Anticipated increased savings/profits resulting from entrenchment (e.g. increased crop production, use of recycled nutrient/carbon source)

If the sludge is to be used for the restoration of habitat, a similar cost benefit analysis can be conducted to determine the viability of deep row entrenchment in contrast with alternatives.

[4] Note that while stockpiling of sludge at treatment plants is not technically legal, it is a common practice at many South African WWTWs. DRE may be a good solution for dealing with large amounts of stockpiled sludge.

What about other crops?

While the study that these guidelines emanate from focused on DRE of sludge in timber plantations, the same approach can be used on land used for other crops (e.g. sugarcane, which is a common crop in South Africa). eThekwini Municipality disposed of sewage sludge in sugarcane plantations (surface application) over a period of three years, and this was considered a sustainable approach. Doing the same thing using DRE would simply require digging trenches to bury the sludge. In this case, more sludge could be applied over a given area since sludge is buried. Since sugarcane has a shorter growing cycle and different nutrient-uptake characteristics compared to *Eucalyptus*, research should be done to investigate the accumulation of nutrients and pollutants in sugarcane plots with entrenched sludge.

One benefit of using DRE on crops, other than timber, is that digging trenches and burying sludge will be much simpler without the stumps and roots encountered in plantations.

1.3 SITE CHARACTERISATION AND SELECTION

A site with any of the following characteristics should not be considered for deep row entrenchment unless mitigation measures can be taken to alleviate any potentially negative impacts:

- Within the 100-year flood line (wetlands, vleis, pans and flood plains) due to risk of water pollution.
- Unstable areas (fault zones, seismic zones and dolomitic or karst areas)
- Steep gradients (greater than 15°) due to potential for instability and erosion, and greater movement of pollutants
- Distance to fissured rock below surface less than three m
- Areas of groundwater recharges
- Highly permeable soils (>5 cm/s percolation rate)
- Areas immediately upwind of a settled area
- Natural habitat of endangered species which could be disturbed by entrenchment activity

If the site is to be surveyed for the first time, the following characterisations should be completed to assess whether the site is suitable and, if it is, to establish baseline data to be used to assess the impact of entrenchment on the environment over time. Characterisations should be submitted as expert reports with the EIA application:

- **Topography and hydrogeology:** Location and depth of hard, impervious layers and permanent and perched water tables should be characterised. The direction and flow of underground waters and potential for underwater drainage should be assessed.
- **Soil:** The surface and subsoil soils should be assessed in terms of structure, permeability, and cation exchange capacity (CEC) to indicate the extent to which the soil will retain contaminants and minimise leaching into the surrounding area. Soils should have a clay content of at least 20% and a pH of above 6.5 to limit mobility of metals. Lime can be added to the soil to raise the pH. A baseline analysis of the nutrients, trace elements and metals present in the soil should be conducted to assess the impact of sludge on native soil over time.

  The Department of Water and Sanitation provides two systems of assessing the metal content in the receiving soil depending on the use of sludge. In cases where sites with limited public access are used to cultivate industrial crops (e.g. timber), maximum permissible levels (MPL) are provided for metal concentrations for the receiving soil. For more details, refer to Part 4 of Volume 4 of the *Guidelines.* This system is designed for wastewater sludge. As household faecal sludge comes from domestic sources it is not expected to contain harmful levels of metals. However, if pits are used as receptacles for excessive trash and pharmaceuticals, faecal sludge *may* contain contaminants of concern.

- **Surface water:** If there are any rivers or streams near the site these should be identified and sampled to determine baseline values, which can be used for comparative purposes, should surface contamination occur during sludge entrenchment.
- **Groundwater:** The aquifer must be classified in terms of yield, depth, and strategic value. A buffer of 200 m should be maintained from surface water, boreholes and the recharge zone of major aquifers, sole-source aquifers, or other strategic aquifers. The hydraulic gradient should be determined to assess the position of the monitoring boreholes. Groundwater quality (up gradient and down gradient) should be assessed to establish baseline values for monitoring.
- **Site stability assessment:** An engineering assessment must be completed to inform the spacing and orientation of trenches. As a precautionary principle, the shear strength of sludge should be assumed to be zero. Trenches should be dug parallel to the ground contours, not parallel to the slope direction.

1.4 CHARACTERISATION OF SLUDGE

An initial characterisation of both the soil and sludge can provide information to optimise application rates and economic gain. These include:

- Physical characteristics: pH, total solids (TS), volatile suspended solids (VSS), volatile fatty acids (VFA)
- Nutrients: Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP) and potassium
- Metals and micro-elements
- Organic pollutants

Testing of sludge to determine pollutant loads must be done any time there is reason to believe there has been a change in the sludge stream at the wastewater treatment works or if there is reason to believe pollutants have been disposed of in a pit. Unless sludge has undergone special treatment to kill pathogens, it can be assumed that it poses a risk for disease transmission and safety measures should be followed for transport, handling, and burial.

While there are some restrictions on the use of microbiological class[5] ***B*** or ***C*** sludge or pollutant class ***b*** or ***c*** sludge for the growing of crops to be eaten by humans or livestock, there are no restrictions on any of the categories for industrial crops except for restricting public access where sludge with microbiological class ***B*** or ***C*** is applied to the surface. As proper burial overcomes the risk of human contact, deep row entrenchment can be considered for all sludge classes.

1.5 DESIGNING AND PREPARING THE SITE

The site should be designed and prepared to allow adequate access for heavy trucks and field equipment in all weather conditions.

Trenches should be dug parallel to the contours of the slope. Trench spacing and dimensions will depend to some degree on the results of the soil stability assessment and depth to the water table. Enough space

[5] See Introduction for sludge classification system

must be left to accommodate the vehicle, which is delivering the sludge, and the backfill heaped beside the trench without the trench collapsing. It is advisable to prepare test trenches to ensure that the desired dimensions and spacing of trenches are feasible for the specific site conditions.

In terms of the impact on degradation of entrenched sludge over time, optimal dimensions for trenches are 800 mm deep and 600 mm wide. This allows for burial of 500 mm of sludge. This could be reduced to 250 mm, which will save on the cost of excavating trenches, but it will reduce the amount of sludge that can be buried. The spacing between rows should be determined by standard practice for the intended tree species but should also take into consideration soil stability, with adequate space to accommodate the vehicles digging the trenches and delivering the sludge. Assuming a row spacing of three m between the centres of trenches 800 mm deep and 600 mm wide, this will allow for an application rate of 990 m^3 of sludge per hectare of plantation, allowing a covering of 300mm of soil over the entrenched sludge.

The backfill soil should be heaped over the trench to allow for settling and to prevent erosion. Monitoring boreholes should be located to intersect groundwater moving away from a disposal site.

1.6 HANDLING OF SLUDGE

Due to the likelihood of viable pathogens in sludge, it should be handled as a hazardous waste (containing infectious substances) during transportation. Transporters must be informed of the nature and risks of the load and carry accurate documentation. Hazchem placards should be fitted to the vehicles. All road accidents must be reported to the Department of Transport Local Authorities, the Competent Authority and the Department of Water and Sanitation, and steps must be taken to minimise the impact of any contamination on public health and the environment.

1.6.1 Storage

Storage of sludge at the disposal site is not recommended because of the issues of odour, vector attraction and potential contamination of the site surface or leachate. Sludge should ideally be delivered directly to the trench and covered with soil the same day. If storage of WWTW sludge on site cannot be avoided, it should be stored in a specially prepared pit to avoid surface contamination and covered securely so that it cannot be accessed by animals or other vectors. If sludge is stored in an area for more than 90 days, then the area is considered a disposal area and a disposal permit is required. VIP sludge should not be stored on site because of its higher vector attraction factor.

1.6.2 Preventing transmission of pathogens

It is recommended that sludge producers (municipalities, in most cases) provide regular (three monthly) deworming treatment to workers working with sludge and provide a full orientation to educate workers about pathogens, routes of transmission and procedures to protect their health before they begin work. Workers must wear protective gear while handling sludge to prevent infection by bacteria, viruses, or intestinal parasites in the sludge. Eggs can become airborne when sludge is handled and so it is important that workers wear masks, gloves, boots, and overalls when handling sludge. It is also critical that rigorous protocol be established to avoid transfer of pathogens to surfaces by wearing contaminated gloves, boots or clothing out of the site or when driving vehicles and to ensure that vehicle wheels do not become contaminated, carrying pathogens with them when they leave the site. It is also important that workers are provided with the means to disinfect their clothing so that contaminated clothing is not taken to their homes, increasing the likelihood of infection of their family members. Facilities should be provided at the site for workers to shower and disinfect their hands as needed during and at the end of their workday.

1.7 APPLICATION OF SLUDGE

1.7.1 Application rate

While the Department of Water and Sanitation recommends an application rate limit of 120 tonnes dry sludge/ha/year for surface and shallow incorporation of sludge, it also provides a formula for calculating a permissible application rate (PAR) which can be used to demonstrate that higher application rates can be safe for a particular soil without negatively impacting the environment.

The authorising authority may approve a higher application rate based on the characteristics of the site in terms of soil properties, depth to aquifer, type of aquifer, distance from surface water resource, and other characteristics. Entrenching sludge for forestry allows for far higher loading rates than would be possible on the surface and moderates the impact of metals in a few ways different to other utilisation options:

Application rate should consider:
Amount of sludge
Area available
Regulations
Environmental risks

The WRC research on DRE of wastewater treatment sludge suggests that the positive impacts on *Eucalyptus* yields are not very different whether 120 tonnes/ha or higher rates of sludge are applied. The optimum application rate would need to be investigated for other crops.

However, in cases where land area is limiting, it is also possible to bury larger amounts of sludge with little risk to pollution of the environment.

- While high loading rates for surface application of sludge for agriculture would dramatically increase the presence of pollutants in run-off, entrenched sludge at any loading rate should have no contact with surface water if application was completed without contaminating the soil surface.
- While surface application of sludge results in highly aerobic conditions, under which nitrification occurs rapidly and metals mobilise more quickly through the soil profile, entrenchment results in anaerobic conditions, resulting in slow release of pollutants from the sludge as tree roots introduce oxygen into the sludge over the course of several years.
- While landfill disposal creates conditions where sludge is entrenched and nutrients and pollutants have no means to move, except through the soil profile, deep row entrenchment involves the planting of trees or other crops, which take up nutrients, leachate, and metals, minimising the movement of these out of the trench. While uptake of high levels of metals in edible crops could represent a health risk, uptake by industrial crops represents no health risks.

While surface application is usually done yearly or more frequently, once-off application at high loading rates can be used with entrenchment to match the growing cycle of the crop. This also minimises human contact with sludge, as application is both far less frequent and, once applied, the covering soil provides a barrier between the sludge and workers.

Data from sites used for entrenchment in the US for nearly 30 years and sites currently in use in South Africa over three years indicates that application rates of 360 to 800 tonnes dry sludge/ha/year provide maximum benefit to trees and have not negatively impacted the environment. However, ideal loading rates and risk to the environment will vary depending on tree species, pollutant levels in receiving soil and sludge, and site factors such as soil permeability.

The permissible application rate (PAR) can be calculated as follows:[6]

$$\text{PAR} = \frac{\text{MPL} - \text{Soil}_{\text{conc}}}{\text{Sludge}_{\text{conc}}} * 3900$$

Where:

PAR	= permissible application rate (tonne/ha)
MPL	= maximum permissible level (mg/kg) (See Table 1)
$\text{Soil}_{\text{conc}}$	= the actual metal content of the soil (mg/kg)
$\text{Sludge}_{\text{conc}}$	= metal concentration in the sludge that will be applied (mg/kg)
3900	= conversion factor to account for soil density (1.3 t/m^3) and sludge incorporation depth of 300 mm

As discussed previously, these guidelines were put in place for management of wastewater sludge and are not designed for pit sludge, which may be less stable and more variable in terms of potentially harmful components. However, as pit sludge originates from domestic sources, it is not expected to contain high levels of pollutants. In the absence of parameters set specifically for pit sludge, the wastewater guidelines can provide a measure of safety in the entrenchment of faecal sludge.

1.7.2 Application method

Sludge should be delivered directly to trenches to prevent surface contamination and contamination of vehicles, which may drive over sludge deposited at the side of trenches. Trenches should be backfilled the **same day** with a minimum of 300 mm native soil cover. This will result in an overburden, which will subside over time. Should burial require more than one day, sludge should be covered by at least 200 mm of soil at the end of the day to avoid vector attraction.

1.7.3 Planting and care of trees

Trenches can be levelled at the time of planting, and trees can be planted using standard forestry practices. This study has found that trees planted on or between rows of entrenched sludge grow equally well, as sludge can be accessed laterally by roots. There is no need to plough the soil prior to sludge application.

Adding lime to soil

If pH of the receiving soil is below the recommended level of 6.5, lime should be added. The best time to do this is once sludge has been applied and buried. Lime can be spread evenly over the whole site after the DRE is complete. The lime will gradually work its way down into the soil, thus having the desired impact of raising the soil pH, which will make most contaminants less mobile.

It should also be noted that if lime stabilisation was used to stabilise the sludge before burial, the buried sludge will also have the effect of raising the soil pH.

[6] Guidelines Vol. 4 p. 22

PRACTICAL CONSIDERATIONS FOR APPLICATION OF SLUDGE:

Digging trenches

* Can be done **manually** using local labour or using a **TLB**
* Should be **parallel to site contours**
* To allow access to dug trenches by the truck, digging of trenches and sludge delivery should happen simultaneously on a well-planned schedule.

Accessing trenches

* Leave **enough space** so the sludge delivery truck may drive up perpendicular to trenches
* In timber plantations, the presence of tree stumps may preclude the use of plant for digging trenches and delivering sludge.

Applying the sludge (getting from truck to trench)

* If truck is perpendicular to trenches, tip the sludge into the trench. Then, spread it using spades or rakes until the sludge level looks even. **Note this option requires trenches to be spaced far enough to allow trucks to turn perpendicular to the trench** (10 metres suggested).
* If trenches are spaced such that trucks will not be able to safely turn perpendicular to the trenches, **a "cross-trench" or delivery trench can be dug**, which connects two adjacent trenches. In this way, the truck can reverse up to the delivery trench, tip the sludge, and then drive straight out. The sludge can then be spread to the trenches using spades or rakes until even.

Achieving correct sludge depths

* **Before delivering sludge**, determine how much sludge (i.e. how many truckloads) should be delivered to the trench to achieve desired depth
* If trenches are dug parallel to the contours (i.e. on contour), the sludge can be evened out across the length of the trench.
* To make it easier to see where the sludge level should end, insert wooden pegs in the trenches with markings that show sludge level.

Achieving correct cover depth

* Use pegs, as described above, to show the desired depth. Backfill the trenches until the pegs are buried.
* Otherwise, use as much excavated material in the backfilling process as needed to create a heap over the trench. **Backfill material should extend between 50 and 100mm above the surrounding soil** to allow for settling.
* If you have achieved an even sludge depth across the trench, your cover depth should also be even.

PPE

* Provide all workers with adequate PPE to protect them from contact with the sludge. This includes **heavy duty gloves, masks, gumboots, and work uniforms.**
* If possible, provide a **groundcover sheet** adjacent to all trenches prior to sludge application. Workers will stand on this and be required to clean their boots prior to stepping off, reducing the chance of environmental contamination.

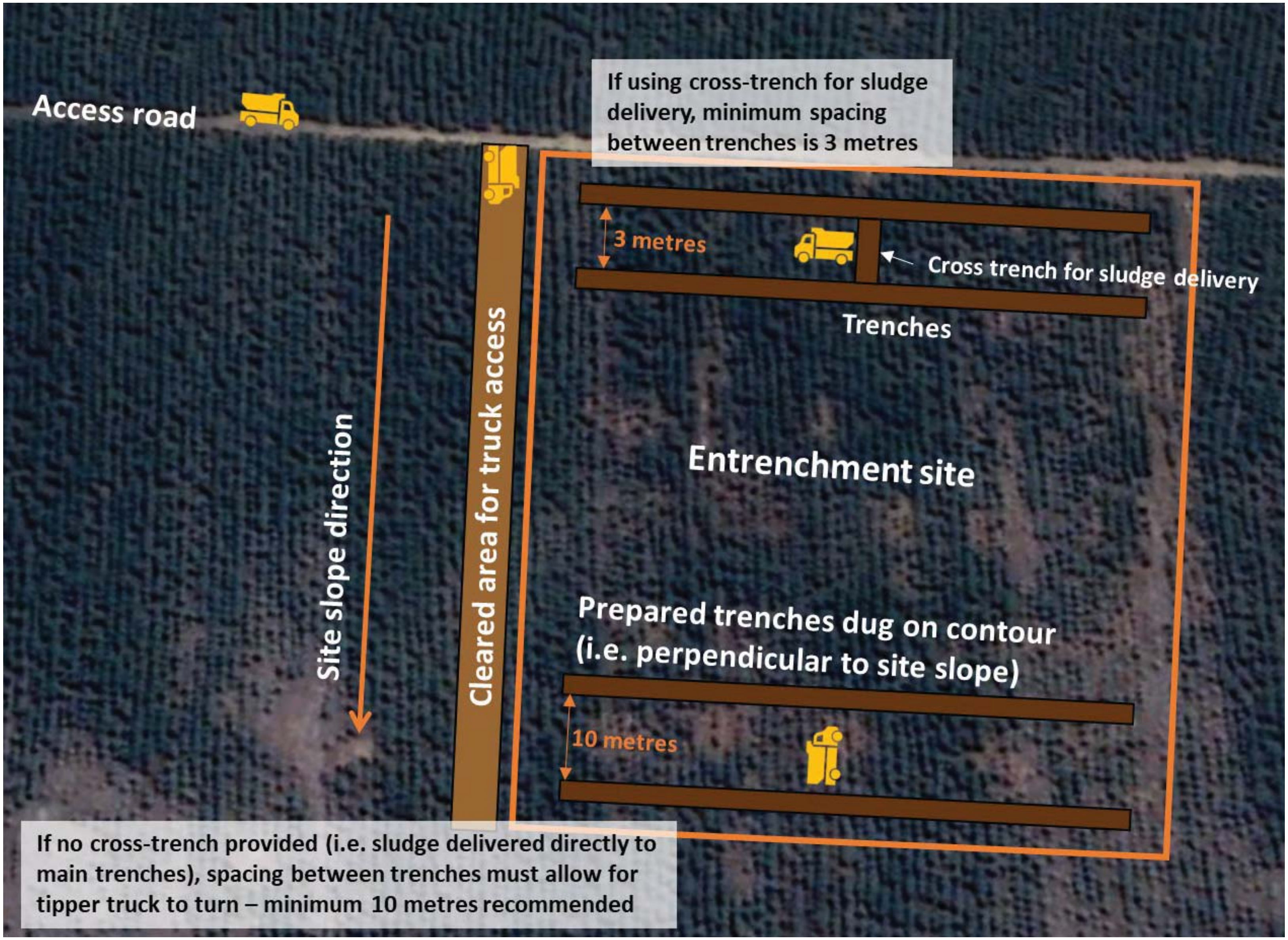

Figure 1: Example entrenchment site layout

1.8 MONITORING

It is the duty of the sludge user to ensure that both during and after the period that sludge is being actively utilised, the safety of groundwater is not compromised, and pathogenic material is safely contained. The baseline values of groundwater and soil should be established before sludge is entrenched at the site to provide a basis for assessing the impact of the entrenched sludge on the site over time. It should be kept in mind that unanticipated factors may arise which could alter the environmental impact of entrenchment during or after the period of use. For example:

- Heavy rains or flooding may cause pollutants and contaminants to rise to the surface or move further, more quickly or in higher concentrations through groundwater
- Encroachment of human settlement may reduce buffers, result in use of water near the entrenchment site for drinking which was not the case at the time of the site characterisation and increase the risk of human contact with contaminated areas
- Informal use of the site which may disturb sand covering which contains pathogens: e.g. sand winning, building, grazing

Should the sludge disposal site be affected by any of the above, sludge entrenchment should be suspended until conditions once again are conducive to continuation, if in fact this should occur.

Some basic guidance is provided below, but more detailed information on monitoring the site can be found in the *Guidelines for the Utilisation and Disposal of Wastewater Sludge*: Volume 4.

1.8.1 Surface and groundwater

Monitoring surface and groundwater on the site should include both microbiology (faecal coliforms and *E. coli*) and chemistry: alkalinity, organic nitrogen, nitrate-nitrogen, ammonium-nitrogen, chlorides, pH, COD, zinc, cadmium, copper, and specific conductivity. Nitrate-nitrogen ($N0_3$) should not exceed 10 mg/ℓ in groundwater if the water will be used for drinking. If the depth of the water table is less than 5 m, monitoring should be done three monthly for dry sludge and monthly for liquid sludge and during the rainy season. Composite samples should be collected and analysed 20-50 m upstream and downstream from the site and from any boreholes located within 1 km of the site. Less frequent monitoring may be adequate where the soil clay content is greater than 35%, where dewatered sludge is entrenched above a water table deeper than 10 m, or where liquid sludge is entrenched above a water table deeper than 20 m. In some cases, monitoring of groundwater may not be necessary due to the depth of the water table or other factors. This must be demonstrated through a study conducted by a qualified person. Detailed procedures and methodology for sampling and testing surface and groundwater are provided in the *Guidelines for the Utilisation and Disposal of Wastewater Sludge* (Volume 3, Appendices 1.3, 3 and 4.)

1.8.2 Soil

Monitoring of soil allows the movement of pollutants to be detected before they reach the groundwater, providing an early warning system. If sludge of pollutant class ***b*** or ***c*** is being used, soil must be monitored to ensure that metal content does not exceed the Maximum Permissible Level. (See Section 9.1.7.1). Increased concentrations of chloride provide a first indicator of the movement of elements and the possibility of contamination. The required frequency of monitoring will be determined by the clay content and pH of the soil and the water content of the sludge. If the site contains different soil types, different monitoring schedules may be necessary. Soils should be sampled at 100 mm intervals to a depth of at least 500 mm below the bottom of the trench. Crops can be monitored for uptake of metals throughout the growing cycle by comparing foliage samples with samples from crops in similar soils.

1.9 MANAGING RISKS TO ENVIRONMENT AND PUBLIC HEALTH

If sludge has been deposited directly from the transport vehicle into trenches without spilling and covered with 300 mm soil, there is no need to restrict access to the site for the public who may use the forest recreationally. This level of control will likely not be possible, and contamination is likely to occur. If any surface area has been contaminated by contact with sludge during application, those areas should be covered with an additional 300 mm of soil or fenced off for 3 years with signage clearly indicating a biohazard. If general contamination of the site has occurred, the entire site should be restricted for a period of 3 years with all workers entering the site wearing appropriate protective equipment and trained in procedures to protect themselves from infection with pathogens.

Run-off from a site with surface contamination should be prevented from leaving the site by constructing cut-off trenches or bund walls down-gradient of the entrenchment site to intercept run-off. The bund wall must be high enough to intercept the surface run off with 0.5 m to spare. The water must be recycled on site or treated before it is discharged. Similarly, if groundwater monitoring indicates elevated levels of pollutants in the leachate, leachate should be collected in a drainage pond and recycled or treated. Planting of vegetation can also be used to take up ground and surface water and slow movement from the site.

1.10 CLOSURE OF SITE

If entrenchment is to be discontinued at the site, an aftercare plan should be developed to manage potential ongoing risks to public health or the environment dependent on the planned future use of the site by the forestry company. Soil samples should be assessed for pathogen viability and levels of metals and nutrients, which could migrate to the groundwater over time. If there does seem to be a risk, the plan should include ongoing monitoring until the risk is resolved and should address issues of ongoing restriction of the site to people, animals or agricultural use if needed to protect public health. If the final rotation of trees has been harvested, a final planting of trees or other plants can be used to assist with the management of both issues, preventing contact with pathogens by humans or animals through digging or farming and providing a sink for nutrients and limiting the movement of soil water, which may contain pollutants.

2 DECENTRALISED ENTRENCHMENT

Entrenching VIP sludge, septic tank sludge, raw sewage or treated sewage at small, decentralised sites near the source of the sludge has several advantages over transport to and treatment at municipal wastewater treatment works (WWTW):

- Operations can be handled by a small business
- Lower transport costs
- Minimal overhead and infrastructure required
- Minimal skills required for daily operation (no complex processes or machinery to manage)
- Timber or fruit can be grown to benefit the local community

- Easier for small or rural municipalities to set up than hazardous waste sites (less red tape)

Deep row entrenchment of faecal sludge planted with trees can provide effective management of risks that would be involved with landfill disposal of faecal sludge:

- Direct entrenchment of sludge and burial the same day prevent contamination of surfaces or equipment with pathogens
- Small, dedicated sites with restricted access provide the control of a hazardous waste landfill without the red tape
- Solid waste disposed of in VIPs is automatically co-disposed of with sludge, with the potential for disposal of other solid waste with the sludge if needed
- Planting of trees creates a nutrient sink, reducing movement of potentially harmful nutrients from the trench
- Utilisation of sludge by trees allows for repeated disposal of sludge at the same site over cycles of entrenchment and harvest, unlike landfills where re-use of site can only be done by adding additional layers

Deep row entrenchment of faecal sludge is also a better option than sending it to a centralised WWTW for a few reasons:

- Most WWTWs are not designed to handle concentrated sludge generated in on site sanitation systems
- Smaller, decentralised DRE sites can reduce transport costs compared to transport to a centralised WWTW

2.1 LEGAL REQUIREMENTS

In the future, regulations may be promulgated to allow the concentration of faecal sludge such that, for example, the waste from an entire small village could be entrenched on one site. However, South Africa's Waste Management Act and Environmental Management Act currently preclude this option without following the kinds of processes outlined in the foregoing sections of this guideline. Therefore, the guidance provided in Section 1.1 should be followed, **requiring both EIA and WULA processes.**

2.2 SITE CHARACTERISATION AND SELECTION

Requirements for site selection and characterisation in terms of environmental and public safety are the same as for deep row entrenchment for forestry and can be found in Section 1.3 of this document.

The following factors should be considered to assess the long-term viability of the operation:

- Is the site large enough to accommodate the volume of sludge it will receive over the growth cycle (trench size/volume/size of community serviced/planting cycle – i.e. trenches that are planted are tied up for 6-9 years, can stockpiling be avoided?)
- Distance to source of sludge and means of transport (are VIPs that will need emptying in future years located further from the burial site?)
- Access to site for vehicles transporting sludge

2.3 CHARACTERISATION OF SLUDGE

While the characteristics of VIP sludge, in contrast to WWTW sludge, may be highly variable from pit to pit, the following assumptions can be made:

- Microbiological content: Pit sludge can be expected to contain high levels of viable pathogens and therefore can be assumed to have a microbiological classification of c.
- Stability: Unless a particular pit has been left unused for more than a year, VIP sludge contains both fresh sludge and sludge, which may be several years old, representing all stability classes. Because it does contain some fresh, unstable sludge, it must be classified as Stability class 3, requiring vector reduction that is provided by covering it with earth during entrenchment.
- Pollutant content: VIP sludge can be assumed to contain low levels of pollutants because it originates from domestic sources.

Based on the above assumptions, sludge from on-site sanitation systems can be assumed to have a sludge classification of C3a. Based on the *Guidelines*, C3a sludges are only appropriate for non-agricultural beneficial use (e.g. DRE) or further treatment processes.

2.4 DESIGNING AND PREPARING THE SITE

Trenches should be dug parallel to the ground contours. Trench spacing and dimensions will depend on the spacing of trees. It is advisable to prepare test trenches to ensure that the desired dimensions and spacing of trenches are feasible for the specific site conditions.

In terms of the impact on the degradation of the entrenched sludge over time, optimal dimensions for trenches are 800 mm deep and 600 mm wide, spaced 2.4 m apart edge to edge (or further apart). This will allow for an application rate of 990 m^3 per hectare with 300 mm backfill covering the sludge. The backfill over the trenches should be left heaped or ridged until planting to allow the backfill to settle and prevent erosion. Monitoring boreholes should be located to intersect groundwater moving away from a disposal site.

Provision should be made at the site for cleaning, disinfection and storage of equipment and protective gear, which may have come into contact with pathogens in the sludge. Facilities should be provided at the site for workers to shower and disinfect their hands as needed during and at the end of their workday. Workers should not be required to take work overalls or boots home for cleaning due to the risk of transmitting diseases from contaminated clothing.

2.5 HANDLING OF SLUDGE

Guidelines for safe transport and preventing the transmission of pathogens during the handling of sludge are provided in Section 1.6 of this document. VIP sludge should not be stored at the disposal site due to its vector attraction factor.

2.6 APPLICATION OF SLUDGE

Sludge should be delivered directly to trenches to prevent surface contamination and contamination of vehicles, which may drive over sludge deposited at the side of trenches. The trenches are then backfilled with a minimum of 300mm native soil. Sludge should be covered the same day it is delivered to the trenches to prevent odour and attraction of vectors. Particularly if sludge burial takes place over multiple days, the sludge should be covered with at least 200 mm of soil to eliminate odours and vector transmission, as shown in Figure 2.

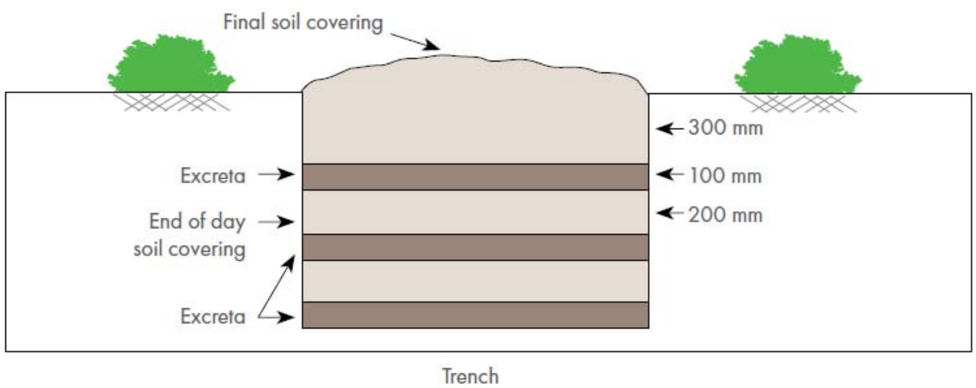

Figure 2: Disposal trench for sludge from on-site sanitation systems (Red Book, Section K)

2.7 PLANTING OF TREES

Trees may be grown to produce timber for building, fencing, fuel or for the paper and pulp industry. Species, which have a high demand for water, will assist in absorbing the leachate produced by sludge, reducing the risks of groundwater contamination. Trees with some nitrogen-fixing capacity, such as wattle (*acacia mearnsii*) will benefit less from increased nitrogen loading through sludge. While fruit can be grown safely on trees planted on sludge buried on site at households, fruit should not be grown commercially for sale unless adequate measures are taken to disinfect the fruit from possible surface contamination. A variety of other crops can be considered for planting over buried sludge, such as maize, sugarcane, or wheat, but current research in South Africa does not provide information about the responses of these crops to sludge.

2.8 MONITORING

It is the duty of the sludge user to ensure that both during and after the period that sludge is being actively utilised the safety of groundwater is not compromised, and pathogenic material is safely contained. Baseline values of groundwater and soil should be established before sludge is entrenched at the site to provide a basis for assessing the impact of the entrenched sludge on the site over time. It should be kept in mind that unanticipated factors may arise which could alter the environmental impact of entrenchment during or after the period of use. For example:

- Heavy rains or flooding may cause pollutants and contaminants to rise to the surface or move further, more quickly or in higher concentrations through groundwater
- Encroachment of human settlement may reduce buffers, resulting in use of water near the entrenchment site for drinking, which was not the case at the time of the site characterisation.

2.9 SURFACE AND GROUND WATER

Monitoring of water on the site should include both microbiology (faecal coliforms and *E. coli*) and chemistry: alkalinity, organic nitrogen, nitrate-nitrogen, ammonium-nitrogen, chlorides, pH, COD, zinc, cadmium, copper, and specific conductivity. Nitrate-nitrogen ($N0_3$) should not exceed 10 mg/ℓ if the water will be used for drinking. If the depth of the water table is less than 5 m, monitoring should be done three monthly for dry sludge and monthly for liquid sludge and during the rainy season. Composite samples should be collected and analysed 20-50 m upstream and downstream from the site and from neighbouring residential wells. Less frequent monitoring may be adequate where the soil clay content is greater than 35%, where dewatered sludge is entrenched above a water table deeper than 10 m, or where liquid sludge is entrenched above a water table deeper than 20 m. In some cases, monitoring of groundwater may not be necessary due to the depth of the water table or other factors. This must be demonstrated through a study by a qualified person. Detailed procedures and methodology for sampling and testing surface and groundwater are provided by DWS (Herselman & Snyman, 2009).

2.9.1 Soil

Monitoring of soil allows the movement of pollutants to be detected before they reach the groundwater, providing an early warning system. The required frequency of monitoring will be determined by the clay content and pH of the soil and the water content of the sludge. If the site contains different soil types, different monitoring schedules may be necessary. Soils should be sampled at intervals to a depth of at least 500 mm below the bottom of the trench.

2.10 PROTECTING PUBLIC HEALTH AND THE ENVIRONMENT

Animals and the public must be restricted from sites, which are in use for burial of VIP sludge to prevent sludge being disturbed, and pathogens spread. The site should be fenced securely with a gate that is locked when workers are not on the property. Stringent protocols must be followed by workers to prevent the spread of pathogens via vehicle wheels, tools, or protective wear as they enter and exit the site.

2.11 CLOSURE OF SITE

If entrenchment is to be discontinued at the site, soil samples should be assessed for pathogens and metals, and viability and levels of metals and nutrients, which could migrate to the groundwater over time. If there is a risk of ongoing contamination, an aftercare plan should be developed to manage potential threats to public health or the environment; dependent on the planned future use of the site by the municipality or the company that owns the site until year soil sampling indicates that the levels of pathogens and metals have reduced to within acceptable limits. A final planting of trees or other plants on the site can assist with preventing contact with pathogens by humans or animals through digging or farming.

3 ON-SITE BURIAL OF SLUDGE

Depending on the status of public health in the area, faecal sludge found in on-site sanitation systems (e.g. VIP latrines and urine diverting dry toilets) might contain significant levels of pathogenic organisms. This sludge is therefore regarded in South Africa as hazardous waste, and therefore becomes problematic to transport and dispose if it is concentrated in large volumes (as borne out by the preceding section of this guideline). By far the least cost lowest risk disposal option is to bury the faecal sludge close to the containment system from which it was abstracted. This will have less impact on the groundwater than the pit from which it was abstracted, as most of the sludge removed from the pit is stabilised.

In the future, regulations may be promulgated to allow the concentration of faecal sludge such that, for example, the waste from an entire small village could be entrenched on one site. However, South Africa's Waste Management Act and Environmental Management Act currently preclude this option without following the kinds of processes outlined in the foregoing sections of this guideline.

Sludge that is removed from an on-site sanitation system can be buried on-site if the homeowner agrees and if an appropriate burial site can be found. On-site burial of faecal sludge reduces the risks (in terms of disease transmission) and costs of transporting faecal sludge to a disposal or treatment site. This option also eliminates the costs and difficulties involved with treatment or other disposal options.
To utilise the sludge beneficially, trees, which yield fruit, building material, shade or fuel, can be planted above or alongside the buried sludge, with the following benefits:

- Nutrients which could potentially contaminate the groundwater are taken up by the trees
- Nutrients available in sludge improve the quality/quantity of fruit or wood, enhancing food security or economic security
- Householders' health risks are minimised, as they are unlikely to expose the pathogens buried in sludge through digging, planting, or play if trees are planted over the burial site(s).

3.1 SITE SELECTION AND PREPARATION

No permit or notification of authorities is required for on-site burial of sludge from a dry on-site system. However, as burial of sludge on site essentially involves digging small pits, the same variables should be considered for site selection as those for on-site sanitation systems, such as Ventilated Improved Pits (VIPs). In particular, the following factors should be considered in siting burial locations for sludge on site:

- If groundwater is present in the pit, sludge should not be buried at locations lower on the site and should be placed in shallower holes.
- On-site burial should not be used in very sandy or gravelly soils because of the potential of groundwater contamination. (See Section 2.3)
- Burial holes should not be located on eroded banks or cutaways where activity could erode the vertical face into the sludge itself, exposing pathogens.
- Burial holes should not be located within 15 m of a stream.

Holes or trenches should be prepared of adequate proportions to contain the sludge while also allowing for 300 mm of soil backfill on top of the sludge surface. This cover is partly to keep animals and people away from the sludge, and partly to provide space for trees to be planted above the sludge.

The volume of sludge removed from a full VIP will depend on the dimensions of the pit. Typically, the volume will range between 1.5 m^3 and 2.5 m^3. Assuming a volume of 2.0 m^3, the recommended dimensions for a disposal pit are 2 m long by 1 m wide by 1.3 m deep. Alternately, a pit that is 1.4 m by 1.4 m dug to the same depth will have the same capacity. Depending on soil conditions and the desired number and location of trees to be planted, sludge can also be buried in a trench or divided between several different planting holes. If a single disposal trench is used rather than a pit, the recommended dimensions would be 8 m long by 0.5 m wide by 0.8 m deep.

3.2 TRANSFER OF SLUDGE FROM CONTAINMENT TO BURIAL HOLES

Sludge may contain a variety of harmful pathogens. These can become airborne when the sludge is disturbed, meaning that they can settle on surfaces or enter workers' lungs. It is essential that workers removing sludge follow careful protocols to protect themselves as well as household surfaces.

Contamination can occur by workers placing contaminated tools or gloves on household surfaces (walking around in contaminated boots, laying tools on the ground, benches, etc), touching taps or door handles with contaminated gloves or hands, washing hands or equipment under household taps or borrowing householder tools or spilling sludge on the ground.

Basic principles to be kept in mind are:

- Pit emptiers must wear protective clothing (masks, overalls, gloves, and boots)
- Work areas (lip of pit, area where tools and equipment are placed) must be protected with tarpaulins to prevent surface contamination
- Workers must not use tools belonging to the household for pit emptying
- Workers must not wash contaminated tools, clothing, or hands at the household tap
- Any contamination which occurs must be remedied and the householder must be alerted

Pit emptiers should be provided with long handled tools, protective equipment for themselves and the site, drums for transporting the sludge and the necessary equipment to deal with contamination of surfaces should it happen (lime, clean shovel, stakes, tape). As an alternative to manual emptying, a portable vacuum pumping system, such as the Pitvaq (www.pitvaq.com), can be used, or even a vacuum truck if pit access is not a problem.

After tarpaulins are placed on the lip of the pit, a drum is placed on the tarpaulin. Workers remove the sludge from the pit into the drum using long handled shovels and rakes, or a vacuum pump. Tools are placed on the tarpaulin and the drum is carried to the disposal pit, where care is taken not to spill the sludge outside the pit. If any sludge is spilled it should be scraped up and disposed of in the pit, and the spill area should be doused with a disinfectant solution when the site is cleaned up.

Additional information on health, safety, and management while emptying can be found in:

Research Report: Louton, B., Beukes, L., Naidoo, D., and Still, D. (2018). *Understanding and Addressing the Exposure of Workers, the Public, and the Environment to Pathogens during Pit Emptying* (Annexure C). WRC Report No. 2134/1/18. Click here.

Training booklet: *Keeping yourself and others safe from diseases during vault emptying.* Click here.

Training videos: *Oh Shit! Health and safety management programme for pit emptying.* Click here.

3.3 PLANTING AND CARE OF TREES

After sludge is placed in the hole, the top 300 mm of the hole is backfilled with soil using a clean spade and the remainder of the soil that has been removed is heaped over the burial site. After trees have been planted over or near the disposal pits, householders should be provided with information on how to care for their trees (pruning, diseases, etc). The period that the buried sludge will provide an adequate nutrient supplement will depend on the tree species, nutrient values in the native soil and the quantity of sludge buried. Typically, the tree will not require any supplementary fertilisation for at least five years. After that, if necessary, householders can work manure and composted organic waste into the soil around the tree to provide additional nutrients. Based on research by Still et al. (2010), all pathogens should be inactive within three years after burial.

3.4 PROTECTING PUBLIC HEALTH AND IMPROVING SANITATION

Once sludge has been buried on site, clear instructions should be given to the householders that the sites should not be disturbed through digging or planting for a minimum of three years to prevent contact with buried pathogens, which may still be viable.

If any contamination of surfaces has occurred during transfer of sludge from the pit to burial holes, these areas should be scraped clean and then treated with disinfectant.

Diarrhoeal diseases are a significant cause of the high rate of death among children under five years of age in South Africa. These diseases are spread through contact with faeces which happens when a person does not wash his or her hands with soap after using the toilet or when open defecation is practiced. In addition, it is very common for residents of communities with a history of poor sanitation to be infected with intestinal parasites, which are also spread by contact with faeces. Both diarrhoeal diseases and intestinal parasites can pose a serious threat not only to young children but to the elderly and to individuals who are malnourished because of poverty or who have weakened immune systems because of HIV, TB, or other illnesses. It is therefore recommended that municipalities take advantage of pit emptying as a natural point in the cycle of on-site sanitation provision to provide hygiene education and deworming medication to all members of a household. The household should be provided with a dose to be taken immediately and a follow up dose to be taken after six months.

4 USING THE DRE GUIDELINE TOOLBOX

To compliment this guideline, the DRE Guideline Toolbox has been created as an MS Excel workbook, which automates some calculations and guides users through the determination of whether DRE is a good option for dealing with sludge from WWTWs or on-site sanitation systems. This section of the document presents the Toolbox and provides example calculations. Each sheet is presented in detail. It is important to note that while the Toolbox presents the various assessment steps in a specific order, these may be done in a different order depending on the project needs. For example, while the sheets assume that sludge will be characterised before an appropriate site is selected, this may not be the case if, for example, a municipal forest area requires soil enhancement, and from this need, sludge sources are identified. The toolbox is there to assist and can be used in whatever order is appropriate.

4.1 ABOUT THE DRE TOOLBOX

The first sheet in the workbook, titled “About the DRE Toolbox,” presents an overview of how to use the toolbox, including an overview of each sheet included in the workbook. Cells have been formatted based on the type of information included in them, to make it clear where users are mean to enter data. This information is presented in Table 4-1 as well as in this first sheet of the toolbox.

Table 4: Cell descriptions for the DRE Toolbox

DESCRIPTION OF CELLS		
Cell type	**Instruction**	**Description of formatting**
Data entry cells	Enter data in these cells	Thick cell border with white fill colour
Linked cells	Do not edit	Blue fill colour, regular (non-bold) text
Titles/labels	Do not edit	Cell filled with colour and with bold text
CLEAR CELLS	Click to clear cells	Red button with white text, linked to a macro that will clear the data entry cells on the sheet

4.2 SLUDGE PRODUCERS’ CHECKLIST

The Sludge Producers’ Checklist sheet provides an overview of the steps to consider before implementing deep row entrenchment. Though this tool may be used by sludge users who have an interest in the benefits of DRE, it is more likely that sludge producers will consider it as a low-cost, beneficial method for dealing with sludge. This sheet will be populated as the other sheets are filled out, and users will continually revisit this sheet to update the status of different tasks. A snapshot of this list is shown in Figure 4-1, showing the primary tasks to undertake:

1. Define the sludge to be entrenched
2. Identify available options for sludge handling
3. Identify an appropriate site for DRE
4. Determine the cost-benefit threshold for various options
5. Develop implementation and safety plan
6. Ongoing monitoring

As information is entered on the other sheets in the workbook, cells on this sheet will be populated. As the user completes various tasks from the above list, they can enter the status of the activity using drop-down menus under the “STATUS” column. An example of this is shown in Figure 1.

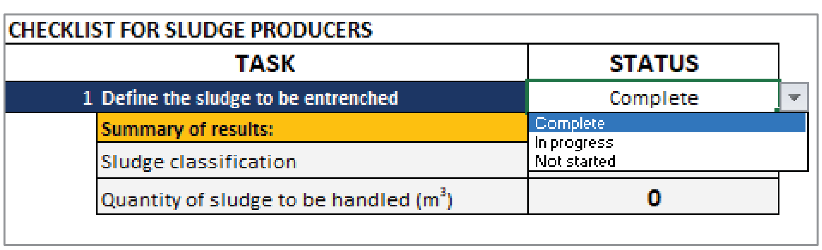

Figure 3: Example drop-down menu for selecting the status of tasks on the sludge producers' checklist

CHECKLIST FOR SLUDGE PRODUCERS

TASK	STATUS
1 Define the sludge to be entrenched	
Summary of results:	
Sludge classification	**A3a**
Quantity of sludge to be handled (m^3)	**0**

TASK	STATUS
2 Identify available options for sludge handling	
Summary of results:	
The following options are available to you based on the sludge classification:	
Agricultural use via surface application at agronomic	NOT RECOMMENDED
On-site or off-site disposal	NOT RECOMMENDED
Beneficial use (once-off high rate sludge application on PUBLIC ACCESS sites, e.g. DRE)	NOT RECOMMENDED
Beneficial use (once-off high rate sludge application on PRIVATE LAND, e.g. DRE)	YES
Further treatment (e.g. composting, drying)	YES

TASK	STATUS
3 Identify an appropriate site for DRE	
Summary of results:	
Site unacceptable	
hectares are available for sludge application	

4 Determine the CBA threshold

Summary of results (note this only accounts of transport and disposal and exludes any emptying or treatment

Option	Overall cost (ex VAT)	R/m^3 sludge	Hectares required
Status Quo	R0	R0	n/a
Deep Row Entrenchment	R100,000	#DIV/0!	0.0
Landfill Disposal	R50,000	#DIV/0!	n/a
Surface application	R100,000	#DIV/0!	0

Select preferred option	

Not covered in this toolbox:

TASK	STATUS	
5 Develop implementation and safety plan		**Refer to Sludge Guidelines Volume 1 to further assess options**
6 Ongoing monitoring		

Figure 4: Snapshot from DRE Toolbox - Sludge Producers' Checklist

4.3 SLUDGE CHARACTERISATION

The next sheet in the workbook provides a template for characterising sludge, both in terms of quantity and classification as per the *Guidelines*. The primary information entered for sludge characterisation is presented in Table 5, with a description of what information should be entered in each data entry cell. Some cells include drop-down menus as above while others are free-entry cells. For on-site sanitation systems, an additional set of cells are provided to help users estimate the quantity of sludge requiring emptying and disposal, based on the type of sanitation system used and the number of households. This is summarised in Table 6.

Table 5: List and description of fields to be completed on sludge characterisation sheet

1	Source (ON-SITE/WWTP):	Drop-down menu: On-site or WWTP
	Number of households	For on-site systems, enter number
2	Volume of sludge (m³):	Volume of sludge to be disposed
3	Type of application:	Drop-down menu: once-off or continuous
	Desired frequency of application (no. years)	If continuous, enter X, "every X years"
4	Existing sludge treatment processes? (Tick all that apply)	
	☐ Drying beds	
	☐ Anaerobic Digestion	
	☐ Chemical addition (specify chemical	Enter chemicals used
	☐ Heat Treatment (specify temperature:)	Specify temperature
	☐ Other (specify:)	Specify other treatment
4	**Has the sludge been characterised?**	Drop-down menu: yes or no
5	**Determine Microbial Class**	
	Faecal coliforms (CFU/g dry)	Enter number
	Helminth ova (Viable/g dry)	Enter number
6	**Determine Stability Class**	
	Sludge density (kg/m³)	Enter number
	COD level (mg/litre)	Enter number
	Moisture content of sludge (%)	Enter number
	Have you planned for or designed to comply with sludge stabilisation/vector control options?	Drop-down menu: yes or no
	Assume sludge stability rating= 3 OR consider vector control options in Appendix 3 of the Sludge Guidelines, Vol 1	Drop-down menu: Stabilisation options, *Guidelines*
	Prompt here based on stabilisation option selected above	Drop-down menu: based on option selected in above cell
	With what certainty can you meet the requirements of the option selected above? (This refers to the minimum frequency with which you can meet this requirement)	Drop-down menu: 75% or 90% confidence
7	**Determine Pollutant Class**	
	Arsenic (mg/kg)	Enter number
	Cadmium (mg/kg)	Enter number
	Chromium (mg/kg)	Enter number
	Copper (mg/kg)	Enter number
	Lead (mg/kg)	Enter number
	Mercury (mg/kg)	Enter number
	Nickel (mg/kg)	Enter number
	Zinc (mg/kg)	Enter number

Table 6: List and description of fields to estimate sludge produced from on-site sanitation systems

Total number of people served	Enter number (if unsure, assume 5 people per household)
Type of sanitation	Drop-down menu: dry vs. waterborne
Type of storage	For waterborne, drop-down menu: leach pit vs. septic tank
Flush volume	For waterborne, drop-down menu: low vs. conventional flush
Assumed accumulation rate (litres/person/yr)	Determined based on type of system entered above
Volume of sludge produced (m^3/yr)	Calculated based on above cells
Emptying frequency (no. years)	Enter X number of years between emptying programmes
Total volume of sludge (m3)	Calculated total volume based on sludge produced and emptying frequency

Based on the information entered in the cells, the sheet determines the sludge classification in terms of microbial, stability, and pollutant classes, as per the *Guidelines*. Based on the determined classification, different options for disposal are assessed for their appropriateness, based on the guidance in the *Guidelines*. Example outputs based on data from two different treatment plants are provided on the next two pages. The plant and sludge information provided comes from the *Guidelines for Utilisation and Disposal of Wastewater Treatment Works Sludge* (Snyman & Herselman, 2006), Volume 1: Part 7. This section of Volume 1 also presents an overview of appropriate management options for sludge based on its classification.

Example WWTP No. 1 (Snyman & Herselman, 2006)

Sludge was characterised using three grab samples, and the results are presented below:

Microbiological parameters	**Helminths (viable ova/g)**	5.7
	Faecal coliforms (CFU/g)	1.79E+06
Metals	**Arsenic (mg/kg)**	35
	Cadmium (mg/kg)	70.9
	Chromium (mg/kg)	2791
	Copper (mg/kg)	2920
	Lead (mg/kg)	3758
	Mercury (mg/kg)	7.7
	Nickel (mg/kg)	600
	Zinc (mg/kg)	20533

Description, taken from *Guidelines* (Snyman & Herselman, 2006): *This Plant produces waste activated sludge (WAS) and primary sludge that is anaerobically digested. The WAS and primary sludge [are] pumped to a heated anaerobic digester. The anaerobic digester has a sludge retention time of 19 days and a volatile solids (VS) reduction of 40% is achieved (95% of the time). The resulting anaerobic digested sludge (AD) is dried on drying beds (typically 40% dry solids).*

The microbiological parameters in the sludge are high and therefore it is classified as Microbiological class C. The Stability class classification is 1 since the Plant complies with at least one vector attraction reduction options (Option 1) > 90% of the time. The Ni, Pb and Zn contents of the sludge are high (Pollutant class c).

The output from the DRE Guideline Toolbox sludge characterisation sheet is shown below:

SLUDGE CLASSIFICATION	**C1c**
Microbiological	C
Stability	1
Pollution	c

The following options are available to you based on the sludge classification:

Agricultural use via surface application at agronomic rates	NOT RECOMMENDED
On-site or off-site disposal	YES
Beneficial use (once-off high rate sludge application on PUBLIC ACCESS sites, e.g. DRE)	NOT RECOMMENDED
Beneficial use (once-off high rate sludge application on PRIVATE LAND, e.g. DRE)	NOT RECOMMENDED, BUT POSSIBLE WITH SOURCE CONTROL
Further treatment (e.g. composting, drying)	YES

The results show that the sludge is classified as **C1c**, which agrees with Snyman and Herselmen (2009). Furthermore, the sheet shows a broad overview of which options are available for this sludge. Due to the high microbial and pollutant (i.e. heavy metals) contamination, this sludge is only appropriate for controlled disposal or further treatment. However, beneficial use, such as DRE on private land, is possible if source control is implemented (i.e. industrial effluent entering the WWTWs).

Example WWTP No. 3 (Snyman & Herselman, 2006)

Sludge was characterised using three grab samples, and the results are presented below:

Microbiological	**Helminths (viable ova/g)**	0
	Faecal coliforms (CFU/g)	3.66E+08
Metals	**Arsenic (mg/kg)**	23
	Cadmium (mg/kg)	5.6
	Chromium (mg/kg)	125
	Copper (mg/kg)	260
	Lead (mg/kg)	150
	Mercury (mg/kg)	8.2
	Nickel (mg/kg)	141
	Zinc (mg/kg)	2157

Description, taken from *Guidelines* (Snyman & Herselman, 2006): *Plant 3 is an activated sludge plant with nitrification, denitrification and biological phosphorus removal. There is no reduction in moisture content and currently the sludge is disposed on-site to dedicated land. Laboratory aerobic digestion tests (bench scale) at 20°C have shown volatile solids (VS) reduction of 17% after 30 days.*

The faecal coliform count of the sludge is high and therefore it is classified as Microbiological class C. The Stability class is 3 since tests done to proof compliance to vector attraction reduction option 3 was not achieved. The metal concentration of the sludge is low, and the Pollutant class is a.

The output from the DRE Guideline Toolbox sludge characterisation sheet is shown below:

SLUDGE CLASSIFICATION	C3a
Microbiological	C
Stability	3
Pollution	a

The following options are available to you based on the sludge classification:

Agricultural use via surface application at agronomic rates	NOT RECOMMENDED
On-site or off-site disposal	NOT RECOMMENDED
Beneficial use (once-off high rate sludge application on PUBLIC ACCESS sites, e.g. DRE)	NOT RECOMMENDED
Beneficial use (once-off high rate sludge application on PRIVATE LAND, e.g. DRE)	YES, WITH RESTRICTION
Further treatment (e.g. composting, drying)	YES

The results show that the sludge is classified as C3a, which agrees with Snyman & Herselman (2006)Furthermore, the sheet shows a broad overview of which options are available for this sludge. Agricultural use via surface application and beneficial use on public lands are both not recommended due to high microbial contamination and the unstable nature of the sludge. Disposal is also not recommended, as the sludge is low in pollution from heavy metals, making beneficial use or beneficiation the preferred option in terms of resource recovery and sustainability. Beneficial use (e.g. DRE on private lands) is possible if measures are taken to limit vector attraction and contamination, as described in the DRE Guideline.

4.4 SITE APPROPRIATENESS

The SITE APPROPRIATENESS sheet allows users to enter specific characteristics of the identified site to assess the suitability of that site for DRE. This assessment is based on physical characteristics of the site along with the metals content of the soil on the site. It is important to note that soil samples must be taken of the site and analysed for texture and metals content to complete this sheet.

The fields to complete on the physical characteristics of the site are shown in Table 7, along with the key criteria determining the site's appropriateness. Once data is entered, the sheet automatically determines if this site is appropriate.

Table 7: Fields and data to enter about physical site characteristics to determine site appropriateness

	SITE CHARACTERISTICS	Data	Criteria
1	Soil texture (%):		
	Gravel	Enter percentage	
	Sand	Enter percentage	
	Clay	Enter percentage	***>20%***
2	Soil pH	Enter number	***>6.5***
3	Driving distance from source to site (km)	Enter number	
4	Depth of water table (m)	Enter number	***>5 m***
5	Distance to surface water	Enter number	***>200 m***
6	Type of surface water	Drop down	
7	Distance to settlement/households (m)	Enter number	
8	Authorised for Forestry through EIA?	Drop down	***YES***
9	Within 1 in 100-year flood line?	Drop down	***NO***
10	Unstable? (Fault zone, seismic zone, or dolomitic/karst area)	Drop down	***NO***
11	Site gradient (degrees)	Enter number	***<15°***
12	Fissured rock below surface?	Drop down	
13	Permeability of soil (cm/s)	Enter number	***<5 cm/s***
14	Endangered species habitat?	Drop down	***No***
15	Space available for DRE (hectares)	Enter number	***> required***
16	Type of site	Drop down	
17	Public access to site	Drop down	

This sheet also provides an opportunity to assess the Permissible Application Rate (PAR) based on metals content of the sludge and the background soil. This was described in section 1.7.1 of the DRE Guideline. The Maximum Application Rate (MAR), as per the *Guidelines*, is 120 tonnes/hectare. If the PAR is lower than the MAR, then the PAR applies. If the PAR exceeds the MAR, a higher application rate may be possible. This requires special permission but may be worthwhile given that more sludge can be buried in a smaller area, reducing costs of DRE. At the bottom of this section, if the PAR exceeds the MAR, the user is prompted to decide whether they would like to override the MAR. If they do not, the MAR is used in further calculations.

Table 8: Data entry section for metals content in the site soil to determine Permissible Application Rate – sludge levels are based on WWTP #3 shown above.

Elements	Total Maximum Threshold (TMT), mg/kg	Background soil level (mg/kg)	Sludge level (mg/kg)	PAR (tonne/ha)
Arsenic (As)	2		23	339
Cadmium (Cd)	3		5.6	2089
Chromium (Cr)	350		125	10920
Copper (Cu)	120		260	1800
Lead (Pb)	100		150	2600
Mercury (Hg)	1		8.2	476
Nickel (Ni)	150		141	4149
Zinc (Zn)	200		2157	362
			OVERALL PAR	**339**

The PAR exceeds the Maximum Application Rate (MAR) of 120 tonnes/ha.

You may be able to get permission to apply amounts greater than 120 tonnes/ha, especially if you use deep row entrenchment. Deep row entrenchment has less environmental risks, as the sludge is buried and covered with soil.

OVERRIDE MAR?	

4.5 OPTION SUMMARY

The OPTION SUMMARY sheet provides a high-level financial assessment of a basic set of options for sludge disposal or utilisation. There are many other options available, which involve further beneficiation of sludge, but these are not included in this toolbox. The toolbox presents three basic options for disposal or utilisation. The options are listed below, along with the specific data that is required for the high-level cost analysis.

1. Deep row entrenchment
    a. Sludge burial depth desired (250 mm or 500 mm)
    b. Distance from sludge source to DRE site
2. Landfill disposal (the default option for many WWTPs)
    a. Distance from sludge source to landfill
    b. Gate fee
3. Surface application
    a. Distance from sludge source to surface application site

Additionally, some unit costs are used in the model, and the user can override these in white data entry cells if required (e.g. excavation cost). Based on the volume of sludge to be disposed of and the hectares required for DRE and surface application, costs are determined for each option in terms of total cost, cost per volume of sludge, and total hectares required. This ultimately demonstrates a high-level estimate of the cost-effectiveness of each option and allows users to compare the space efficiency of the utilisation options (DRE and surface application). As larger volumes of sludge can be applied through DRE than through surface application, space may be a limiting factor, more than cost.

A sample output from this sheet is provided in Table 9. The key assumptions in this calculation are presented below the table. With this information, the user of the Toolbox could consider the various options available and decide on the most appropriate option in terms of long-term sustainability, beneficiation, cost, land requirement, and others.

Table 9: Example output from Option Summary sheet, comparing options

Option	Overall cost (ex VAT)	R/m³ sludge	Hectares required
Status Quo	R0	R0	n/a
Deep Row Entrenchment	R129 500	R1 295	1.3
Landfill Disposal	R111 500	R1 115	n/a
Surface application	R118 500	R1 185	15

NOTE: Key assumptions:

1. *100 m^3 of sludge requiring disposal*
2. *Distance from sludge source to each destination is 20 km*
3. *DRE burial depth is 500 mm*
4. *Landfill gate fee is R350/tonne*
5. *No sludge disposal method is currently in use, so overall cost for the Status Quo is R0.*

4.6 FINALISING THE PROCESS

Once the user has gone through each sheet, they can revisit the SLUDGE PRODUCERS' CHECKLIST to indicate their final decisions. The final two steps in the DRE implementation process are developing a plan for implementation and health and safety, along with implementing ongoing monitoring. These processes are not included in the toolbox but should be implemented in consultation with relevant technical personnel. Furthermore, these tasks are supported by the DRE Guideline and the *Guidelines for Utilisation and Disposal of Wastewater Treatment Sludge* (Snyman & Herselman, 2006).