

**PREMISE FOR THE DEVELOPMENT OF VOLUME 1
AND 2 OF THE SOUTH AFRICAN SLUDGE GUIDELINES**

HG Snyman • JE Herselman

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Water Research Commission



PREMISE FOR THE DEVELOPMENT OF VOLUME 1 AND 2 OF THE SOUTH AFRICAN SLUDGE GUIDELINES

by

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“Permissible utilisation and disposal of sewage sludge”

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EXECUTIVE SUMMARY

BACKGROUND

Land disposal and agricultural reuse of sewage sludge currently has to comply with the guidelines as described in the 1st Edition of the Permissible Utilisation and Disposal of Sewage Sludge (WRC, 1997). These guidelines captures the requirements of the Department of Water Affairs and Forestry, National Department of Agriculture and the National Department of Health and deal with application of sewage sludge to land and, amongst other criteria, set permissible limits for concentrations of heavy metals in sludge suitable for unrestricted (limited to an average application of 8 ton/ha/year over 25 years) agricultural land use. Due to limitations of the guideline to only a few application possibilities and difficulty of interpretation, an addendum to the guidelines (WRC, 2002) was prepared to broaden the treatment and disposal possibilities for sewage sludge. This addendum links the handling and disposal of sewage sludge to several other legislative documents and was intended as an interim document to assist in the responsible handling of sewage sludge. In parallel to the development of the Addendum, the WRC initiated a research programme to further develop the knowledge base for the management of sewage sludge in the South African context. Although the results of these research projects do not give all the answers, they do enable the formulation of an updated (2nd Edition) version of Permissible Utilisation and Disposal of Sewage Sludge to combine the relevant aspects of the addendum and limits for metals, nutrients and organic pollutants based on scientific criteria to ensure credibility and user acceptance.

The overall objective of this project was to develop the second edition of the South African Sludge Guidelines entitled: "Permissible utilisation and disposal of sewage sludge". The development of the second edition of the South African Sludge Guidelines is a phased approach consisting of:

- Compiling a report detailing international sludge management and regulatory trends (Addressed in this report)
- Developing a concept document that details the proposed rationale and appropriate limits for the 2nd Edition of the South African Sludge Guidelines. (This document was distributed to the project Reference Group and specific identified stakeholders before the open workshop in preparation for the coming workshop.)
- Presenting the concept document in an open workshop to invite comments from legislators and stakeholders.
- Compiling the final draft sludge guidelines after incorporating the comments and suggestions from the workshop. (This document was tabled for discussion at a second workshop to debate and reach consensus on the rationale behind the sludge guidelines and the proposed limits and loads.)
- Compiling the final document

This report details the outcome of the first activity that was to establish and document the status quo situation internationally and gather local information emanating from recent research projects. To set the scene, the history of sewage sludge management legislation and guidelines in South Africa was documented.

INTERNATIONAL SLUDGE MANAGEMENT AND REGULATORY TRENDS

According to Dentel (2003) opinions and policies regarding sludge management differ widely internationally. The difference may be ascribed to two sources. The first may be broadly defined as geographical factors, including geo-political, technical, and economic constraints. The second may be considered as the philosophical or ethical factors in developing environmental policies, and specifically here, the acceptable practices for sludge disposal.

During this study, it soon became apparent that the US and Europe are actively debating sludge recycling and disposal, mostly due to the potential risks of the agricultural use of sludge to human health and the environment. However, in cases such as Europe, this debate was probably initiated due to recent health "scares" such as mad cow disease that have cast doubts on the safety of the food products on the markets and on the ability of existing regulations and controls to minimise human exposure to potential risks.

In Europe, the farming community play a prominent role in the decision whether sludge should be used beneficially in agricultural practices or not. Countries in favour of agricultural land spreading do so because this practice is considered economically viable and it is considered that the potential risks are sufficiently reduced by the existing legislation. A comparison with the national legal requirements also demonstrates that "tight" legal constraints (such as very low limit values for pollutants in sludge) do not necessarily imply a greater acceptance of the use of sludge in agriculture.

In the US, the Environmental Protection Agency and the wastewater treatment industry promote the recycling of sewage sludge. Approximately 5.6 million dry tons of sewage sludge are used or disposed of annually in the United States, approximately 60% of that is used for land application. The so-called Part 503 rule that governs land application of sewage sludge is intended to protect public health and the environment. The chemical and pathogen land-application standards in the Part 503 rule were developed differently. The chemical standards were developed based on extensive risk assessments and the pathogen standards are technologically based requirements aimed at reducing the presence of pathogens and potential exposures to them by treatment or a combination of treatment and use restrictions. The scientific basis of the Part 503 rule was recently re-assessed. The committee convened by the National Research Council (NRC) did an independent evaluation of the technical methods and approaches used to establish the chemical and pathogen standards for sludge, focusing specifically on human health protection and not ecological or agricultural issues. They found no documented scientific evidence that the Part 503 rule has failed to protect public health. No causal association between sludge exposures and adverse health outcomes has been documented. However, to assure the public and to protect public health, they recommended an update of the scientific basis of the rule to: (1) ensure that the chemical and pathogen standards are supported by current scientific data and risk-assessment methods; (2) demonstrate effective enforcement of the Part 503 rule; and (3) validate the effectiveness of sludge management practices.

The agricultural use of sewage sludge is therefore still a popular management option in many countries even after some countries revisited their regulations. It is recommended that the South

African sludge guidelines encourage the agricultural use of sewage sludge as it is believed to be the most appropriate for our environmental and socio-economic situation.

Inorganic constituents

The use of ceiling limits that restrict the maximum concentrations of inorganic contaminants that are allowed in sludge is widely applied. Cadmium, copper, lead, mercury, nickel, zinc, arsenic, chromium are regulated by many countries. In general, the South African metal limits are lower than those applied in Australia, the US and those detailed by the European Union. Europe (some countries), Australia and the US, tend to derive the ceiling limits based on a combination of good practice (i.e. what should be achievable) and protecting soils from exceeding risk-based limits under nominal application scenarios rather than attempting to maintain "background" concentrations. In general, a maximum contaminant load or soil limit is specified unless the inorganic constituent concentrations are comparable to a receiving soil contaminant limit – in other words, the sludge can be used as a topsoil replacement from a contaminant perspective. Canada and New Zealand have adopted ceiling limits based on the nitrogen content of the sludge.

Organic constituents

The EC, US and Australian approaches to regulating organic contaminants in sludge differ widely. The Australian guidelines detail limits for organochlorine pesticides and polychlorinated biphenyls for the protection of food standards in conjunction with cattle grazing. In contrast, the EC directive does not include limits on organic contaminants, but there are a variety of limits for organic contaminants within member states. The EC directive have proposed limits for a range of organic compounds, including linear alkyl benzene sulphonates (LAS) (2,600 mg/kg sludge), endocrine disrupting chemicals such as nonyl phenol ethoxylates (NPE) (50 mg/kg sludge) and dioxins (100 ng total equivalency/kg). The US studied the risks associated with organic contaminants and excluded chemicals based on sewage sludge analytical data coupled with a combination of exclusion rules, screening and formal risk assessments. At the completion of the processes, regulatory intervention was only considered warranted for the inorganic contaminants and for compounds with dioxin-like-activity. However, limits for dioxin-like-compounds have not yet been promulgated within the 503 rule. The ceiling limits for organics in sludge in New Zealand are extremely restrictive (although they are based on higher allowable loads compared to South Africa), while countries such as Canada (Ontario) do not regard the organic constituents to be a major concern.

Pathogens

The pathogens that are generally subject to regulation are salmonella, enteric viruses, helminth ova, and oocysts and oocysts of protozoa.

In Europe, the US and Australia, classification is based on a philosophy of combining prescriptive treatment processes with microbiological criteria, for example *E. coli* per gram sludge. Classification involves a two level system with a 'high quality' and often unrestricted use grade sludge based on intensive treatment, and a 'base' or restricted grade of sludge based on relatively standard approaches such as anaerobic mesophilic digestion. Material that is raw or inadequately treated for the above

classification is typically considered unsuitable for land application. The guidelines/regulations also normally describe treatment processes such as mesophilic anaerobic digestion and composting. Although the jurisdictions are in practice roughly aligned on the generics of treatment classification for the "class B" requirements, the end use controls are a source of significant differences. Jimenez *et al.* (2003) (Mexico) argues that the pathogenic organisms in sludge should be the focus of sludge legislation in developing countries. She states that the low level of sanitation in developing countries cause high concentrations of parasites in sludge. In New Zealand, *Campylobacter* is also monitored due to the high rate of campylobacteriosis disease in New Zealand.

Vector attraction and odour reduction

Vectors such as flies, mosquitoes, birds and rodents are potential carriers of disease. They can transmit pathogens to humans and other hosts physically through contact, or biologically by playing a specific role in the life cycle of the pathogen. Reduction of the attractiveness of sludge to vectors reduces their potential for transmitting disease and are normally achieved by either subjecting the sludge to specific physico-chemical processes or conditions, or preventing access to the sludge by vectors, usually by incorporating the sludge into the soil.

Management requirements

This section detailed the approach adopted in New Zealand as the fundamental principles are well documented. In general, the guidelines argue that sludge can and should be used beneficially as sludge possess significant soil conditioning and fertilising properties. In fact, the wide array of elements they contain that are essential for plant growth and the organic content of sludge have led some authors to suggest that sludge are a more complete fertiliser than most other proprietary fertilisers. However, the presence of a wide variety of chemicals in sludge (albeit in trace amounts) with the potential for uptake by plants and animals, together with the potential presence of pathogens means that sludge cannot be treated like other fertilisers. A fundamental premise of these Guidelines should be that sludge can be beneficially recycled to land providing that both the process of production and the process of applying the sludge to land are subject to adequate management control and providing the sludge are applied at a rate that does not exceed the agronomic nitrogen needs of crops. The guidelines were developed to protect human health. The sludge management framework needs to be flexible and enabling while managing the risk appropriately.

The UK, Canada, US, Canada and Victoria (Australia) recognise that waste materials such as sewage sludge contain elements that can be either desirable or undesirable for agriculture. They have developed guidelines geared to the use of the beneficial elements such as nitrogen and suggest management practices to control the undesirable elements.

Public perception and acceptance

The general public's opinion on the use of treated sewage sludge as a soil amendment in agricultural practices could potentially change the current or future practices based on their support or lack thereof. It is speculated that odour influences public perception of sewage sludge reuse to a far greater extent than any contaminant or pathogen. The European Commission has documented an extensive stakeholder analysis that was summarised in this document. In South Africa, this will probably play a major role in the sustainability of using sludge in agricultural practices.

RECOMMENDATIONS

The following general approach was recommended:

In the development of the second edition of the sludge guidelines, it is proposed that sustainable management options be encouraged.

The guidelines of some countries support one or more of these options for that particular country. For example, in the US legislation that supports several options was developed including land application of sewage sludge, surface disposal of sewage sludge and sewage sludge incineration. It is recommended that South Africa adopt a similar approach to encourage the implementation of one of the above management options, rather than trying to develop a single guideline to address all the management options. This will also simplify the document (s) for the users, as each guideline will be dedicated to the management, technical and legislative aspects associated with a particular option.

Each of the management option/s has different regulatory requirements. Also, the characterisation requirements for each option would be different.

It is therefore proposed to follow a process similar to that adopted by the Water Research Commission, Department of Water Affairs and Forestry and Department of Health for the development of the series entitled: "Quality of Domestic Water Supplies" (WRC, 1998). All the documents were not developed at the same time. It was clear from the start of the project that several documents will form part of the series and how would these relate to each other.

The following series of documents are therefore proposed for the 2nd Edition of the South African Sludge Guidelines:

Volume 1: Management Options for the Use or Disposal of Wastewater Sludge

In this volume, the user is guided to decide on the appropriate management option for the particular case.

Volume 2: Requirements for the agricultural use of Wastewater sludge

This volume will address appropriate sludge quality, load, soil and crop requirements for the beneficial use of sewage sludge in agricultural practices. The legal and management requirements will also be addressed.

Volume 3: Requirements for the on-site and off-site disposal of Wastewater sludge

This volume will address the legal, technical and management requirements associated with various disposal options such as landfill and lagoons, dedicated land disposal and ocean disposal. This volume will highlight that these practices are not sustainable. The appropriate remediation approach for some of the options, such as dedicated land disposal will also be addressed in this volume.

Volume 4: Requirements for the beneficial use of wastewater sludge

This volume will address the legal, technical and management requirements associated with the use of sewage sludge in the production of commercial products such as bricks, cement and fertilisers.

Volume 5: Requirements for the thermal sludge management practices and for commercial products containing wastewater sludge

This volume will address the legal, technical and management requirements associated with the incineration of sewage sludge.

The monitoring, sampling and analytical methods pertaining to each use/disposal will be detailed in the relevant volume. It is recommended that this project deal with Volumes 1 and 2.

SCIENTIFIC PREMISE FOR VOLUMES 1 AND 2

This document builds on the knowledge base reported in the literature review of South African and international sludge management guidelines and legislation. This document summarises the thought process, proposed rationale and appropriate limits for the 2nd Edition of the South African Sludge Guidelines. The document was served as a discussion document that was distributed to a reference group and specific identified stakeholders before an open workshop as preparation for the workshop held on 4 May 2004 at the WISA Conference held in Cape Town.

Proposed structure and rationale

The guidelines are based on the principle of sustainability by offering different sustainable options for sludge handling and disposal. This can be achieved by either utilising the calorific energy value of the sludge; utilising the useful constituents such as carbon and nutrients; or extracting the useful constituents from the sludge.

It was recommended that South Africa adopt the second option i.e., utilising the useful constituents such as carbon and nutrients in the sludge, particularly in agricultural practices as the basic tenet of sludge management. However, the team recognised that not all sludge generated in South Africa is suitable for agricultural application. For these sludges, the other two sustainable options can be considered. It is therefore necessary to develop guidelines for other management options such as on-site and off-site disposal and thermal sludge management, and to provide for innovation.

Sludge classification

The Guidelines adopted a classification system that is more in line with international trends that specifically classifies sludge in terms of the pathogen content, stability and inorganic pollutants.

Maximum permissible pathogen content for each microbiological class was recommended. These limits were based on the maximum permissible values of the US EPA for the "unrestricted use" quality and the South African maximum permissible values for the "general use" quality (class B). The US EPA does not specify limits for *Ascaris* Ova for class A sludge. In this case, the values of the South African Sludge guidelines were adopted.

It was recommended that the vector attraction reduction criteria of the US EPA 503 Sludge rule be adopted. These criteria (or very similar) have been adopted by many other countries including Australia.

The document noted that the organic and inorganic pollutant limits and load restrictions will be different for various applications. It is therefore recommended that the different volumes that deal with various applications address the premise for the pollutant limits that pertain to the particular use or disposal option. It is suggested that a general classification system be adopted that is detailed and described in Volume 1. The specific limits, monitoring requirements and analytical methods will then be described in detail in each Volume, but refers back to the generic classification system detailed in Volume 1. For the purpose of Volume 1 and 2, it was recommended to exclude the monitoring of organic pollutants in sludge. This recommendation was motivated by the current knowledge, international trends and practical implications.

Structure of Volume 1

It was recommended that this volume be structured to guide the user to make an informed choice for the best sludge management option(s) in a specific case. The document should address the general aspects such as classification and enable the user to logically follow a decision making process.

Structure of Volume 2

The scientific premise for this volume is based on a risk assessment and management process, associated with the agricultural use of sludge. The risk assessments were based on a source, pathway and receptor analysis and proposed management options to minimise the risks that were classified as significant (high). The risks associated with the nutrients contaminating surface and groundwater can be minimised by limiting the load.

In terms of the metals, it was recommended that ceiling limits for soil and sludge be adopted for agricultural use. The metal concentrations should be determined prior to the application of sludge. If sludge has already been applied (for agricultural purposes), the metal constituents should be measured in the soil and regarded as the background values.

The report recommends that until this information is available, no organic pollutant ceiling limits be developed for the agricultural application of sludge. The document details the proposed different pathogen classes and limits for various indicator organisms. In terms of vector attraction reduction options and odour control, it is recommended that no restrictions be applied to class A and B sludge, but that the agricultural use of a class C sludge be forbidden unless certain management criteria are met.

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1 INTRODUCTION

Land disposal and agricultural reuse practices in South Africa previously had to comply with the "Guide: Sewage Sludge, Utilisation and Disposal" (1991). These guidelines were revised in 1997 (Permissible Utilisation and Disposal of Sewage Sludge, Edition 1, 1997) with later amendments to the heavy metal loading and usage restrictions. The guidelines deal with application of sewage sludge to land and amongst other criteria set permissible limits for concentrations of heavy metals in sludge suitable for unrestricted (limited to an average application of 8 ton/ha/year over 25 years) agricultural land use. Due to limitations of the guideline to only a few application possibilities and difficulty of interpretation, an addendum to the guidelines (WRC, 2002) was prepared to broaden the treatment and disposal possibilities for sewage sludge. This addendum links the handling and disposal of sewage sludge to several other legislative documents and was intended as an interim document to assist in the responsible handling of sewage sludge. In parallel to the development of the Addendum, the WRC initiated a research programme to further develop the knowledge base for the management of sewage sludge in the South African context. These research projects address the following aspects:

- **WRC Project Number 1209:** An evaluation of dedicated land disposal practices for sewage sludge (WRC Report 1209/01/05)
- **WRC Project Number 1210:** Laboratory and field scale evaluation of agricultural use of sewage sludge (WRC Report 1210/01/04)
- **WRC Project Number 1240:** A technical and financial review of sludge treatment technologies (WRC Report 1240/01/04)
- **WRC Project Number 1283:** A metal content survey of South African sewage sludge and an evaluation of analytical methods for their determination in sludge (WRC Report 1283/01/04)
- **WRC Project Number 1339:** Survey and methodology for analysing organic pollutants in South African sewage sludge (WRC Report 1339/01/05)

Although the results of these research projects do not give all the answers, they do enable the formulation of an updated Permissible Utilisation and Disposal of Sewage Sludge, Edition 2 document. This new edition should combine the relevant aspects of the addendum and limits for metals, nutrients and organic pollutants based on scientific criteria to ensure credibility and user acceptance.

Against this background, the Water Research Commission awarded a contract to the East Rand Water Care company to develop the second edition of the South African Sludge Guidelines under a project entitled: "Permissible utilisation and disposal of sewage sludge".

1.1 Objectives

The overall project objective was to develop the second edition of the South African Sludge Guidelines entitled: "Permissible utilisation and disposal of sewage sludge".

1.2 General project approach

The second edition of the South African Sludge Guidelines was developed in a phased approach consisting of:

- **Literature survey**

The sludge guidelines and/or legislation of other countries together with the rationale behind the limits (load, metals, nutrients and organics) were sourced and documented. Local information emanating from recent research projects in South Africa were consulted to establish unique local factors that might influence the revised South African Sludge Guidelines.

- **Concept document**

A concept document that includes the proposed rationale and appropriate limits for the 2nd Edition of the South African Sludge Guidelines was developed. The draft document was distributed to a reference group and specific identified stakeholders before the open workshop in preparation for the coming workshop.

- **Open workshop**

The draft document was presented at an open workshop at the WISA conference in May 2004 to invite comments from legislators and stakeholders. The outcomes of the workshop was documented and comments incorporated into the guidelines.

- **Draft sludge guidelines**

The comments and suggestions from the workshop was incorporated and a final draft document will be compiled. A second workshop will be organised to coincide with the WRC steering committee meeting to debate and reach consensus on the rationale behind the sludge guidelines and the proposed limits and loads. Apart from the reference group that has already been selected, key other stakeholders will be identified to assist in the process.

- **Final document**

The comments from the workshop will be incorporated and additional work proposed at the workshop will be done to compile the final report to present to the WRC.

1.3 Deliverables

The following deliverables were expected of this project:

- Report that documents the sludge guidelines and rationale of other countries.
- Concept document for discussion at the open workshop and minutes of the open workshop.
- Draft sludge guidelines.
- Minutes of the stakeholder workshop and final document; Sludge Guidelines, Ed 2.

2 RECOMMENDED APPROACH

2.1 Sustainable sludge management

Sustainable management options include options that do not harm the environment by either the use of a non-renewable resource or a build-up of a substance in the environment. Unsustainable management options include all disposal practices such as stockpiles, landfill and dedicated land disposal.

With current knowledge, there are three ways in which sludge management can contribute to sustainable development:

- Utilising the calorific energy value of the sludge (example: generating heat, in some cases resulting in a product); or
- Utilising useful constituents such as organic matter and nutrients (example: agricultural use); or
- Extracting useful constituents from the sludge (example: extraction of phosphorus).

It was decided that South Africa would adopt the second option i.e., utilising the useful constituents such as carbon and nutrients in the sludge, particularly in agricultural practices as the basic tenet of sludge management. South African soils have very low organic carbon contents and the use of sludge in agriculture can benefit the soil both chemically and physically. The cost of inorganic fertilizers is also very high and the use of sludge as an alternative can reduce these costs to the farmer. All the participants at the different workshops indicated that agricultural use would be the best method of wastewater disposal. Many studies and case studies done by scientists and consultants to metropolitan councils have proven that the other two options are rarely financially viable in South Africa. On the other hand, many scientists and practitioners have recognised the benefits associated with the agricultural use of sludge and found it to be a viable and sustainable option in South Africa.

However, we also need to be realistic and recognise that not all sludge generated in South Africa is suitable for agricultural application. For these sludges, the other two sustainable options can be considered. Factors that could exclude sludge from agricultural application could include:

- Sludge that is compromised by the contaminants such as heavy metals or organic contaminants;
- Agricultural land that is not available within a viable distance; and/or
- Community resistance against such practices.

It is therefore necessary to develop guidelines for other management options such as on-site and off-site disposal, other beneficial uses except agriculture, thermal sludge management practices and to provide for innovation. It was decided that each sludge management option would be developed as a separate guideline document to simplify the document(s) for the users, as each guideline will be focused on the management, technical and legislative aspects associated with a particular option. Each of the management options has different regulatory requirements. Also, the sludge classification

requirements (ceiling limits etc.) for each option would vary. It should be recognised that the receptor that need to be protected is different for different disposal methods. For example groundwater would be a significant receptor when disposing of sludge in a landfill. However, if sludge is incinerated, the atmosphere (air pollution) would be the significant receptor. In other applications, such as the agricultural application of sludge, several receptors are at risk. It is therefore important to recognise that "one size does not fit all". The analytical methods used to determine the risk of sludge to the environment would also vary between disposal options. In the case of disposing sludge in a landfill, the pollution risk of the sludge to the groundwater would best be predicted with the TCLP extract, while in the case of agricultural application the risk for plant uptake would best be measured with the NH_4NO_3 extraction.

It was therefore decided that the following documents would be developed:

Volume 1: Selection of Management Options

Volume 2: Requirements for the agricultural use of sludge

Volume 3: Requirements for the on-site and off-site disposal of sludge

Volume 4: Requirements for the beneficial use of sludge

Volume 5: Requirements for the thermal sludge management practices and for commercial products containing sludge

2.2 Volume 1: Selection of Management options

In this volume, the initial comprehensive characterisation of the sludge is described. Based on the results of the characterisation, appropriate management options can be selected for the particular case. The document directs you to the appropriate volume(s) to use.

2.3 Volume 2: Requirements for the agricultural use of sludge

This volume describes the legal requirements and restrictions related to the safe use of sludge for the production of crops.

- This volume should be used if stabilised sludge is used as a **soil conditioner** at an application rate designed to provide the amount of nitrogen needed by the crop but at the same time minimise the risk of nitrogen leaching. This includes both commercial as well as small scale and/or subsistence farming practices.
- This volume can also be used to manage **compost** containing sludge, but is not sold or given to the general public for use. If compost is generated that is of such a high standard that it can be distributed to the general public, the product is seen as saleable product, and the requirements detailed in Volume 5 of the Sludge Guidelines should be followed.

The current project addresses the scientific premise and development of Volume 1 and 2 of the South African sludge guidelines. The authors recommend that Volume 3, 4 and 5 address the aspects as detailed in paragraphs 2.4-2.6 respectively.

2.4 Volume 3: Requirements for the on-site and off- site disposal of sludge

This volume should address the disposal of sludge either at the wastewater treatment plant or on an off-site waste disposal site. This volume can be used for:

- **Managing the phasing out of uncontrolled stockpile facilities.** The Department of Water Affairs and Forestry have indicated that the indefinite storage (exceeding 90 days) of sludge on unlined facilities will no longer be accepted and will need to be phased out over time. This volume assists you to decide on an alternative management option and to rehabilitate the footprint of the stockpile (if required).
- **Operating existing dedicated land disposal sites.** This volume assists you to determine what the environmental impact is of the current practices and how to manage an existing dedicated site to minimise any further environmental impacts. If this work shows that you have exceeded the assimilative capacity of the receiving environment and are negatively impacting on sensitive receptors, you will be required to phase out this practice and rehabilitate the site.
- **Rehabilitation and phasing out of dedicated land disposal sites.** Research has proven that the sudden termination of dedicated land disposal activities without the managing the site closure properly could have additional detrimental effects on the environment. However, if your site proves to have an unacceptable impact, it will have to be phased out in a responsible manner. This volume details the steps to be taken to phase out an operating dedicated land disposal site in a responsible manner.
- **Off-site disposal of sludge in a general or hazardous landfill site.** This section of the volume specifically addresses the co-disposal of sludge in municipal or commercial landfill facilities (both general and hazardous landfill facilities). Sludge disposal in a landfill should adhere to the Minimum Requirements (Department of Water Affairs and Forestry, 1998 (or newest edition). Waste Management Series). This volume assists the reader to understand the requirements stipulated in the Minimum Requirements by specifically explaining the relevant sections that pertain to the management of sludge in landfill operations. The volume details the process of delisting, dewatering requirements and co-disposal ratio requirements.
- **On-site disposal of sludge in a mono disposal landfill or lagoon.** This section of the volume specifically addresses the disposal of sludge in dedicated mono-disposal facilities and sludge lagoons. These practices need to comply with the Minimum Requirements (Department of Water Affairs and Forestry, 1998 (or newest edition). Waste Management Series). This volume assists the reader to understand the requirements stipulated in the Minimum Requirements by specifically explaining the relevant sections that pertain to the management of sludge in mono-disposal facilities and sludge lagoons. The volume details the process of delisting, dewatering requirements and the liner and closure requirements.

- **Disposal of sludge to the marine environment.** This aspect was still actively debated at the time of publication of this document. It is therefore unclear if sludge disposal would be permissible in future. This section in the Volume refers to the latest information on the interpretation of the "Operational Policy for the Disposal of Land-derived Water Containing Waste to the Marine Environment of South Africa - Edition 1, 2004" (Department of Water Affairs and Forestry, Water Quality Management Series, Sub-Series No. MS 13)

This volume should describe the legal requirements and restrictions related to the on-site and off-site disposal of sludge and give detail requirements and guidance on:

- Managing the phasing out of unlined stockpile facilities;
- Operating existing dedicated land disposal sites; and,
- The rehabilitation and phasing out of dedicated land disposal sites.

The other options directly or indirectly addressed in other guidelines and policies published by the Department of Water Affairs and Forestry are:

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

This Volume should therefore refer to these documents and guide the reader to the relevant sections. The Volume also should mention some waste specific details (such as research findings on delisting of waste) that should simplify compliance.

2.5 Volume 4: Requirements for the beneficial use of sludge

This volume should be used if sludge is or will be used in an innovative beneficial manner. **Note:** If sludge is used in agricultural practices at agronomic rates, Volume 2 should be used and not Volume 4.

Volume 4 can be used for:

- **Rehabilitation of mine tailings.** Inorganic waste material such as mine tailings could in some cases benefit from the addition of organically rich material. However, in some cases, the addition of organic material can cause more environmental problems. These activities must therefore be done responsibly. This volume details the process to follow to use sludge in the rehabilitation of organically poor material such as mine tailings.
- **Using sludge to aid remediation of contaminated soil.** It has been proven that the micro organisms and the organic material in sludge can enhance the process of bioremediation of contaminated soil. Sludge can be used for both the remediation of hydrocarbon-contaminated soils as well as for the remediation of soils that has been contaminated with inorganic pollutants such as metals. The sludge can also be used as an **adsorbent** by incorporating it into highly oil

contaminated soil. The sludge will absorb the free oil, which increases the ability of the micro-organisms to degrade the contaminant. This volume gives some guidelines on how to apply the principle of using sludge for the remediation of contaminated soil.

- **Using sludge as a nursery growth medium.** When preparing a nursery growth media, the sludge component may exceed the agronomic rate. This will not cause any detrimental environmental effects as the seedlings and pot-plants are distributed and planted in natural soils. Care should be taken not to expose the public to high levels of pathogens. This volume gives some guidance on how to use sludge as a nursery growth media.
- **Once-off high rate application.** An example of once-off high rate application of sludge is during the construction of golf courses. This volume gives guidance on these practices.
- **Covering of landfills.** Sludge could be used as part of the capping material for landfills. This volume gives guidance on these practices.
- **Beneficial land application at high loading rates.** Some crops such as instant lawn can be cultivated on sludge loads much higher than the recommended agronomic rates. The lawn is removed with the sludge attached to the root zone. This means that the topsoil is not removed as the sludge serves as the root support structure. However, these practices must be managed to avoid nitrate leaching and other negative environmental effects. This volume details the requirements for the beneficial agricultural use of sludge at high loading rates.

Note: This volume excludes the use of sludge in agricultural practices where sludge is used at agronomic rates (refer to **Volume 2**).

Several other beneficial thermal processes such as using sludge to manufacture bricks or pellets also exist. However, the manufacturing of these products includes at least one high temperature step and the product often has a commercial value. For this reason, these products are addressed in **Volume 5**.

2.6 Volume 5: Requirements for the thermal sludge management practices and for commercial products containing sludge

This volume could be divided into two parts. The first part should address the use of thermal methods to manage sludge and the second part should address the use of sludge to manufacture a saleable product. These aspects can be combined in one volume as many of the saleable products include a thermal process in the manufacturing process. For example, the use of sludge in the brick manufacturing process could be seen as both a thermal process and saleable product.

Use of thermal methods to manage sludge

- **Incineration in dedicated incinerators.** This volume addresses the requirements for the incineration of sludge with specific reference to the operational requirements and management of the air emissions.
- **Incineration in furnaces, cement kilns etc.** Sludge can also be co-incinerated in industrial processes such as industrial furnaces and cement kilns. This volume addresses the requirements of these practices. This will include the use of sludge in the manufacturing of **bricks**.

Using sludge to produce saleable products

The requirements for a saleable product are understandably much stricter than the controlled use of sludge products. Saleable products should be adequately disinfected. For this reason, composting is addressed in both Volume 2 and 5. Some plants in South Africa generate compost that is not completely disinfected. For this type of compost, restrictions apply as addressed in Volume 2. For high quality compost destined for the general public, the process requirements and quality criteria are high, but few restrictions apply after the product leaves the manufacturing process. The same principles apply for:

- **Manufacturing pellets from sludge.** The pellets, which resemble commercial fertilisers, could be enriched with additional plant nutrients.
- **Manufacturing bricks, paving, artificial rocks and other products.** Many innovative product applications have emerged internationally. Many of these applications are financially not viable in South Africa. However, this volume gives guidance on how to adopt such a process in the South African legislative environment.

3 LITERATURE REVIEW

3.1 The History of Sewage Sludge Management Legislation and Guidelines in South Africa

Prior to 1970, control of activities such as sewage sludge treatment, disposal and utilisation were generally accepted as the sole responsibility of local authorities. During the decade from 1970 to 1980 the Department of Health realised its responsibility and expanded departmental activities in the environmental health sphere. The Department of Health embarked on a research project during 1979, to obtain the necessary information for controlling the use of sewage sludge (Viviers *et al.*, 1988).

At that stage, the regulatory requirement was governed by Section 20 of the Health Act, 1977 (Act 63 of 1977) which stated that: "Every local authority shall take all lawful, necessary and reasonable practicable measures to maintain its district in a hygienic condition and to prevent the occurrence of nuisances, unhygienic or offensive conditions or any other condition which will or could be harmful or dangerous to the health of any person within its own district or the district of any other local authority and where such conditions have occurred, to abate or to remedy such conditions." In general these duties and related powers pertained to sewage purification and sludge treatment, storage, processing, utilisation and disposal.

Viviers *et al.*, (1988) developed a set of guidelines that had the following features:

- All types of sewage sludge may be utilised.
- A limited number and only essential requirements and conditions were imposed.
- A limited number of quality control determinations were required.
- Some flexibility in application was allowed.

- The unsatisfactory impact on human health and the environment could be minimised to acceptable levels.

Table 3.1(a) indicates the maximum allowable potentially toxic metals and elements (hereafter generically referred to as metals) concentration for sludge aimed for unrestricted use (type D) as stipulated in the guidelines for the use of sewage sludge published by the Department of Health (Viviers et al., 1988).

Table 3.1(a): The metal concentration of sludge for unrestricted use (Type D)

Metal	1988 Limit (mg kg⁻¹ dry sludge)
Cd	20
Co	100
Cr	2750
Cu	750
Hg	10
Mo	25
Ni	200
Pb	250
Zn	2750
As	15
Se	*NR
B	NR
F	NR

*NR = No recommendation was made in the report (Viviers et al., 1988).

The Sludge Management Division (SMD) of the Water Institute of Southern Africa (WISA) was formed in 1988 as a Working Group of WISA. At the beginning of 1989, the Sludge Management Working Group became the Sludge Management Division. This group compiled an information document titled: "Sewage sludge utilisation and disposal information document" edited by Prof. GA Ekama who at that time was the chairperson of the Sludge Management Division (Water Institute of Southern Africa, 1993). This document contained a copy of the "Guide: Permissible utilisation and disposal of sewage sludge" published by the Department of Health (1991) by which sludge application to land was managed in terms of the Health Act. The maximum permissible Cr and Pb concentrations for sludge aimed for unrestricted use (type D) differ in the 1988 and 1991 guidelines (Tables 3.1 a and b). The 1991 guidelines were subject to considerable debate as consensus was not reached by all the government departments that had an interest in sludge application to land; i.e. Department of Health, Department of Water Affairs and Forestry, Department of Agriculture and the Department of Environment Affairs and Tourism. The 1991 guideline was therefore used as an interim guideline while negotiations were taking place between the government departments. Lötter and Pitman (1997) also described the different legal requirements for metals by the Department of Health and the Department of Agriculture. A final draft of the "Guide: Permissible utilisation and disposal of sewage sludge" was published in June 1994 with no changes to the maximum permissible metal concentration of type D sludge.

Table 3.1(b): Comparison between the metal concentration of sludge in the 1991 and 1997 sludge guidelines

Metal	1991 Limit (mg kg⁻¹ dry sludge)	1997 Limit (mg kg⁻¹ dry sludge)
Cd	20	15.7
Co	100	100
Cr	1750	1750
Cu	750	50.5
Hg	10	10
Mo	25	25
Ni	200	200
Pb	400	50.5
Zn	2750	353.5
As	15	15
Se	15	15
B	80	80
F	400	400

(DEPARTMENT OF HEALTH, 1991; WRC, 1997)

The "Permissible utilisation and disposal of sewage sludge, Edition 1" known as the 1997 Sludge Guidelines, was finally published in 1997 and was aimed at assisting organisations involved in sewage treatment to promote safe handling, disposal and utilisation of sewage sludge (WRC, 1997). In essence, the South African sludge classification remained the same (Table 3.1c). Sewage sludge was classified in four categories according to the potential to cause odour nuisances, fly breeding and transmit pathogenic organisms to man and his environment.

Sludge of type A to C can be utilised as a soil ameliorant under certain restrictions and the sludge producer remains responsible for the safe handling and disposal/use of the sludge. The restrictions on the use of the sludge types were amended in the 1997 guideline. Type D sludge could be used without restrictions to a maximum of 8 t (ha a)⁻¹. Some of the maximum permissible metal concentrations for sludge aimed for unrestricted use (type D) were amended considerably (Table 3.1(b)). The new metal limits were derived based on a risk factor calculation to minimise the risk to the aquatic environment (Department of Water Affairs and Forestry, 1998).

The guideline published in 1997 (WRC, 1997) was perceived to be overly restrictive, specifically with regard to some of the metal standards. For example, of the sludges from 77 wastewater treatment plants evaluated for compliance with type D sludge, none of the sludge, including those from plants treating mainly domestic sewage, complied (Snyman et al., 2000). However, when the origin of these limits were investigated, after publication of the guidelines, it was found that from the way the allowable concentrations were calculated, they appeared to be the available metal fraction and not the total extractable metal fraction as originally interpreted. This was not stipulated in the guideline. It therefore seemed as if the Cd, Cu, Pb and Zn limits were overly stringent.

Table 3.1(c): Classification of sewage sludge

Type of Sewage Sludge	Origin/Treatment (Examples)	Characteristics-Quality of Sewage Sludge
TYPE A	Raw sludge Cold digested sludge Septic tank sludge Oxidation pond sludge	Usually unstable and can cause odour nuisances and fly-breeding Contains pathogenic organisms Variable metal and inorganic content
TYPE B	Anaerobic digested sludge (heated digester) Surplus activated sludge Humus tank sludge	Fully or partially stabilised - should not cause significant odour nuisance or fly-breeding Contains pathogenic organisms Variable metal and inorganic content
TYPE C	Pasteurised sludge Heat-treated sludge Lime-stabilised sludge Composted sludge Irradiated sludge	Certified to comply with the following quality requirements: Stabilised - should not cause odour nuisances or fly-breeding Contains no viable <i>Ascaris</i> ova per 10 g dry sludge Maximum 0 <i>Salmonella</i> organisms per 10 g dry sludge Maximum 1000 Faecal coliform per 10 g dry sludge, immediately after treatment (disinfection/sterilisation) Variable metal and inorganic content
TYPE D A sludge product produced for unrestricted use on land with or without addition of plant nutrients or other materials	Pasteurised sludge Heat-treated sludge Lime-stabilised sludge Composted sludge Irradiated sludge	Certified to comply with the same quality requirements as the TYPE C sludge. Maximum metal and inorganic content in mg kg ⁻¹ dry sludge (Table 3.1(b)) User must be informed about the moisture and N P K content. User must be warned that not more than 8 t ha ⁻¹ yr ⁻¹ (or 0.8 kg.m ⁻² yr ⁻¹ *) (dry sludge) may be applied to soil and that the pH of the soil should preferably be higher than 6.5.

* Note: WRC 1997 refers to 1 kg.10 m⁻²

3.1.1 The origin of the maximum allowable metal concentrations for a type D sludge in the 1997 Sludge Guidelines

The sludge guidelines metal limits were the result of a Water Research Commission facilitated round-table debate between the Department of Agriculture and Land Affairs, Department of Health, Department of Water Affairs and Forestry and the Water Institute of Southern Africa to agree on one set of metal limits to include in the 1997 Sludge Guidelines. Each department had a set of maximum metal concentration values based on criteria that are applicable to the population or resource the specific department was mandated to protect. For example, the consultant for the Department of Water Affairs and Forestry was briefed to recommend maximum metal concentrations for a type D sludge that would ensure the prevention of pollution of the aquatic system. At that stage, the consultant was also involved with the development of the Waste Management Series, Minimum Requirements (Department of Water Affairs and Forestry, 1998), which deals exclusively with the handling, classification and disposal of waste. He was asked to evaluate the metal limits within the framework of the Minimum Requirements, concentrations and total load of selected inorganic and organic contaminants in sewage sludge. He had to make certain assumptions and accepted the same

worst case scenario of 1.5% for runoff from sludge applied land areas to surface waters as used in the risk models employed in the Minimum Requirements (Department of Water Affairs and Forestry, 1998).

The recommended maximum permissible metal concentration for a type D sludge that was therefore recommended by the Department of Water Affairs and Forestry was based on the report submitted by their consultant (Fourie, 1996). Table 3.1.1(a) illustrates the metal concentrations allowed in sewage sludge when applied at a rate of 8 dryt (ha yr)⁻¹ for twenty five years based on the load principles stated by the Minimum Requirements (Department of Water Affairs and Forestry, 1998).

Table 3.1.1(a): Metal concentrations allowed in sewage sludge - 1997 Sludge Guidelines

Metal	Concentration (mg kg⁻¹ dry sludge)
Cd	15.7
Co	3 485
Cr(III)	2 373
Cu	50.5
Hg	11.1
Mo	NR*
Ni	575
Pb	50.5
Zn	353.5
As	30.3
Se	131
B	NR*
F	NR*

*NR = No recommendation was made in the report (Fourie, 1996).

The recommended values presented by the other parties remained those published earlier by the Department of Health (1991) as "Guide: Permissible Utilisation and Disposal of Sewage Sludge" (Draft 2, A11/2/5/4, 1991). Lötter and Pitman (1997) tabled the requirements of the Department of Health and the Department of Agriculture. The authors presumed that these were the values that were discussed at the round table discussion during the development of the 1997 Sludge Guidelines. Table 3.1.1(b) lists the maximum allowable metal values for sewage sludge suggested by the different governmental departments.

Table 3.1.1(b): Recommended maximum allowable metal values for sewage sludge

Metal	Department of Water Affairs and Forestry¹	Department of Health²	Department of Agriculture³
	Concentration (mg kg⁻¹ dry sludge)	Concentration (mg kg⁻¹ dry sludge)	Concentration (mg kg⁻¹ dry sludge)
Cd	15.7	20	20
Co	3 485	NR*	NR*
Cr(III)	2 373	1 750	1 200

Metal	Department of Water Affairs and Forestry ¹	Department of Health ²	Department of Agriculture ³
	Concentration (mg kg ⁻¹ dry sludge)	Concentration (mg kg ⁻¹ dry sludge)	Concentration (mg kg ⁻¹ dry sludge)
Cu	50.5	750	1 200
Hg	11.1	10	25
Mo	NR*	25	NR*
Ni	575	200	200
Pb	50.5	400	1 200
Zn	353.5	2 750	3 000
As	30.3	15	80
Se	131	15	NR*
B	NR*	80	100
F	NR*	400	NR*

Sources: ¹ Fourie, 1996; ² Ekama, 1992 and Lötter and Pitman, 1997; ³ Lötter and Pitman, 1997

*NR = No recommendation was made

Since consensus could not be reached between the different government departments, it was agreed that they would publish the lowest values for each of the metals resulting in the allowable limits of the 1997 Sludge Guidelines as listed in Table 3.1(b).

3.1.2 Comments made by the wastewater industry on the 1997 Guideline

The wastewater industry was concerned since none of the wastewater treatment plants in South Africa could comply with the new guidelines. However, in the foreword of the 1997 Sludge Guidelines, it was indicated that the guide was a consultative publication, seeking comments from all concerned parties on the criteria and approaches adopted to ensure the upgrading and improvement of the guide.

Cape Town Metropolitan Council took the initiative to organise a forum to formally comment on the 1997 Sludge Guidelines in September 1999. These comments were forwarded to the Department of Water Affairs and Forestry. At this meeting Prof. GA Ekama explained the basis on how the allowable metal concentrations for the Cd, Cu, Pb and Zn were calculated by the consultant representing the Department of Water Affairs and Forestry. A sample calculation for Cd is detailed in Table 3.1.2.

Table 3.1.2: Calculation of metals limits – 1997 guidelines

METAL	Cadmium (Cd)	
Teratogenicity	Negative	
Carcinogenicity	Positive, Class B but <1%	
Acute Ecotoxicity	NOEC = 31 ppb = 0.031 mg/ℓ ppm = Highly Hazardous, HG2	
Acceptable Risk	0.1 x 0.31 = 0.031 mg/ℓ (ppm) = 31 ppb = EEC	
Total amount / ha (runoff)	$\frac{30}{0.66} \times \frac{100}{1.5}$	= 3 133 g /ha

METAL	Cadmium (Cd)	
Concentration / hectare soil	$\frac{3\,133 \times 1\,000 \text{ mg}}{1\,520\,000 \text{ kg soil}}$	= 2.06 ppm
Maximum load of sludge (Health)	8 000 kg / ha / yr	200 000 kg / ha / 25 yr
Cd concentration allowed in Sewage Sludge at rate of 8 000 kg / ha / yr for 25 years (DWAf)	$\frac{3\,133 \times 1\,000 \text{ mg}}{200\,000 \text{ kg sludge}}$	= 15.7 mg / kg (ppm)

Snyman et al. (2000) and Snyman (2001) explained the basis and the impact of these assumptions. These publications explain the metal limits set for a type D sludge. Cd, Cu, Pb and Zn levels in the 1997 Sludge Guidelines should be interpreted as the available fraction and not the total fraction, as is the case for the other elements indicated in Table 3.1(b). The reason for this interpretation is explained in section 3.1.1.

3.1.3 The interpretation of the Cd, Cu, Pb and Zn limits in the 1997 Sludge Guidelines

The Waste Management Series, Minimum Requirements (Department of Water Affairs and Forestry, 1998), aims to protect the environment by recommending that the load of a certain contaminant should not exceed an acceptable risk level. In a waste disposal site, this load is calculated as the Estimated Environmental Concentration (EEC) that represents the exposure from a hazardous substance in waste, should it enter into the environment. The EEC is compared to the acceptable risk level (ARL) calculated as 10% of the LC_{50} to determine whether a substance can be delisted (Table 3.1.2). Ten percent (0.1) of the LC_{50} represents the concentration at which the risk to the population (for example *Daphnia*) would be one in 300 000 and could potentially leach to the groundwater. Delisting is the reclassification of the hazardousness of a compound from a high hazard rating to a lower hazard rating. Delisting can be achieved in one of two ways. The following example details the scenario based on Copper.

- If the EEC is less than the acceptable risk level, the waste can be delisted. In the case of sewage sludge, if a sludge contained $> 50.5 \text{ mg Cu, kg}^{-1}$ dry sludge, it would exceed the acceptable risk level and remain in a Hazard Rating 2 that would need to be disposed of in a H:H landfill site. This is the case of a sludge being disposed of at a rate of 8 t (ha yr)^{-1} for 25 years. However, the Minimum Requirements do allow for a second route of delisting a waste.
- The effective estimated environmental concentration can be determined by using the Toxicity Characteristic Leaching Procedure (TCLP). The EEC can therefore be re-evaluated by doing a TCLP to prove that, because of the low mobility, the substance is less hazardous than that indicated by the original tests based on the total concentration. Therefore, if a Cu concentration in a sewage sludge sample is extracted using the TCLP and reveals a concentration $< 50.5 \text{ mg kg}^{-1}$ dry sludge, the sludge can be delisted to be disposed of in a general landfill site (G:B⁺).

The TCLP (which represents the leachable fraction) was developed to measure leachability of specific compounds from a waste and hence the risk to pollute groundwater. The TCLP (leachable) is typically

used when a waste is to be landfilled in a site that receives a variety of organic and inorganic wastes. The procedure simulates the dissolving action of the organic acid leachate formed in a landfill, where hazardous waste has been co-disposed with general waste. It can be used to determine the mobility of organics and inorganics in liquid, solid, and multiphase wastes. As explained, the revised metal concentrations in Table 3.1.1(b) are considered to be less or equal to the acceptable risk level, which is derived as $0.1 \times LC_{50}$ (Department of Water Affairs and Forestry, 1998). The TCLP (leachable) has historically not been used by the wastewater industry to assess the amount or quality of sludge that can be safely used in agricultural practices. Most wastewater laboratories have used the aqua regia (total) extraction, which gives a measure of the acid soluble fraction.

3.1.4 The development of an addendum to the 1997 Sludge Guidelines

The Water Research Commission, Department of Water Affairs and Forestry, Department of Agriculture and Department of Health, with the assistance of Sludge Consult and a committee representing the different sectors of the water industry, compiled an explanatory addendum of the 1997 Sludge Guidelines. Addendum to Edition 1 (1997) of the Permissible Utilisation and Disposal of Sewage Sludge (WRC, 2002) served to clarify certain of the issues in the 1997 Sludge Guidelines (WRC, 1997). The addendum now advised to use both total and leachable extraction methods to characterise sewage sludge. Based on the results of these methods a decision can be made on the best treatment and disposal route for a specific sludge. The document also guides the reader through the legislative route that should be followed and the relevant regulatory agency.

3.2 Principles applied internationally in the development of sludge guidelines

Internationally, opinions and policies regarding sludge management differ widely. The difference may be ascribed to two sources. The first may be broadly defined as geographical factors, including geo-political, technical, and economic constraints. The second may be considered as the philosophical or ethical factors in developing environmental policies, and specifically here, the acceptable practices for sludge disposal (Dentel, 2003).

Philosophies and policies should provide management principles to guide action to achieve certain objectives. In the case of the management of sewage sludge, it is important to decide what these objectives should be.

As a developing country, sustainable development is of utmost importance and the developers of all the environmental legislation and guidelines adopted this principle in the last few years. This is especially relevant after the World Summit on Sustainable Development held in South Africa in 2002.

Sustainable development defined as...

“development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends”

(Australian National Strategy)

This definition of sustainable development includes factors such as financial viability (BATNEEC), availability of appropriate skills and management principles such as the precautionary principle. It is proposed that the development of the 2nd Edition of the South African Sludge Guidelines should adopt "sustainable sludge management" as a guiding principle.

3.2.1 Sustainable sludge management options

With current knowledge, there are three ways in which sustainable management of sewage sludge can be achieved:

- Utilising the calorific energy value of the sewage sludge; or
- Utilising useful constituents (carbon and nutrients); or
- Extracting useful constituents from the sludge.

The guidelines of some countries support one or more of these options for that particular country. In the USA the US EPA Part 503 (US EPA, 1993 ;US EPA, 1994) developed legislation that supports several options:

- Land application of sewage sludge.
- Surface disposal of sewage sludge.
- Sewage sludge incineration.

It is recommended that South Africa adopt a similar approach to encourage the implementation of one of the above management options, rather than trying to develop a single guideline to address all the management options. This will also simplify the document (s) for the users, as each guideline will be dedicated to the management, technical and legislative aspects associated with a particular option. This is one of the reported difficulties associated with the South African sludge guidelines as it currently stands. The guidelines and associated addendum (WRC 1997; WRC 2002) attempt to address all the management options and legislative requirements of various options in one concise document.

Each of the management options have different regulatory requirements. Also, the characterisation requirements for each option would be different. For example, the pathogenic content of the sludge is much more important for land application than for incineration. Similarly, the acceptable nutrient, metal, organic and inorganic concentrations will be different depending on the management option and the resource (and receptors) that needs to be protected.

It is therefore proposed to follow a similar process adopted by the Water Research Commission, Department of Water Affairs and Forestry and Department of Health for the development of the series entitled: "Quality of Domestic Water Supplies" (WRC, 1998). All the documents were not developed at one time. It was clear from the start of the project that several documents will form part of the series and how these interact with each other.

The following series of documents are therefore proposed for the 2nd Edition of the South African Sludge Guidelines:

Volume 1: Selection of Management Options

In this volume, the user is guided to decide on the appropriate management option for the particular case.

Volume 2: Requirements for the agricultural use of Wastewater sludge

This volume will address appropriate sludge quality, load, soil and crop requirements for the beneficial use of sewage sludge in agricultural practices. The legal and management requirements will also be addressed.

Volume 3: Requirements for the on-site and off-site disposal of Wastewater sludge

This volume will address the legal, technical and management requirements associated with various disposal options such as landfill and lagoons, dedicated land disposal and ocean disposal. This volume will highlight that these practices are not sustainable. The appropriate remediation approach for some of the options, such as dedicated land disposal will also be addressed in this volume.

Volume 4: Requirements for the beneficial use of wastewater sludge

This volume will address the legal, technical and management requirements associated with the use of sewage sludge in the production of commercial products such as bricks, cement and fertilisers.

Volume 5: Requirements for the thermal sludge management practices and for commercial products containing wastewater sludge

This volume will address the legal, technical and management requirements associated with the incineration of sewage sludge.

The monitoring, sampling and analytical methods pertaining to each use/disposal will be detailed in the relevant volume. It is recommended that this project deal with Volume 1 and 2.

3.2.2 Agricultural use of sewage sludge internationally

To date, the South African sludge guidelines (Water Institute of Southern Africa, 1993; WRC 1997) were mainly focussed on beneficial use of sewage sludge in agricultural practices. Through the publication of the addendum (WRC, 2002), the other options were also addressed.

Internationally many authors argue that the agricultural use of sewage sludge is a sustainable management option.

For example, New Zealand has recognised and documented that land application of sludge to agricultural land is considered a viable long-term strategic option when carried out in accordance with EPA guidelines (GHD, 2003). The USA, Canada, Australia, Mexico and some European countries support agricultural use of sludge. Most of these countries, do however, distinguish between sludge and sewage sludge. Sludge include sewage sludges mixed with other materials that have been treated and/or stabilise to the extent that they can be safely and beneficially applied to land. Sludge have significant fertilising and soil conditioning properties as a result of the nutrients and organic material content (GRD, 2003).

Agricultural use of sewage sludge in Europe

In Europe, the debate on sludge recycling and disposal has recently received growing interest. This is due to some concerns expressed regarding the potential risks of the agricultural use of sludge to human health and the environment (European Commission, 2002). The debate on the use of sludge in agriculture originated mainly in Northern Europe at the beginning of the 1990s, before gaining in momentum from 1995 onwards. Analysing the context of this period is crucial to understanding the various stakeholders' attitudes, motivations and positions concerning the use of sludge. In particular, the recent health "scares" related to GMOs (Genetically Modified Organisms), dioxins, and BSE (Bovine Spongiform Encephalopathy or "mad cow disease") have cast doubts on the safety of food products on the markets and on the ability of existing regulations and controls to minimise human exposure to potential risks.

The concern expressed about food safety is also related to growing pressure on the agricultural sector, which in certain countries is considered by consumer associations or nature protection associations as being too focused on intensive production and not sufficiently concerned about the impact of its activities on human health and on the environment.

The above holds true for most European countries, however, certain countries are under considerable pressure from both sewage sludge, i.e. a high rate of production per inhabitant, and from other fertilising materials, in terms of nitrogen and phosphate content. This is one reason why the debate has not been the same in all countries and has been most heated in the Netherlands, Flanders and Scandinavian countries (European Commission, 2002).

Past and current events show that it is possible to divide countries up into the following groups (European Commission, 2002):

- In the Netherlands and Flanders, the debate on the use of sludge in agriculture is over, as the regulatory requirements have blocked almost all use of sewage sludge in agriculture since 1991 in the Netherlands and 1999 in Flanders. The effect of this legislation is clearly indicated in Table 3.2.1(a).
- In countries such as Denmark and the United Kingdom, the debate is now mostly over. In Denmark, new regulations on the use of sludge in agriculture have played a large part in ending the debate, as they are considered sufficiently strict to reduce risks to an acceptable level. In the United Kingdom, the debate on sludge recycling was heated until an agreement was reached in

September 1998 between Water UK, representing the 14 UK water and sewage operators, and the British Retail Consortium (BRC), representing the major retailers. In addition, farmers' associations support the agricultural use of sludge, both for economic and for agronomic reasons.

- The cases of Germany and Sweden are special. In Sweden, a voluntary agreement was signed in 1994 between the Swedish Environmental Protection Agency (SEPA), the Swedish Federation of Farmers (LRF) and the Swedish Water and Waste Water Association (VAV) concerning quality assurances relating to the use of sludge in agriculture. However, in October 1999 the LRF recommended that their members stop using sludge because of concerns about the quality of sludge. In Germany, opinion has recently swung in favour of agricultural land spreading, mainly because this practice is considered economically viable and it is considered that the potential risks are sufficiently reduced by the existing legislation. However, political developments in 2001 have considerably heated the debate, which is quite high at present as some Länder support further regulatory constraints on sludge land spreading.
- In Austria, France and Walloon, a national (or regional) agreement is currently under negotiation between the different parties, and hence the debate is heated. The situation is particularly tense in France where the farmers' unions supported, until recently, the development of the agricultural recycling of sewage sludge, on the condition that additional quality controls and an insurance fund system were set up. The situation has now changed, as farmers' unions (the FNSEA and CDJA) have asked for a ban on the use of sewage sludge, officially because the current methods used are not considered to be sufficient to address the risks related to the agricultural recycling of sludge.
- In Finland and Luxembourg, the farming community is generally hostile towards the use of sludge for land spreading, mainly because of the pressure to use animal manure for land spreading. For example, the Finnish Union of Agricultural Producers asked for a ban on the use of sewage sludge for land spreading in 1990, and have renewed their stand against the use of sludge in agriculture in 2001.
- In Ireland and Portugal, farmers support, in some cases, the agricultural use of sludge, both for economic and for agronomic reasons (mainly in terms of organic matter and phosphorus content) although it is difficult to obtain information on this matter. In both countries, the use of sludge seems to be too recent an issue to generate much public debate.
- In Spain, Italy and Greece, the debate remains limited, as far as can be judged from the available information.

A comparison with the national legal requirements also demonstrates that "tight" legal constraints (such as very low limit values for pollutants in sludge) do not necessarily imply a greater acceptance of the use of sludge in agriculture. The Swedish experience demonstrates this best (European Commission, 2002).

Table 3.2.1(a) illustrates the percentage sludge applied to land in Europe.

**Table 3.2.1(a): Status of agricultural use of sewage sludge
in Europe**

Country	Status	% to Land
Australia	Under negotiation between relevant parties	20%
Denmark	Accepted use	62%
Finland	Farming community against/banned land application	31%
France	Farmers Union ask for ban until risks addressed	60%
Germany	Supported in some provinces, debate ongoing	40%
Luxemburg	Farming community against land application	70%
Netherlands	Regulations practically prevent land application	<4%
Spain	Debate is limited	46%
Sweden	Farmers group recommended stop using sludge due to concerns about quality	35%
United Kingdom	Agreement between water companies and retailers to apply sludge to land	54%

(GHD, 2003)

Agricultural use of sewage sludge in the USA

Since the early 1970s, the US Environmental Protection Agency (EPA) and the wastewater treatment industry have promoted recycling of sewage sludge. With the prohibition of ocean disposal of wastewater residuals in 1992, the use of sewage sludge as soil amendments (soil conditioners or fertilizers) or for land reclamation has increased to reduce the volume of sewage sludge that must be landfilled, incinerated, or disposed of at surface sites. Approximately 5.6 million dry tons of sewage sludge are used or disposed of annually in the United States, approximately 60% of that is used for land application.

The regulation governing land application of sewage sludge was established by EPA in 1993 in the Code of Federal Regulations, Title 40 (Part 503), under Section 405 (d) of the Clean Water Act (EPA, 1993). The regulation is intended to protect public health and the environment. The Part 503 rule established management practices for land application of sewage sludge, concentration limits and loading rates for chemicals, and treatment and use requirements designed to control and reduce pathogens and attraction of disease vectors (insects or other organisms that can transport pathogens).

The chemical and pathogen land-application standards in the Part 503 rule were developed differently. For chemicals, EPA conducted extensive risk assessments that involved identifying the chemical constituents in sludge judged likely to pose the greatest hazard, characterising the most likely exposure scenarios, and using scientific information and assumptions to calculate concentration limits and loading rates (amount of a chemical that can be applied to a unit area of land). Nine inorganic chemicals in sludge are currently regulated, and EPA is considering the addition of a class of organic chemicals (including dioxins) to its regulation. Monitoring data on some of the regulated inorganic chemicals indicate a decrease in their concentrations over the past decade, due in part to the implementation of industrial and commercial wastewater pre-treatment programmes. Thus, the chemical limits for sludge can be achieved relatively easily. In contrast to the chemical standards, the

pathogen standards are not risk-based concentration limits for individual pathogens but are technologically based requirements aimed at reducing the presence of pathogens and potential exposures to them by treatment or a combination of treatment and use restrictions. Monitoring sludge is required for indicator organisms (certain species of organisms believed to indicate the presence of a larger set of pathogens) (EPA, 1993; National Academy of Science, 2002).

In 2002, the Committee on Toxicants and Pathogens in Sludge Applied to Land published a document (National Academy of Science, 2002) in which they reported the results of their re-assessment of the scientific basis of the Part 503 rule and to address public-health concerns at the request of the EPA. The committee convened by the National Research Council (NRC) did an independent evaluation of the technical methods and approaches used to establish the chemical and pathogen standards for sludge, focusing specifically on human health protection and not ecological or agricultural issues.

They found no documented scientific evidence that the Part 503 rule has failed to protect public health. No causal association between sludge exposures and adverse health outcomes has been documented. However, they recommended additional scientific work to reduce persistent uncertainty about the potential for adverse human health effects from exposure to sludge. There have been anecdotal allegations of disease, and many scientific advances have occurred since the Part 503 rule was promulgated. To assure the public and to protect public health, they recommended an update of the scientific basis of the rule to:

- Ensure that the chemical and pathogen standards are supported by current scientific data and risk-assessment methods.
- Demonstrate effective enforcement of the Part 503 rule.
- Validate the effectiveness of sludge management practices (National Academy of Science, 2002).

These activities indicate the US EPA plans to continue supporting the use of sewage sludge in agricultural practices, but it will be more regulated in future (Abo-Orf, 2003)

Agricultural use of sewage sludge in South Africa

The data presented in section 3.2 argues that the agricultural use of sewage sludge is still a popular management option in many countries even after some countries revisited their regulations. In South Africa no scientific proof of adverse environmental or human health effects from the agricultural use of sewage sludge could be found. This does not include practices such as dedicated land disposal, lagoons or other storage mechanisms such as stock piles, where evidence of NO₃ pollution has been reported in the underlying groundwater resource (Herselman *et al.*, 2004).

According to Ekama (1993), 42 % of South African sewage sludge is applied to land. A more recent study done by Herselman *et al.* (2004) indicates that a large percentage of works (33 %) of the more than 200 works interviewed are stock piling their sludges (Figure 3.2.1). This practice is not sustainable and the sludge guidelines should encourage other management options.

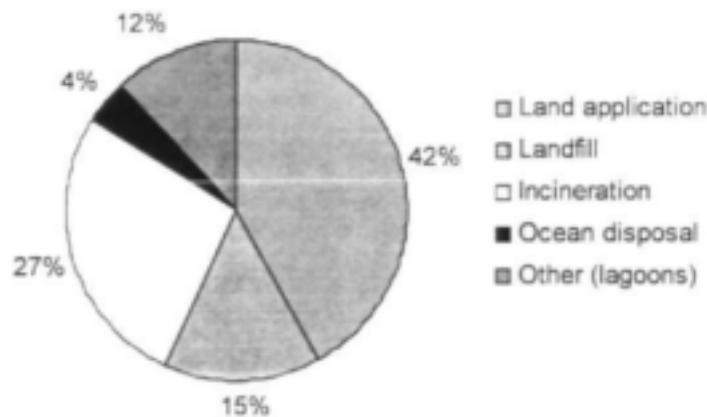


Figure 3.2.1: Estimated percentage of total sludge mass disposed of by different methods
(Adapted from Ekama, 1993)

There are several advantages associated with using sludge in agricultural practices. Sludge acts as a soil conditioner to facilitate nutrient transport, increase water retention and improve soil tilth (Ekama, 1993). The improvement of the soil physical properties through the increase in organic carbon could play an important role in promoting the agricultural application of sewage sludge in the future in S.A. Generally, many soils in S.A. are low in organic matter due to rapid decomposition by micro organisms and the use of mineral fertilizers. This has led to the occurrence of widespread erosion and deterioration of soil physical status (Korentajer, 1991). Sludge also serves as a partial replacement for chemical fertilizers. The major plant nutrients (nitrogen, phosphorus and potassium) in sludges are not substantially removed during sludge processing, therefore the nutrients could improve the soil's nutritional status after sludge application. Sludge also contains essential plant micronutrients such as Cu, Zn, Mn and B (Ekama, 1993). These characteristics should be utilised whilst managing the potential risks associated with the sludge through appropriate guidelines and/or legislation. Table 3.2.1(b) lists the potential risks and benefits associated with the use of sewage sludge in agricultural practices (Smith, 1996).

Table 3.2.1(b): Environmental impact risk and benefit assessment for sewage sludge recycling to agricultural land

Environmental parameter	Metals	Organic contaminant	Pathogens	Nitrogen	Phosphorus	Organic matter
Human health	L	P(L)	L	B	B	B
Crop yield	L	L	L	B	B	B
Animal health	L	L	L	B	B	B
Groundwater	L	L	L	P	L	L

Environmental parameter	Metals	Organic contaminant	Pathogens	Nitrogen	Phosphorus	Organic matter
Surface water	L	L	L	P(L)	P(L)	B
Air quality	L	L	L	P(L)	na	na
Soil fertility	P	L	L	B	B	B
Natural ecosystems	P	P	L	P	P	B

(B = beneficial effect, L = low risk, P = possible risk, na = not applicable) (SMITH, 1996)

Based on the evidence presented in this section, the project team recommends that the guideline development should support the continued agricultural use of sewage sludge. This is due to the unique environmental and socio-economical situation.

The remainder of the literature survey will focus on international guidelines and regulatory documents pertaining to the use of sewage sludge in agricultural practices.

3.3 International Trends In Sludge Guidelines And Regulations For The Agricultural Use Of Sewage Sludge

In this section the regulatory frameworks for the agricultural use of sewage sludge in the United States, Canada, Mexico, Europe, Australia (Victoria) and New Zealand approaches are discussed in terms of:

- Sludge classification systems.
- Inorganic constituents.
- Organic constituents.
- Pathogenic organisms.
- Vector attraction and odour reduction.
- Management requirements.

The sludge legislation and guidelines were selected based on the:

- International standing of the country in environmental terms.
- Amount and quality of the research and development invested in the guidelines.
- Climate and socio-economic indicators.
- Availability of the regulations and guidelines in English.
- The amount of sewage sludge that is applied to land.

In addition to the sludge guidelines that were studied and discussed in detail, some information was extracted from "A Global Atlas of Wastewater Sludge and Sludge Use and Disposal. International Association on Water Quality. Scientific and Technical Report No. 3 (Matthews, 1996). Although dated, this is an excellent overview of 25 countries' sludge practices.

3.3.1 Terminology

Two terms need to be discussed in detail: "Sludge" and "Sewage Sludge".

Sludge

Many of the international guidelines clearly distinguish between "sludge" and "sewage sludge". Sludge is loosely defined as sewage sludge that has been treated/stabilised and has sufficiently low levels of contaminants, such that it can be safely used for beneficial land application. Sewage sludge with inadequate treatment or high contamination pathogen content is not considered suitable for land application and hence is not included within the definition of sludge. A 'loose' definition is used, because the actual definitions of qualitative statements such as 'adequate treatment' vary between different regulatory approaches (Reid, 2002). It is recommended that the reference group give some consideration and recommend whether the word "Sludge" should be adopted in South Africa.

Sewage sludge

Locally, several terms are used to describe the residue emanating from the treatment of domestic wastewater. These include sewage sludge, wastewater sludge, domestic sludge, humus, sludge etc. The National Water Act (Act 36, 1998) no longer uses the words sewage, but rather describes it as water containing waste. The Water Act defines waste as "any solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted". The development of the second edition of the sludge guidelines is an opportunity to revisit the terminology used for "sewage sludge". It is recommended that the reference group give this some consideration and recommend a suitable term for "sewage sludge".

3.3.2 International sludge classification systems

In South Africa, unstable sludge is classified as a Type A sludge and the most stable sludge that also complies with inorganic and organic limits is classified as Type D sludge. Internationally, the trend for sludge classification normally adopts a two-tier system:

- (1) A classification system based on the pathogenic and/or stability of the sludge with a Type A sludge being the more stable and highest quality.
- (2) Classification system based on the contaminant issues (organic and inorganic).

The US EPA Part 503 subpart D describes three classification systems of sludge, and specifies their criteria. Two of the classes (Class A and B) include indicator bacteria and/or pathogen criteria, and the third type of sludge that is considered exceptional quality (EQ) sludge, which include both the pathogen and heavy metal criteria (Vesilind and Spinosa, 2001).

Canada (Ontario) does not have a formal classification system, but requires the stabilisation of the sludge as well as restrictions on certain contaminants (including some salts such as Na) (Ministry of Environment, Ontario, 1996).

In Mexico, sludge is classified using two systems based on type (metals) and class (microorganisms). The types are divided in "Excellent" and "Good" and the classes include Class A, B and C, with class A indicating the most stringent microbiological limits (NOM-004-ECOL-2002, 2002).

In Europe, most member states adopted the so called Council Directive 86/278/EEC between 1988 and 1993. No formal classification could be found, but limit values for metals are prescribed. Regulatory requirements on pathogen content in sewage sludge still remains limited to national guidelines of each member state (European Commission, 2001).

Within Australia, sludge regulation and management is primarily the responsibility of individual states and territories. However, a draft national guideline (National Water Quality Management Strategy (NWQMS): *Draft Guidelines for Sewerage Management – Sludge Management*) was distributed for public comment in May of 2002. The draft guideline defines three pathogen grades (P1, P2 and P3), which are based on prescribed treatment processes and microbiological standards. It also details vector attraction reduction measures. Grade P1 sludge are considered suitable for unrestricted use, and grades P2 and P3 have increasing degrees of end use restriction (Reid, 2003).

In New Zealand, a grading system was adopted whereby sludge are assigned to stabilisation (microbiological) grade A or B and a chemical contaminant grade a or b. An A grade biosolid is one in which pathogens and vector-attracting compounds such as volatile solids, have been substantially reduced or removed by an "acceptable" pathogen reduction process. Grade B sludge have a lesser degree of stabilisation and will contain pathogens. To achieve contaminant Grade a, the concentrations of all the contaminants (ie metals and organochlorine compounds) within the sludge must be at, or below, specified limits. A biosolid is classified as Grade b even if only one of the contaminants exceeds the limit specified for a Grade a biosolid (NZWERF, 2003). If a biosolid does not meet the process and product standards for Aa, Ab, Ba, or Bb sludge, the biosolid should be considered a "sludge" rather than a biosolid and it should (therefore) be treated or blended with another substance in order to meet the biosolid product standard or disposed of via an alternative route (NZWERF, 2003).

It is recommended that the reference group consider the following proposal:

- To adopt a classification system that will align the South African sludge guidelines with the international trend.

3.3.3 Inorganic constituents

International limits for metals in sludge

The different metal limits for sewage sludge for several countries were extracted from Matthews (1996) and presented in a figure for each inorganic constituent (Appendix 1: Figures A1a-e). Many of these limits have since been revised and the basis for the metal limits is not always clear from this publication. Most countries only have total metal limits. The data was used to identify the following trends:

- South Africa's As limit is comparable with the Netherlands, which is considered an extreme example of low limits in the EC member states (Reid, 2002);
- South Africa and China are the only countries that have limits for B;
- South Africa, Australia, Austria and Switzerland are the only countries that have Co limits;
- South Africa, USA (Wisconsin), France and Australia are the only countries with Se limits.

A comparison between the US, European and Australian sludge regulations – Inorganic constituents

Reid (2002) published a review paper where he documented an evaluation of the regulatory frameworks in the United States and Europe and contrasted those with the Australian approach. The next few paragraphs highlight his findings followed by an evaluation of the other countries that were not included in his study.

The US, Europe and Australia have some commonalities in the regulatory framework and the inorganic contaminants selected for regulation but there are also fundamental and very significant differences. With regard to similarities, the focus is on similar inorganic contaminants, with cadmium, copper, lead, mercury, nickel, and zinc regulated in all jurisdictions. Other inorganic contaminants, namely arsenic, chromium, molybdenum and selenium, are less consistently regulated. An additional commonality between the US, EC and Australian jurisdictions is the use of ceiling limits that restrict the maximum concentrations of inorganic contaminants that are allowed in sludge. These regulated inorganic contaminants and the ceiling sludge limits are described in Table 3.3.3 (a). The table also includes the limit values from the Netherlands, as an extreme example of low limits in selected EC member states (Reid, 2002). The South African total metal limits have been included for comparison. In general, the South African metal limits are lower than those applied in Australia, the US and those detailed by the European Union.

Table 3.3.3(a): Sludge ceiling limits for inorganic contaminants in different countries

Contaminant	South Africa ¹	Australia National	US 503 rule	EC 86/278/EEC	EC redraft ²	Netherlands
Sludge ceiling limits (mg/kg sludge dry weight)						
As	15	60	75	-	-	15
Cd	20	20	89	20-40	5 / 2	1.25
Cr	1 750	500-3000	-	-	800 / 600	75

Contaminant	South Africa ¹	Australia National	US 503 rule	EC 86/278/EEC	EC redraft ²	Netherlands
Sludge ceiling limits (mg/kg sludge dry weight)						
Cu	750	2500	4300	1000-1750	800 / 600	75
Pb	400	420	840	750-1200	500 / 200	100
Hg	10	15	57	16-25	5 / 2	1.75
Mo	25	-	75	-	-	-
Ni	200	270	420	300-400	200 / 100	30
Se	15	50	100	-	-	-
Zn	2 750	2500	7500	2500-4000	2000 / 1500	300
Table notes:						
1. In order to compare the values on the same basis, only the total limits for South Africa was included (WRC 2002).						
2. Values refer to proposed ceiling limits for medium term (2015) / long term (2025).						

(ADAPTED FROM REID, 2002)

Although the use of ceiling limits is consistent, the fundamental differences in regulatory approaches become apparent when the ceiling limits were compared. The US limits are relatively permissive, being typically 2-4 times higher than the limits in the EC directive and the draft National Australian guideline (Table 3.3.3(a)). Ceiling limits implemented by individual EC member states such as the Netherlands, can be so restrictive that only a small percentage of sludge production is within the limits. The extremely low ceiling limits in the Netherlands reflect a philosophy of managing sludge land application by maintaining inorganic contaminants in the soil at 'background' levels. The approaches elsewhere in Europe, Australia and the US, tend to derive the ceiling limits based on a combination of good practice (i.e. what should be achievable) and protecting soils from exceeding risk-based limits under nominal application scenarios (Reid, 2002).

Of greater practical significance for land application are the receiving soil limits and 'unrestricted grade' limits that have been adopted in the respective jurisdictions (Table 3.3.3(b)). The draft National Australian guideline, as with most Australian states, established a high quality grade (C1) that is considered to have sufficiently low levels of contaminants that no specific regulatory controls are placed on the product to control contaminant risks i.e. from a contaminant perspective, the use of the product is unrestricted. The philosophy driving the C1 numerical limits is based on a scenario where the sludge product is land applied to the extent that it becomes a topsoil replacement. Therefore, the C1 limit is analogous to a receiving soil contaminant limit, with the adopted value representing the most stringent receiving soil limit for protection of the environment, human health (nominally a child ingesting sludge amended soil) and agricultural produce. In Australia, the environmental and human health values are adopted directly from the National Environment Protection (Assessment of Site Contamination) Measure (1999), while limits for protection of agricultural produce have been derived on a case-by-case basis for the protection of food standards (Reid, 2002).

In contrast to the draft Australian national guideline approach of establishing both an 'unrestricted' grade limit and a receiving soil limit, the European Directive only establishes a receiving soil limit. This is, however, coupled to soil pH restrictions and annual loading rates expressed as kg

contaminant/ha/day. The US derived risk assessment based soil limits, but hasn't directly regulated on these limits, using them in conjunction with nominal application scenarios to derive their unrestricted grade (EQ) limits. As illustrated in Table 3.3.3 (b), the US EQ limits and the derived risk based soil limits are typically 10-20 times more permissive than the limits imposed in Australia and Europe (Reid, 2002).

The table also shows the maximum soil metal and inorganic content based on the values documented in the 1991 South African Sludge Guidelines (WISA, 1993). A revised table of the maximum soil metal and inorganic content was documented in the 1997 Sludge Guidelines (WRC, 1997) but because the values include both leachable and total content, they could easily be misinterpreted. For example, the maximum soil Cu content is documented as 100 mg/kg in the 1991 guidelines (WISA, 1993) and 6.6 mg/kg in the 1997 Guidelines (WRC, 1997). The latter value was derived in a similar manner as detailed in Table 3.1.2, and is therefore by default a leachable value and is not based on soil health and agricultural objectives.

The major differences between the US and the European / Australian limits reflect the differing basis for the regulations. The US EPA methodology focused on a risk assessment approach, whereby various algorithms were used to assess potential risks to plants, animals consuming sludge amended soils, children ingesting sludge and consumers of plant and meat products. The US EPA attempted to account for the lower bio-availability of metals in sludge and sludge amended soils compared to other matrixes, and therefore focused heavily on field trials. While the philosophy driving the approach has a strong scientific basis, the assumptions underlying the 503 rule have been subject to significant criticisms from some authors. Key amongst the concerns of these authors is: 1) the selection of relatively resistant plant species for uptake studies; 2) whether evidence of short term reductions in bioavailability would continue into the long term; 3) a bias towards non-acidic soils; and 4) issues such as the use of 50% effect levels and geometric means of data, rather than focusing on the most sensitive species (Reid, 2002).

Table 3.3.3(b): Soil limits and 'unrestricted grade' sludge limits for inorganic contaminants in different countries

Contaminant	South Africa ¹	Australia National ²	US 503 rule ³	EC 86/278/EEC ⁴	EC redraft ⁴
	mg/kg dry weight				
As	2	20	41	-	-
Cd	2	1	39	1-3	0.5-1.5
Cr	80	100-400	-		30-100
Cu	100	100	1500	50-140	20-100
Pb	56	150-300	300	50-300	70-100
Hg	0.5	1	17	1-1.5	1-1.5
Mo	2.3	-	-	-	-
Ni	15	60	420	30-75	15-70
Se	2	3	36		-
Zn	185	200	2800	150-300	60-200

Contaminant	South Africa ¹	Australia National ²	US 503 rule ³	EC 86/278/EEC ⁴	EC redraft ⁴
mg/kg dry weight					
1 South African values based on 1991 Sludge Guidelines (WISA, 1993) 2 Australian draft national guideline limits are both the receiving soil limit and the 'unrestricted' grade limit. They are expressed as a range to enable some flexibility in the development of state specific guidelines. 3 503 rule limits are the Exceptional Quality grade limits. 4 EC limits are linked to soil pH.					

In contrast to the US EPA risk-based approach and a focus on data from sludge field trials, the EC directive and member states such as the UK have focused on protection of the most sensitive components of the soil ecosystem, such as microbiological process and plants. Lowest observed effect concentrations (LOEC) were typically used, some based on pot trials with metal salts. Attempts were made to account for alterations in bioavailability in different soils, by linking selected limit values to pH. The inorganic limit values referenced in the Australian guidelines tend to reflect this approach. The protection of food standards, especially cadmium, has also been a key driver within Australia and Europe, but wasn't directly taken into account in the US (Reid, 2002).

There are some uncertainties regarding future directions of regulatory constraints to sludge land application, with the early drafts of the EC directive proposing reductions in the current levels (Tables 3.3.3(a) and (b)). If universally adopted, the phased introduction of the ceiling limits and soil limits could significantly reduce the amount of current sludge production that can be utilised. However, it is important to acknowledge that: 1) the limits in the early drafts have not been supported by a transparent 'effects' based assessment; and 2) the proposals have not yet reached a formal draft and spirited discussion would be expected during consultation with the member states. It is also important to note that even if a reduction in metal limits did eventuate, this may not lead to a drive away from the land application as a management route, since additional pressures have also been brought onto landfill and incineration disposal options (Reid, 2002).

The NRC (National Academies, 2002) review of the 503 rule was not intended to evaluate the appropriateness of the approach used to derive the inorganic standards and therefore the recommendations neither criticised nor endorsed the current requirements. The recommendations concluded that risk assessment methodologies had evolved since the development of the 503 rule and suggested that a revised multi-pathway risk assessment should be performed. As the review noted, this could theoretically result in limits for individual contaminants staying the same, increasing or decreasing (Reid, 2002).

Within Australia, there appears to be widespread regulatory support for the protectiveness of the limits proposed in their National guideline and reflected in individual state guidelines. Indeed, there have been recent moves to examine potential relaxation of the limits for copper and zinc, particularly in relation to composted products. As a result of these issues, a National research programme is being developed, targeted at the development of bioavailability indexes for cadmium, copper and zinc. This data should ultimately enable more effective regulation of these compounds, rather than a reliance on measures such as total metal concentrations (Reid, 2002).

Mexico

In Mexico (which is seen as a developing country), the official standard for the use or disposal of sludge (NOM-004-ECOL-2002, 2002) standard sets the limits for pollutants in sludge that will be reused or disposed. It does not regulate the application of the sludge, only the quality. According to the Chairman of the Committee, there will be another standard that will regulate the application. Table 3.3.3(c) lists the maximum allowable limits for heavy metals in sludge according to the Mexican standard. The prescribed analytical extraction method prescribes an aqua regia extraction (NOM-004-ECOL-2002, 2002).

Table 3.3.3(c): Mexican maximum allowable limits for heavy metals in sludge (Total)

Parameter (as total)	South Africa ¹ mg/kg (total values)	TYPE EXCELLENT mg/kg TS	TYPE GOOD mg/kg TS
As	15	41	75
Cd	20	39	85
Cr	1 750	1 200	3 000
Cu	750	1 500	4 300
Pb	400	300	840
Hg	10	17	57
Ni	200	420	420
Zn	2 750	2 800	7 500
¹ WRC, 2002			

Canada

On a national basis, Canada have set maximum acceptable metal concentrations in processed sewage, sewage-based products and other by-products with a total nitrogen content of five per cent (5%) or less represented for sale as fertilizers or supplements (Agriculture and Agri-food Canada, 1995) (Table 3.3.3(d)). The by-products include, but are not limited to composted manure, municipal waste tankage, garbage tankage, leather tankage, industrial sewage.

Table 3.3.3(d): Canadian maximum acceptable metal concentrations in processed sewage sludge

Metal	South African Total Metal Limit ¹	Canadian Total Metal Limit ²
Concentration mg/kg		
As	15	75
Cd	20	20
Co	100	150
Hg	10	5
Mo	25	20
Ni	200	180
Pb	400	500
Se	15	14
Zn	2750	1 850

1. WRC, 2002
2. Acceptable concentrations in these products increase proportionally with total nitrogen content above 5%.

Table 3.3.3(d) details the Canadian maximum acceptable metal concentrations in processed sewage sludge. Sewage-Based Products and other By-Products Containing 5% N or Less and Represented for Sale as Fertilizers or Supplements

The maximum acceptable metal concentrations in Table 3.3.3(a) are based on the assumption of a cumulative total application to soil of 200 tonnes per hectare of a 5% nitrogen product. Such a product, applied annually at a rate that would provide 220 kg N/ha (or 4 400 kg product/ha) would cause the maximum acceptable cumulative metal (Table 3.3.3(b)) additions to soils to be reached in 45 years.

These metal concentration standards are adopted as a result of long-term effects of heavy metals in soils. Some metals are relatively phytotoxic, others are toxic to animals or man. Some of the non-essential metals have long-term cumulative effects that are not fully understood.

The standards are conservative. This is because significant metal concentrations are already present in the soils of some areas. In addition, uncontrolled factors such as soil acidity, soil cation exchange capacity and plant species all affect the degree of uptake of some of the metals (Agriculture and Agri-food Canada, 1995). These standards should not be viewed as superseding provincially administered sewage sludge utilisation and disposal guidelines, where such guidelines exist.

Table 3.3.3(e): Canadian maximum acceptable cumulative metal additions to soil

Metal	Maximum Acceptable Cumulative Metal Additions to Soil
As	15 kg/ha
Cd	4 kg/ha
Co	30 kg/ha
Hg	1 kg/ha
Mo	4 kg/ha
Ni	36 kg/ha
Pb	100 kg/ha
Se	2,8 kg/ha
Zn	370 kg/ha

It is the aim of these standards to ensure that use of processed sewage and other by-products will continue to be safe and pose a minimum potential for detrimental effects from metal contamination.

The two elements, molybdenum (Mo) and zinc (Zn) are also plant nutrients. For this reason, higher concentrations than those presented herein may be permitted. Products which contain higher Mo and

Zn concentrations may be allowed if they meet all applicable minimum concentration, tolerance, and labelling criteria of the Fertilizers Act and Regulations. This includes representation of the element as a plant nutrient and the associated guaranteed analysis.

On a provincial level, the Canadian State of Ontario's guidelines for the agricultural use of sludge and other wastes detail unique management principles (Ministry of Environment, Ontario, 1996). The guidelines limits for sewage sludge are based on the nitrogen content Table 3.3.3 (c). The guidelines are specifically designed to use the nitrogen content of the sewage sludge optimally without exceeding metal limits. The metal concentrations of the soil on the site must be the same or lower than that listed in Table 3.3.3 (d), column 3.

To limit metal accumulation these Guidelines restrict the amount of heavy metals that can be applied to soil. Only anaerobically digested sludge with ratios of ammonium plus nitrate nitrogen to metal equal to or greater than those in Table 3.3.3 (c), column 2 may be applied on agricultural land. Aerobic sludge and other wastes must have metal concentrations no greater than those in column 4 in mg/kg of solids before being used on agricultural land on an ongoing basis.

Table 3.3.3(f): Criteria for metal content in sewage sludge (Canada, Ontario)

Metals	Anaerobic Sludge		Aerobic, Dewatered and Dried Sludge and Other Wastes	
	Minimum Ammonium + Nitrate Nitrogen ($\text{NH}_4^+\text{-N} + \text{NO}_3^-\text{N}$) to Metal Ratios		Maximum Permissible Metal Concentrations (mg/kg of solids)	
	Present requirements	Long term targets	Present requirements	Long term targets
As	100	480	170	35
Cd	500	4 200	34	4
Co	50	220	340	77
Cr	6	32	2 800	530
Cu	10	45	1 700	380
Hg	1 500	8 400	11	1,4
Mo	180	1 700	94	1,2
Ni	40	210	420	80
Pb	15	75	1 100	220
Se	500	2 800	34	6
Zn	4	20	4 200	840

a Acceptability of sludge will be judged on the basis of the average concentrations of nitrogen, metals and solids during the preceding 12 months.

b All dewatered and dried sludge must meet the appropriate biosolid criteria before dewatering and drying.

c The long term targets are based on the assumption that metal additions to soil from waste materials is undesirable and that application rates of metals should be reduced in the future.

New Zealand

The New Zealand metal limits (Table 3.3.3 (g)) are not land use dependent and recommended for all soils in New Zealand where sludge are applied (NZWERF, 2003). The South African total metal limits have been included in the table for comparison. In general, the South African metal limits are comparable to the Grade B limits for New Zealand. With regards to the target Grade A maximum concentration limits, the New Zealand values are considerably more stringent. The table also shows the maximum soil metal and inorganic content based on the values documented in the 1991 South African Sludge Guidelines (WISA, 1993). The choice of the 1991 values were explained earlier. Here the New Zealand values seem much less stringent compared to the South African values.

This is because the application rate of sewage sludge in New Zealand is based on nitrogen content and applications could be as high as 40 ton/ha/year, while in South Africa, this is limited to 8 ton/ha/year for a Type D sludge. Therefore, the higher the application rates that are allowed, the lower the metal concentrations should be to achieve long term soil metal quality objectives.

Note that after 31 December 2012, no contaminants in Grade A sludge may exceed the soil limits. A transitional period has been proposed to give wastewater treatment plant operators time to set up and implement programmes for cleaner waste streams entering the plant, and to develop sludge treatment facilities.

In the interim, higher contaminant concentrations are allowed. Allowing these contaminants to be present in sludge in higher concentrations than those allowed in soil will not cause sludge-amended soil to approach the soil contaminant limits in the short term, provided sludge are applied in accordance with a set model rule (NZWERF, 2003). There are two reasons for this. First, condition 2 of the model rule limits sludge applications to a nitrogen (N) loading rate of no more than 200 kg per hectare per year (averaged over three years). With an N proportion generally in the range of 1 to 6 %, this means the highest application rate would be 40 tonnes per hectare (assuming 1% N). If sludge with a cadmium concentration of 3 mg/kg are applied every second year for 10 years, the soil cadmium concentrations will only increase by 0.3 mg/kg. A second safeguard is that the transitional figures are not to be used for topsoil replacement products, as this will cause the soil limits to be exceeded.

Table 3.3.3(g): New Zealand soil limits and sludge classification – inorganic constituents

Metals	South African Soil limit or ceiling concentrations (mg/kg dry weight)	New Zealand Soil limit or ceiling concentrations (mg/kg dry weight)	South African maximum metal concentration in sludge (mg/kg dry weight)	New Zealand Sludge limits		
				Grade a Maximum concentration (mg/kg dry weight)		Grade b Maximum concentration (mg/kg dry weight)
				Until 31/12/12	After 31/12/12	
As	2	20	15	20	20	30
Cd	2	1	20	3	1	10
Cr	80	600	1 750	600	600	1 500
Cu	100	100	750	300	100	1 250
Pb	56	300	400	300	300	300

Hg	0.5	1	10	2	1	7.5
Ni	15	60	200	60	60	135
Zn	185	300	2 750	600	300	1 500

3.3.4 Organic constituents

Guidelines regarding organic constituents in the US, Europe and Australia

Reid's paper (Reid, 2002) also documented his evaluation of the regulatory frameworks in terms of organic constituents in the United States and Europe and contrasted this with the Australian approaches. The next few paragraphs highlights his findings followed by the evaluation of the other countries that were not included in his study.

The EC, US and Australian approaches to regulating organics in sludge differ significantly. Within the Australian guidelines, limits on organochlorine pesticides and polychlorinated biphenyls are prescribed, principally for the protection of food standards in conjunction with cattle grazing. In contrast, the current EC directive does not include limits on organic contaminants, but there are a variety of limits for organic contaminants within member states. As examples, Germany and Austria are the only countries to impose limits on dioxins, Denmark regulates linear alkyl benzene sulphonates (LAS), while Sweden is the only country to specifically regulate toluene.

As with inorganic chemicals, the early drafts of the EC directive have caused some concerns regarding the potential impacts of proposed organic limits on land application. Limits are proposed for a range of organic compounds, including LAS (2,600 mg/kg sludge), endocrine disrupting chemicals such as nonyl phenol ethoxylates (NPE) (50 mg/kg sludge) and dioxins (100 ng total equivalency/kg). While the limits for dioxins would not typically constrain the use of European sludge, if adopted, the limits for compounds such as LAS and NPE would be likely to exclude a large percentage of anaerobically digested sludge. The likelihood that the directive will ultimately regulate these compounds at the proposed levels is uncertain, particularly given that the current drafts of the directive have not yet entered a formal consultation process.

The scientific basis of the limits is not transparent, but given a number of recent reviews that have suggested relatively low risks associated with organics such as LAS and NPE, scientific data may not have driven the initial limit values. Nevertheless, organic contaminants in sludge will remain an important issue, as illustrated by the no-grazing recommendations from the farming association in Sweden, a recommendation attributed to the reports of persistent organics such as polybrominated diphenyl ethers and polybrominated biphenyls in sewage sludge (Reid, 2002).

The US explored the risks associated with organic contaminants in the so-called Round One and Round Two assessments, completed respectively in the early and mid 1990s. Both assessments started with large numbers of candidate chemicals, with 400 chemicals considered in round 1 and 200 chemicals in round 2. Chemicals were then removed from the assessment based on sewage sludge analytical data coupled with a combination of exclusion rules, screening and formal risk assessments. At the completion of the processes, regulatory intervention was only considered warranted for the

inorganic contaminants discussed earlier and for compounds with dioxin-like-activity (NRC, 2002). However, limits for dioxin-like-compounds have not yet been promulgated within the 503 rule.

Within the US, the only current proposal to regulate organic chemicals is for those with dioxin-like-activity. A recently released Notice of Data availability outlines the recent human health risk assessment process and the conclusion that current levels of dioxins in sludge pose an extremely low risk even under the relatively high exposure scenario considered – a farm family surrounded by sludge amended fields and consuming a high proportion of produce from the fields. On this basis, the US EPA requested comments regarding the need or otherwise to specifically regulate dioxins. (Reid, 2002).

Although it therefore appears unlikely that the 503 rule will, in at least the near future, include limits for organic contaminants, the longer term is less certain. The NRC review raised some concerns regarding the process used for excluding organics from the 503 rule. The NRC concerns primarily related to analytical methods used to quantify selected organics for risk assessments, exclusion rules used to remove some contaminants (eg < 10% detection frequency) and that the assessments didn't address some contaminants that have more recently been raised as potential concerns. As a result, the NRC recommended that the assessment process be reviewed and updated. (Reid, 2002).

Guidelines regarding organic constituents in the Mexico, Canada and New Zealand

The Mexican standard (NOM-004-ECOL-2002, 2002) does not make provision to regulate organic constituents such as pesticides.

Ministry of Environment, Ontario, (1996) does not regard the organic constituents to be a major concern and states: "There are significant gaps in knowledge with respect to the fate of organic contaminants in sludge applied to land. However, with over twenty-five years of experience in land spreading, there is no evidence to suggest that there are any organic contaminants in sewage sludge that would pose a risk to humans". The concentrations of each industrial organic contaminant should be assessed on a case-by-case basis.

The organic sludge and soil limits for New Zealand is detailed in Table 3.3.5(a) (NZWERF, 2003). The South African limits (WISA, 1991 and WRC, 1997) have also been included in the table for comparison. The 1997 limits were derived in a similar way manner as the metal limits of the 1997 sludge guidelines as described in section 3.2. The 1991 values were adopted from the US EPA at the time. Generally, the maximum permissible limits in sewage sludge is much more stringent than those of South Africa. However as stated in section 3.3.5, the application rate of sewage sludge in New Zealand is based on nitrogen content and applications could be as high as 40 ton/ha/year, while in South Africa, this is limited to 8 ton/ha/year for a Type D sludge. Therefore, the higher the application rates that are allowed, the lower the organic concentrations should be to achieve long term soil quality objectives.

3.3.5 Pathogenic organisms

The pathogens that are generally subject to regulation are *Salmonella*, enteric viruses, helminth ova, and oocysts and oocysts of protozoa (NZWERF, 2003).

Escherichia coli (*E.coli*) is used as a general indicator for the presence of bacterial pathogens found in sewage sludges.

Salmonella spp. bacteria are subject to regulation because outbreaks of gastro-enteritis have in the past been relatively common and experience has shown that reducing *Salmonella* to a low level, as with faecal coliforms, provides a high degree of assurance that other bacterial pathogens do not constitute a health risk. *Salmonella* spp. are so common in the environment that the proper control of salmonellosis is through food hygiene, sewage sludge properly used in agriculture is not involved in the transmission of human salmonella (Smith, 1996 according to NZWERF, 2003).

Table 3.3.5(a): New Zealand soil limits and sludge classification – organic constituents

Parameter	New Zealand Soil limit or ceiling concentrations (mg/kg dry weight)	South African sludge limits (WRC, 1997) (mg/kg dry weight)	South African sludge limits (WISA, 1993) (mg/kg dry weight)	New Zealand Sludge limits		
				Grade a Maximum concentration (mg/kg dry weight)	Grade b Maximum concentration (mg/kg dry weight)	
Organics				Until 31/12/12	After 31/12/12	
DDT/DDD/DDE	0,5	0,35	0,6875	0,5	0,5	0,5
Aldrin	0,02	0,202	Aldrin + Dieldrin 2,00	0,02	0,02	0,2
Dieldrin	0,02	0,303		0,05	0,02	0,2
Chlordane	0,02		150,000	0,02	0,02	0,2
Heptachlor and Heptachlor epoxide	0,02	0,35	4,625	0,02	0,02	0,2
Hexachlorobenzene (HCB)	0,02	16,2	4,875	0,02	0,02	0,2
Hexachlorocyclohexane (Lindane)	0,02	1,36	575,000	0,02	0,02	0,2
Benzene hexachloride (BHC)	0,02	-	-	0,02	0,02	0,2
Total polychlorinated biphenyls (PCBs)	0,1	1,0	0,700	0,2	0,2	0,2
Total dioxin TEQ	0,00001	-	-	0,00003	0,00003	0,00005

There are numerous types of enteric viruses that occur in sewage sludge including Hepatitis A virus, Small Round Structured Viruses including Norwalk virus, and Adeno virus. Some enteric viruses, such as the Adeno virus, are more resistant to physical and chemical agents than others. The types and concentrations of viral agents in sewage sludge are dependent on the level of viral illness present in the associated community (NZWERF, 2003).

Helminths found in sewage sludge include nematodes (roundworms and hookworms), cestodes (tapeworms) and trematodes (flukes). Helminth ova are very resistant to the environmental factors that reduce the numbers of bacterial indicators or animal viruses in sludge. Because of their resistance, the presence/absence of viable helminth ova is used as a criterion for monitoring for the presence of helminths in sludge to be applied to land. *Taenia saginata*, the beef tapeworm, is a helminth of potential concern. It produces eggs that are resistant to environmental stresses. *T. saginata* has a cyst stage in cattle and a worm stage in humans. Problems have generally only arisen where cattle have been grazed on pasture irrigated with untreated human sewage sludge (thereby becoming infected with the larval stage of the tapeworm) and then people have eaten the raw or undercooked beef, becoming infected with viable larvae.

Protozoa found in sewage include *Entamoeba histolytica* (amoebic dysentery) *Giardia entestinalis* (gastro-enteritis), *Cryptosporidium* (gastro-enteritis) and *Balantidium coli* (gastro-enteritis). These organisms generally occur as cysts, which are inactivated by heat and/or lime treatment.

Sludge that have been treated to the point where they are deemed safe for use by the general public are essentially free of pathogens and there is a very low risk to people handling them (NZWERF, 2003).

A comparison between the US, European and Australian sludge regulations – Pathogens

Reid published a second paper exploring the sludge regulatory frameworks in the United States and Europe and contrasting these frameworks with the Australian approaches (Reid, 2003). In the 2003 paper, he concentrated on the regulatory aspects of pathogens in sewage sludge applied to land (Reid, 2003). The next few paragraphs highlights his findings followed by the evaluation of the other countries that were not included in his study.

The majority of regulatory approaches (but not all) currently have the following areas of consistency (Reid, 2003):

- Classification is based on a philosophy of combining prescriptive treatment processes with microbiological criteria, for example *E. coli* per gram sludge;
- Similar treatment processes are described, for example mesophilic anaerobic digestion and composting, and
- Classification involves a two level system with a 'high quality' and often unrestricted use grade sludge based on intensive treatment, and a 'base' or restricted grade of sludge based on relatively standard approaches such as anaerobic mesophilic digestion. Material that is raw or inadequately

treated for the above classification is typically considered unsuitable for land application (Reid, 2003).

'Intensive treatment' grades

The terminology 'intensive treatment' grade was used in Reid's paper (2003) to describe the highest classification grades described by the different regulatory authorities. This descriptor is used because each regulatory authority adopts different nomenclature (for example 'Class A' in the US, 'enhanced treatment' in the UK, 'P1' in the draft national Australian guideline), and so the specific nomenclature is reserved for discussions of the relevant regulatory authority. In addition to the following text, the requirements of the different jurisdiction for achieving an 'intensive treatment' grade sludge product are summarised in Table 3.3.5(b) (Reid, 2003).

United States

The pathogen standards for the US 503 rule were based on operational experience and professional judgment, rather than a formal risk assessment process. The regulatory approach to classification is predominantly based on the previously described combination of validated technologies, ongoing monitoring of process control parameters and compliance with bacterial limits. The valid treatment processes included processes that conform to generic temperature-time curves, specific pH-temperature-time criteria, processes that are listed in the regulations as Processes to Further Reduce Pathogens (PFRP's), or processes that have been more recently assessed and considered as 'equivalent' to PFRP's (Reid, 2003).

To be classified as Class A sludge, the treatment process must operate within defined specifications and achieve a bacteriological standard of < 1000 faecal coliform per gram dry weight (dw) or < 3 *Salmonella* per 4 grams dw. The bacteriological standard applies immediately after treatment process is completed and also after periods of storage (Reid 2003). Sludge from an unlisted process can be classified as Class A if the product achieves the bacteriological limit (i.e. < 1000 faecal coliforms per gram dw or < 3 *Salmonella* per 4 grams dw), < 1 viable helminth ova per 4 grams dw and an enteric virus density of < 1 PFU per 4 grams dw (Reid, 2003).

In addition to the above requirements, meeting the Class A criteria also requires vector attraction reduction (VAR) measures to be undertaken by either biological degradation of putrescible organics, inhibition of biological activity prior to application (e.g. by drying or increasing pH), or through the use of physical barriers (e.g. injection or soil incorporation (US EPA, 1999; Vesilind and Spinoso, 2001). Products that comply with the Class A criteria and the VAR measures are available for unrestricted use from a microbiological perspective.

European requirements

As noted earlier, the Sludge Directive (86/278/EEC) currently provides the overarching legislative basis for sewage sludge treatment and reuse in Europe. Unfortunately, despite the significance of this document, it provides only qualitative criteria rather than quantitative standards for treatment. The definition of treated sludge is "sludge which has undergone biological, chemical or heat treatment, long term storage or any other appropriate process so as significantly to reduce its fermentability and the health hazards resulting from its use" (Reid 2003).

Not surprisingly, given the lack of definitive treatment criteria, the current directive treatment criteria, the current directive is restrictive on acceptable uses of sludge. In contrast to the approach in the US of an 'unrestricted' microbiological grade, there are restrictions on all sludge use. This includes a ten-month post-application withholding period for the use of sludge on land used for fruit and vegetable crops, with the exception of fruit trees. However, it is interesting to note that the directive includes the potential for use of raw sludge by member states and that until recently, this practice was accepted in some jurisdictions

- **Draft EC directive**

Although the current EC directive does not provide detailed criteria on sludge treatment, working redrafts of the directive do include quantitative standards. The redraft describes an 'advanced' treatment grade that is proposed for unrestricted use. As per the US, this classification is based on a combination of prescribed treatment processes and microbiological standards. Examples of treatment processes are described in Table 3.3.5(b).

While the EC commissioned a report to examine treatment standards, they ultimately proposed a number of process criteria significantly more stringent than suggested in the report.

The required microbiological standards for confirmation as 'advanced grade' are i) an initial validation of the processes through a 6 log reduction of a test organism such as *Salmonella senftenberg* W775 and ii) no *Salmonella* spp. Per 50 grams (wet weight) and a 6 log reduction in *E.coli* to less than 500 CFU per gram (EC, 2000)

Although the basis for these provisions is not described, the approach being proposed has some very strong similarities with proposed changes in legislative requirements within the United Kingdom (UK).

It should be noted that while it is always tempting to accept drafts of regulatory documents as indications of future directions, some caution is needed with the draft directive, since the redrafting has not yet been through formal member state consultation (Reid 2003).

- **United Kingdom**

The sludge management framework in the UK is currently of great significance. Recent redrafting of the legislation has been underpinned by a major research initiative. The research has involved three components: 1) development of methods for pathogen analysis and quantification, 2) assessment of

pathogen reductions through key treatments, and 3) quantitative assessment of the resultant food safety risks. Importantly, the research has not only supported the requirements in an existing code of practice 'The Safe Sludge Matrix', but the code has broad support from organisations such as the British Retail Consortium, which represent major supermarkets and consumers (Reid 2003).

In the UK, the key legislation is the UK *Sludge (Use in Agriculture) Regulations 1989*, and proposed amendments to the legislation involve the following definition of *Enhanced treated sludge*: (DEFRA, 2002 according to Reid, 2003):

"sludge or septic tank sludge which has undergone a biological, chemical or heat treatment process, long term storage or any other appropriate process so as to significantly reduce its fermentability and the health hazards resulting from its use, being a process of such a character that it causes *Salmonella* spp to be absent and ensures a 99.9999% (6 log) reduction of the indicator pathogen *E. coli*, with a maximum allowable concentration (MAC) of *E. Coli* of 10^3 per gram dw" (DEFRA, 2002 according to Reid, 2003).

It should be noted that a definition of "*Salmonella* spp. absent" is not provided. Testing for *Salmonella* is based on 2 grams dw of sludge, and hence it is assumed that the criteria is 'not detectable' *Salmonella* per 2 grams dw.

• France

With regards to the range of microbiological standards that are applied, it is useful to note the EC (2001) description of 'hygienised' sludge in France, which is based on:

- < 8 *Salmonella* MPN per 10 grams dw,
- < 3 MPN enteroviruses per 100 grams dw,
- <3 Helminth eggs per 10 grams dw.

The document is not clear on the acceptable uses for 'hygienised' sludge (Reid, 2003).

National Australian guideline

The draft of the national guideline for sludge management *Guidelines for Sewerage Systems – Sludge Management* under the NWQMS makes an important structural distinction from the US and European approach, effectively dividing the 'intensive treatment' grade classification into two categories. However, the philosophy of linking the treatment process with microbiological criteria remains unchanged. (Reid, 2003).

The unrestricted grade (grade P1) includes microbiological criteria of < 1 *Salmonella* per 50 grams dw (i.e. undetected) and < 100 IE. *Coli* I(or thermotolerant coliforms) per gram dw. These microbiological standards are linked to treatments that are comparable to the 503 rule (Table 1). A slightly reduced treatment grade, but still comparable to the requirements in the US and draft European directive is defined as grade P2. This grade involves some restrictions on enduse, for example it is not permitted for use in recreational or residential landscaping. The microbiological standards for grade P2 are < 10 *Salmonella* per 50 grams dw and < 1000 *E.coli* (thermotolerant

coliforms) per gram dw. A number of the prescribed processes are comparable to the P1 requirements, i.e. the composting temperature-time profile is identical, meaning the main practical application is likely to be for producers targeting P1 but who occasionally do not make the relatively stringent P1 microbiological criteria. However, there are also P2 processes described that are not included within the P1 treatment processes (Reid, 2003).

• New South Wales

The most widely recognised guidelines in Australia are the *Environmental Guidelines: Use and Disposal of Sludge Products* (NSW EPA, 1997 according to Reid, 2003). They specify similar treatment processes to the draft national guideline (albeit the presentation is altered). The microbiological standards for the unrestricted grade product are also comparable, listing < 100 *E. coli* per gram dw, < 1,000 faecal coliforms per gram dw and no detectable *Salmonella* per 50 grams dw.

'Class B' requirements

An area of relative consistency international regulation of sludge is in the definition of the 'base' grade of sludge treatment: (Reid, 2003).

- The US part 503 describes a 'Class B' product which is derived from Processes to Significantly Reduce Pathogens (PSRPs), such as mesophilic anaerobic digestion for 15 days at 35°C, coupled to a microbiological limit of < 2x10⁶ faecal coliforms per gram dw;
- While the current EC sludge directive only includes a qualitative description of sludge treatment, the current redraft is more closely aligned with the US approach. The redraft describes a range of 'conventional' treatment processes, which include mesophilic anaerobic digestion for 15 days at 35°C. However, this is coupled to microbiological criteria of a 2 log reduction in *E. coli*. While the US and EC align on processes such as mesophilic anaerobic digestion, there are some differences in listed processes;
- The proposed UK legislative changes include a definition of 'conventionally treated sludge' which is based on a qualitative description of treatment, coupled to a 99% (2 log) reduction of the indicator organism *E. coli*, with a maximum allowable concentration (MAC) of *E. coli* of 10⁵ per gram dw; and
- The draft Australian national guideline includes comparable treatment processes and microbial criteria to the US 503 rule, however the Australian approach is based on the monitoring of *E. coli* rather than faecal coliforms, as in the US. It is interesting to note that the NSW guideline also lists the treatment processes, but relies on more qualitative process descriptors coupled to stabilisation criteria. Microbiological standards are not imposed.

Although the jurisdictions are in practice roughly aligned on the generics of treatment classification, the end use controls are significantly different (Reid, 2003).

Victoria (Australia) microbiological standards

The Victoria (Australia) guidelines (EPA Victoria, 2002) go into detail on how to manage pathogens, vectors and odours. It will therefore be discussed separately. The Victoria (Australia) guidelines (EPA Victoria, 2002) specifically mention three treatment grades (T1, T2 and T3). These grades are based on satisfying three main criteria:

- Defined treatment process(es) with minimum performance criteria (e.g. temperature/time) used to reduce pathogen numbers in sludge.
- Microbiological limits to demonstrate that the defined treatment processes are operating effectively.
- Measures for controlling bacterial regrowth, vector attraction (e.g. insects, birds, vermin) and generation of nuisance odours.

Treatment Grade T1

Grade T1 represents the highest quality grade and from a microbiological perspective is suitable for unrestricted use. Since this guideline does not include regulatory controls on the end use of T1 products, there is a particular emphasis on ensuring adoption of treatment processes that can reliably achieve significant log reductions across a wide range of pathogens (EPA Victoria, 2002).

- **Producing T1 from recognised treatment processes**

There are a restricted number of treatment processes that have been demonstrated as being capable of reliably reducing pathogens to low levels. These treatment processes are described in Appendix 2 and are principally derived from the US EPA 503 Processes to Further Reduce Pathogens (EPA Victoria, 2002).

- **Microbiological standards**

Class A sludge are required to comply with microbiological limits of:

- <100 *E.coli*/gram dw, and
- <1 *Salmonella*/50 grams dw.

No more than 10% of samples are to exceed the limits, and no value shall exceed:

- <250 *E.coli*/gram dw, and
- <1 *Salmonella*/10 grams dw.

The microbial criteria apply immediately after the defined treatment process and also immediately prior to the product being available for unrestricted use. Demonstrating *E.coli* and *Salmonella* removal immediately post the defined treatment process demonstrates effective operation. The criteria

apply immediately prior to the product being available to use, to ensure that bacterial regrowth has not occurred post treatment. The described T1 treatment processes have been assessed as reliably achieving a minimum of 3-log reduction in enteric viruses and a 2-log reduction in helminth ova. The typical performance of the processes would be expected to be significantly better than this minimum (EPA Victoria, 2002).

- **T1 Regrowth Control**

'Stabilisation' is a generic requirement for all Class A sludge to: reduce vector attraction, ensure offensive odours are not generated from the product and ensure that pathogenic bacterial regrowth does not occur.

Ensuring inhibition of pathogenic bacterial regrowth is a particularly significant issue for T1 sludge. Due to the high temperatures characteristic of T1 processes, both pathogenic and non-pathogenic microorganisms are reduced to very low levels. If the sludge are not "stabilised" post treatment, the presence of food sources coupled with the absence of competing microorganisms, provides an opportunity for pathogenic bacteria such as *Salmonella sp.* to repopulate the sludge. Appendix 2 provides suggested measures for different treatment processes to inhibit bacterial regrowth. This is preferably demonstrated by storage of the final product at 25 °C for three weeks, with analysis for *E.coli* and *Salmonella* at the start and end of storage (EPA Victoria, 2002).

Treatment Grade T2 and T3

Grade T2 and T3 sludge are required to meet the associated treatment processes, pathogen standards and routine monitoring, reductions in vector attraction and odour set out in Appendix 2. As with T1 sludge, T2 and T3 sludge must not generate offensive odours that can be detected off-site during either storage or land application.

T3 sludge have a specific restriction on use with cattle grazing, primarily due to concerns with reliability of *Taenia saginata* removal (EPA Victoria, 2002).

Treatment Grade T4

Grade T4 sludge are those which do not meet any of the treatment processes outlined in Appendix 2 and are likely to require site specific risk assessment, EPA works approval and licensing (EPA Victoria, 2002)

Reducing vector attraction and odour

The US EPA defines "Vectors" as any living organisms that are capable of transmitting pathogens from one organism to another, either:

- Mechanically (by transporting the pathogen) or
- Biologically by playing a role in the lifecycle of the pathogen.

Vectors include flies, mosquitos or other insects, birds, rats, and other vermin. The transport of pathogens by vectors can be controlled by any of the following:

- Biological processes which breakdown volatile solids, reducing the available food nutrients for microbial activities and odour producing potential.
- Chemical or physical conditions which stop microbial activity.
- Physical barriers between vectors and volatile solids in sludge.

Vector attraction reduction ("VAR") options are summarised in Table A2.2 (EPA Victoria, 2002).

Sludge will need to satisfy at least one relevant VAR in addition to at least one treatment (pathogen reduction) process to determine the specific Treatment Grade of the product. VAR (particularly for grade T1 and T2 sludge) should be met after or concurrent with pathogen reduction to prevent re-growth of pathogens (EPA Victoria, 2002).

Canadian microbiological standards

The legal and guidelines documentation that was sourced does not specifically refer to pathogenic organism limits. The Ministry of Environment, Ontario (1996) stipulated that all sewage sludge must be stabilised before being spread on land. It recommends anaerobic and aerobic digestion to be used to stabilise sludge and possibly control odours and pathogenic organisms. In general, the sludge are considered as appropriately stabilised, (Ministry of Environment, Ontario, 1996):

- Odours after spreading are no more objectionable than those produced from normal farming practice.
- The pathogenic content of the wastes is no greater than that of digested sewage sludge.

Environment Canada (1984) have published a manual for land application of treated municipal wastewater and sludge that includes a large section on the management of pathogenic organisms in sewage sludge. This document states that "little evidence exists to show that disease is transmitted by land spreading of treated wastewater and sludge. Documented disease transmission to humans from land application programmes is mainly related to the use of raw wastewater on land" (Environment Canada, 1984). The document summarises the international guidelines (although dated) on the suitability of sludge for land application, which includes Canada (Ontario and Alberta). The document highlights the fact that digestion, stabilisation or disinfection are usually required for all types of land application. Extended periods of time are required before grazing is permitted, largely due to helminth ova survival. If these and similar guidelines are followed, with good sludge and land management practices, it is considered that the risk of animal and human infection is limited. However, they recommend continued studies and vigilance to ensure that human health is adequately protected (Environment Canada, 1984).

Microbiological standards in developing countries - Mexican standard

Jimenez *et al.* (2003) argues that the pathogenic organisms in sludge should be the focus of sludge legislation in developing countries. She states that due to the low level of sanitation in developing countries cause high concentrations of parasites in the sludge. However, the metal content in sewage sludge from developing countries could be lower compared to developed countries.

Table 3.3.5(c) lists the microbiological requirements of the Mexican sludge legislation (NOM-004-ECOL-2002, 2002).

Note that the Helminth ova standards for their type B sludge are much higher than all the other countries. A personal communication with Prof Blanca Elena Jiménez Cisneros (Tratamiento y Reúso Apdo. Pstal; Instituto de Ingeniería; Coyoacán, México, D.F) indicated that the Mexican Environmental Department recognise that the Helminth ova concentration in the wastewater sludge is significantly higher than the helminth ova concentration found in the wastewater sludge of developing countries. It is obviously much easier to reach a target value of example 0.25 viable ova/g TS when the starting concentration is in the order of 1 or 2 viable ova/g TS. In Mexico, helminth ova concentration in sludge is often as high as 40 ova/g TS. In Mexico, they have adopted a strategy to reduce the prevalence of helminth ova by adopting a practically achievable standard for their type B sludge (<10 viable helminth ova/g TS). Once they have managed to achieve this, they can strive to achieve the more stringent standards detailed for their Type A sludge.

Table 3.3.5 (c): Maximum allowed limits for pathogens and parasites in sludge in Mexico

Class	Bacterial indicator	Pathogens	Parasites
	Faecal coliforms, MPN/g TS	<i>Salmonella</i> spp. MPN/g TS	Helminth ova, ova/g TS
A	< 1 000	< 3	< 1 ^(a)
B	< 1 000	< 3	< 10
C	< 2 000 000	< 300	< 35

^(a) Viable ova

The South African Sludge Guidelines (WRC 1997) stipulates that a Type C and D sludge should contain no viable *Ascaris* ova per 10 g dry sludge, "maximum" 0 *Salmonella* organisms per 10 g dry sludge and maximum 1000 Faecal coliform per 10 g dry sludge, immediately after treatment (disinfection/sterilisation). Table 4.5.6(a) indicate that the Mexican Standard is less stringent despite the fact that the microbiological aspects are deemed most important. In Mexico, the legislators adopted the US EPA limits for heavy metals and faecal coliforms and modified the limits for *Salmonella* and helminth ova, based on the quality of the sludge. The main difference is that the limits for these two pathogens apply to both classes of sludge (A and B) while the EPA only requires monitoring them in a class A sludge (Jimenez *et al.*, 2003). The Mexican legislation does not include enteric viruses at this stage.

New Zealand microbiological standards

Table 3.3.5(d) details the microbiological standard for New Zealand Grade A sludge (NZWERF, 2003) compared to the South African limits set for type C and D sludge (WRC, 1997).

The high rate of campylobacteriosis disease in New Zealand and its prevalence in the environment make this bacterium of greater concern than *Salmonella* spp. and its measurement has been included in these *Guidelines*. There is potential for regrowth of these organisms in sewage sludge and sludge in storage or after application to land (NZWERF, 2003).

Sludge that do not attain the unrestricted use, or Grade A stabilisation standards, potentially contain pathogens at infectious levels, so they cannot be sold or given away direct to the public and the risks need to be managed by reducing the pathogen levels prior to land application (e.g. by storage), by soil incorporation, by restricting end uses to areas with low public exposure, or by imposing excluding periods following land application (NZWERF, 2003).

In addition to the risk of infection arising from direct contact with sludge that do not attain Grade A stabilisation, there is a potential food safety issue. The survival of some pathogens in the soil, most notably parasites and viruses, is not well understood. Because there is no final barrier (i.e. a kill step such as cooking) with crops that are eaten raw (e.g. salad crops or root crops such as carrots), sludge not attaining the Grade A standard should not be applied directly to these crops without a further waiting period (NZWERF, 2003).

Table 3.3.5(d): Microbiological standard for New Zealand Grade A sludge

Pathogen or indicator organism	South African pathogen guidelines WRC, 1997	New Zealand Product pathogen standard NZWERF, 2003
<i>E. coli</i>	-	< 100 MPN/g
Faecal coliforms	≤1000 MPN/10g	-
<i>Campylobacter</i>	-	< 1/25 g
<i>Salmonella</i>	0 organisms/10 g	< 1/25 g
Enteric viruses	-	< 1 PFU/4g
Helminth ova	No viable <i>Ascaris</i> ova / 10g	<1/4g

The New Zealand guidelines also lists acceptable pathogen reduction processes such as time-temperature processes and high pH processes (NZWERF, 2003).

Future directions and key activity areas

There is a general consistency in the international approaches with regard to the management of sludge microbiological quality. There appears to be limited potential for significant changes in the currently accepted treatment processes or in organisms that are currently used for process monitoring. The key areas of future activity would appear to be in the area of (Reid, 2003):

- Quantitative risk assessments to demonstrate the safety of land application, particularly for sludge where restrictions are applied to their use (for example, a product from mesophilic digestion)
- Refinement of criteria for the validation and assessment of emerging technologies that are not currently prescribed in legislative frameworks; and
- The microbiological criteria that apply for process monitoring of an unrestricted grade product, for example < 1 *Salmonella* per 5 grams dw versus < 1 *Salmonella* per 50 grams dw.

3.3.6 Vector attraction and odour reduction

Vectors such as flies, mosquitoes, birds and rodents are potential carriers of disease. They can transmit pathogens to humans and other hosts physically through contact, or biologically by playing a specific role in the lifecycle of the pathogen. Reduction of the attractiveness of sludge to vectors reduces their potential for transmitting diseases (NZWERF, 2003).

In New Zealand they specifically mention vector attraction reduction (VAR) processes that are very similar to those detailed in the Part 503 rule in the US. VAR can be achieved by either (NZWERF, 2003):

- Subjecting the sludge to specific physico-chemical processes or conditions, or
- Preventing access to the sludge by vectors, usually by incorporating the sludge into the soil

The New Zealand guidelines (NZWERF, 2003), makes provision for stabilisation, specifically aimed at reducing odours and vector attraction. Sludge are stabilised by treating them in a way that reduces or eliminates the potential for putrefaction and which, as a result, reduces pathogens, vector attraction and the potential for offensive odours.

The Ministry of Environment, Ontario (1996) suggests some stabilisation technique such as anaerobic and aerobic digestion to control odours and pathogenic organisms. They consider sufficient odour control if the "odours after spreading are no more objectionable than those produced from normal farming practice".

The Ministry of Environment, Ontario (1996) recognised that when sewage sludge are applied to land close to residences, concerns may arise because of the potential for odours, airborne drift of particles and surface run-off. The level of concern depends upon the application method and land slope. The minimum distances between the spreading site and a residence in a residential area is normally 450 m. For an individual residence not in a residential area the minimum separation distance is 90 m. However, when liquid wastes are injected into the soil, or when it is spread by surface irrigation and is incorporated within twenty-four hours, distances may be reduced. In addition, the distance may be reduced by the farmer when he or she is the owner and occupier of the individual residence. The absolute minimum distances for waste material application in all cases are 50 m from an individual residence (Ministry of Environment, Ontario, 1996).

The Mexican sludge legislation requires that the sludge or sludge generator reduce the vector attraction by one of the 7 options described or any other that demonstrates its effectiveness. These options are technology based and include the reduction of volatile solids, digestion, aerobic processes (> 408C) and treatment with high alkaline materials. The Mexican sludge legislation does not mention the management of odours.

3.3.7 Management requirements

Underlying management principles of the New Zealand guidelines

The underlying principle of the New Zealand sludge guidelines are very well documented (NZWERF, 2003). The principles underlying the approach adopted in the New Zealand Guidelines are outlined below.

Sludge can and should be used beneficially

Sludge possess significant soil conditioning and fertilising properties. In fact the wide array of elements they contain that are essential for plant growth and the organic content of sludge have led some authors to suggest that sludge are a more complete fertiliser than most other proprietary fertilisers. However, the presence of a wide variety of chemicals in sludge (albeit in trace amounts) with the potential for uptake by plants and animals, together with the potential presence of pathogens means that sludge cannot be treated like other fertilisers.

A fundamental premise of these Guidelines is that sludge can be beneficially recycled to land providing that both the process of manufacture and the process of applying the sludge to land are subject to adequate management control and providing the sludge are applied at a rate that does not exceed the agronomic nitrogen needs of crops.

In other words rather than viewing sludge as waste products that should be disposed of (eg by way of land filling) which has its own adverse environmental effects it is viewed as a valuable resource (NZWERF, 2003).

Protection of public health

Sludge being derived from sewage, have the potential to contain pathogen micro-organisms, including salmonella, campylobacter, giardia and entero-viruses. The risk of infection must be eliminated or reduced to an acceptable level by:

- Employing appropriate pathogen-killing techniques during the sludge production process
- Taking precautions with the handling of sludge
- The careful choice of end use
- Temporary exclusion of people from areas where sludge have been applied.

Sludge also contain contaminants (e.g. metals, organic compounds) with the potential to enter the human food chain. The risk of this occurring can be eliminated or minimised by placing appropriate controls on the way sludge are applied and the levels that contaminants are permitted to build up to in soils (NZWERF, 2003).

The sludge management framework needs to be flexible and enabling

The Guidelines provide a broad generic framework for managing sludge. While endeavouring to promote national consistency in the way the application of sludge to land is managed, they do not provide a list of rules to be applied in any situation. This is because it is important to take into account local circumstances and community aspirations in deciding what conditions should be applied to specific proposals (NZWERF, 2003).

Risk management

Risk management is the key to successfully managing sludge application to land in New Zealand. The main way to reduce contaminant loads in sludge is via cleaner production initiatives and/or improved trade waste management, that is, by way of source control or waste minimisation. Both regulation (trade waste bylaws) and education have a role to play.

Risks can be managed by (NZWERF, 2003):

- Pathogen reduction/destruction during sludge manufacture (e.g. via an appropriate heat/time regime or by pH control) and monitoring of this process.
- Controlling vector attraction (disease transmission, odour risk).
- Diluting chemical contaminants via blending (e.g. soil, sand, wood waste, pumice mixes).
- Storage requirements.
- Labelling requirements.
- Setting sludge contaminant limits and monitoring these requirements.
- Establishing contaminant soil limits (maximum permissible levels in the receiving environment) and soil monitoring requirements.
- Soil testing prior to application.
- Control over the application rate (loading) of sludge discharges to land.
- Control over end uses.
- Soil incorporation requirements.
- Public exclusion/stock withdrawal periods (pathogen risks).
- Soil monitoring requirements.
- Soil pH adjustment.

- Requirements for environmental management systems (EMS).
- Quality assurance requirements.

A precautionary approach

It is generally agreed that a precautionary approach needs to be adopted to managing the risks associated with sludge use. This stance recognises that there are gaps in scientific knowledge about the long-term effects of applying sludge to land and acknowledges the importance of healthy soils (NZWERF, 2003).

Applicable management practices in other countries

Canada

Due to the fact that the guidelines for Ontario are specifically geared to land application of sewage sludge, unique management practices and guidelines are presented and worth summarising in this review (Ministry of Environment, Ontario, 1996). They recognise that waste materials such as sewage sludge contain elements that can be either desirable or undesirable for agriculture. The guidelines are geared towards the use of the beneficial elements such as nitrogen and suggest management practices to control the undesirable elements. For example, the application rate of nitrogen should be based on ammonium plus nitrate nitrogen content and fertilizer recommendations and may not exceed 135 kg of nitrogen/ha over a five year period for crops, or a four year period for sod.

Sodium and boron is also discussed in detail. High concentrations of sodium can cause irreversible damage to soil structure. Therefore, wastes applied to agricultural land must conform to set the sodium loads between 200 and 500 kg/ha depending on the soil type. In terms of Boron, the guideline recognises that most crops are boron intolerant, and therefore a limit of 1 kg boron/ha/yr. The hot water soluble boron concentration in the soil, for these crops, should be equal to or less than 1,0 mg/ℓ. For boron tolerant crops, the application limit is 2 kg boron/ha/yr. For these crops, hot water soluble boron concentration in the soil should be equal or less than 1,5 mg/ℓ.

This guideline also addresses non-biodegradable material in the sludge (Ministry of Environment, Ontario, 1996). It states that waste material proposed for application on agricultural land shall contain no foreign non-biodegradable material that may cause human or animal injury or damage to equipment.

The foreign non-biodegradable material content of the waste that will not pass through an 8 mesh screen size Tyler sieve (2,36 mm size openings) shall not exceed the following:

- The concentration (% dry wt) of plastic shall not exceed 1,0% of the total sample
- The total concentration (% dry wt) of all other foreign non-biodegradable materials shall not exceed 2% of the total sample.

Mexico

Mexican sludge legislation (NOM-004-ECOL-2002, 2002) guides the use of sludge depending on the on the type (metals) and class (microorganisms) as shown on Table 3.3.7(a).

Table 3.3.7(a): Potential use of sludge according to the Mexican guidelines

Class	Type	Potential Use
A	Excellent	Urban uses with direct public contact during their application Those established for classes B and C
B	Excellent or Good	Urban uses without direct public contact during their application Those established for class C
C	Excellent or Good	Forestry Soil reclamation Land application (agricultural)

Australia (Victoria)

Victoria (Australia) have developed specific guidelines (consultation draft) that describes the minimum requirements for the management of contaminants and treatment, thereby ensuring sustainable use, but enabling access to the potential benefits of sludge land application – additions of nutrients, trace elements and moisture and improvements in soil structure.

This guideline provides a framework for sustainable sludge land application and the exclusion of these schemes from EPA works approval and licensing provisions. The focus is on desired performance objectives and outcomes through quality management, allowing scope for innovation. Suppliers and users of sludge have flexibility to consider and implement alternative measures to those suggested, provided an equivalent, or better, site-specific solution is achieved. At the same time, those seeking greater direction or certainty can simply apply the suggested measures (EPA Victoria, 2002).

3.4 Public Perception and Acceptance

The scientific evidence of both the risks and benefits associated with the application of sewage sludge to agricultural land has been well documented (Korentajer, 1991). There are probably few scientists who would argue that sewage sludge should be viewed as an unwanted by-product of sewage treatment. The literature pertaining to sewage sludge reveals that an enormous amount of research has gone into understanding and exploiting the benefits of re-using sludge and into better understanding any threat of its reuse on land. The re-use of sewage sludge on land is recognised by both government and the regulators to be the best practical environmental option (Tyson, 2002).

However, the general public's opinion on the use of treated sewage sludge as a soil amendment in agricultural practices could potentially change the current or future practices based on their support or

lack thereof. The general public is not exposed to detailed peer reviewed scientific papers and often rely on information published in the general media. In the US, some environmental activists such as Green Peace and the Citizens Clearinghouse on Hazardous Waste have warned about the dangers of sludge, but most groups have bought into the argument that sludge farming is the least offensive way to manage the problem of waste disposal. Some groups even support sludge farming. During the 1970s, these environmentalists worked for promulgation of the Clean Water Act. Now they find themselves in the awkward position of defending its consequence with having to face huge mountains of sludge. Sarah Clark, formerly of the Environmental Defence Fund, claims that sludge farming "is the best means of returning to the soil nutrients and organic matter that were originally removed. It is recycling a resource just as recycling newspapers or bottles is. If the right safeguards are taken, it can be environmentally protective and even beneficial."

It is speculated that there is another factor which influences public perception of sewage sludge reuse to a far greater extent than anything discussed in this research so far, and that factor is odour. Very seldom does a member of the public register concern or complain about sewage sludge reuse solely due to a fear relating to food safety; they have usually been provoked to complain by having their privacy invaded by odour from sludge spreading activity. If sewage sludge did not smell the public probably would not complain and the overall public perception of the reuse of sewage sludge would improve (Tyson, 2002).

In South Africa a preliminary study was done to establish the extent of knowledge and perception of a group representing the general public regarding the use of sewage sludge in agricultural practices (Snyman and Van der Waals, 2003).

The surveyed group representing households earning less than R5000 per month indicated that only 39% of the respondents were aware of what sewage sludge was before they read the information given to them. After reading the information provided, 71% indicated that they knew that sewage sludge was used as a "fertilizer" in agricultural practices. Most of the respondents were in favour of using sewage sludge as a soil amendment and agreed that it improved the properties of the soil. The results indicated that the respondents did not understand the risks involved in using sewage sludge as an agricultural soil amendment. The wastewater industry will need to embark on a widespread awareness of both the negative and positive impacts relating to the use of sewage sludge in agricultural practices (Snyman and Van der Waals, 2003).

The group surveyed that represented the households earning above R 5000 per month was more informed about the source of sewage sludge. The majority, 79%, indicated that they knew that sewage sludge was used as a "fertilizer" in agricultural practices and were in favour of using sewage sludge as a soil amendment and agreed that it improved the properties of the soil. The majority of the respondents (79%) indicated that they would purchase vegetables grown on sewage sludge-amended soils. 61% of the respondents would consider consuming cooked vegetables grown on sewage sludge-amended soils and 45% were prepared to consume raw vegetables grown on sewage sludge-amended soils (Snyman and Van der Waals, 2003).

The opinion of the farmers who are currently using sewage sludge as a soil amendment was obtained. The farmers were all in favour of using sewage sludge as a soil amendment and none of them currently exceeded the recommended dosage of 8 dryt ha⁻¹ year⁻¹.

The results of this study give a preliminary idea of the perception of the public regarding the acceptability of using sewage sludge as a soil amendment in agricultural practices (Snyman and Van der Waals, 2003).

The European Commission have documented an extensive stakeholder analysis that South Africans can take note of. The section below summarises the stakeholder analyses (European Commission, 2002).

Identifying the main positions, attitude and constraints on the use of the sludge by type of stakeholder is difficult mainly because of the various possible attitudes within one category and because of the possible differences from one country to another. However, on the basis of the information collected in the course of the study done by the European Commission, it was possible to give the following summary of the main stakeholders' position.

Farmers

For farmers the main motivation for the use of sludge in agriculture is the supply of organic fertiliser at a low cost. The main constraints come from their customers either food industries or retailers, who have specific quality requirements. In a growing number of cases, these quality requirements include restrictions on and sometimes the prohibition of the use of sludge in agriculture. In this context, the main consequences for farmers associated with the use of sludge in agriculture could be a reduction in their market share and a drop in profits, as well as additional liability costs in the event of an accident/infection. In this context, farmers require (in countries where the debate is heated) that an insurance system to be set up which would cover them against both possible risks, in order to continue using sludge (European Commission, 2002).

Landowners

Landowners are generally hostile to the agricultural use of sludge. Their attitude is based on two major concerns: liability and land value. Landowners do not want to be held liable in the event of an accident (harm to humans, animals and ecosystems) caused by the use of sludge and wish to prevent any loss in the value of their land. The European Landowners' Organisation (ELO) adopted an official position concerning sludge recycling in agriculture in January 1999, which provides safeguards for the use of sludge. In particular, the findings of the ELO focus especially on the need to strengthen legislation, the need to *"ensure that suppliers accept liability for any economic loss or damage associated with spreading sludge on their land,"* for instance by drawing up a pan-European model contract similar to the model contract developed by the Country Landowners' Association (CLA) in the UK (European Commission, 2002).

Agrifood industry

The main influences on the agrifood industry are marketing and public health concerns. The industry's brand image is one of its most valuable assets and its primary concern is therefore to protect its image from being tarnished. In this sense, the industry's attitude is mainly influenced by the way in which the general public perceives the potential risks of using sludge in agriculture. As most of the members of this industry are sludge producers as well as professional associations of food industries are, in most cases officially in favour of maintaining the use of sludge in agriculture if the quality of sludge can be guaranteed. As sludge producers, these companies are obviously seeking low-cost sludge disposal rates (European Commission, 2002).

Food retailers

The main motivation for food retailers is to be able to purchase agricultural products at a low cost and to secure their market share by maintaining or improving the image of the quality and safety of their products. In this context, as there is still a great deal of scientific debate on the potential risks of the use of sludge in agriculture, land spreading could be perceived as a potential threat to their image. The main concern of food retailers involves the marketing stakes regarding product quality and therefore the extent to which the use of sludge may have an impact, whether real or perceived, on the quality of agricultural products (European Commission, 2002).

Waste treatment companies

The main motivation for waste treatment companies is to maintain long-term disposal and recycling routes for the sludge produced at the lowest possible cost. These companies are therefore aware of the need to maintain agricultural land spreading as a major recycling route for sewage sludge, mainly for economic reasons. In this context, these companies are willing to improve their performance beyond that required by the regulations in order to protect the existing routes for sewage sludge. They are also aware of the need to improve practices and also insist on the need to introduce national policies aimed at improving and controlling the quality of waste water entering the sewers (European Commission, 2002).

The main waste management companies do not exclusively focus their business on sludge recycling. However, the main economic driver behind their subsidiaries specialised in organic waste management has led them to increase awareness of the importance of sludge quality control and of improving land spreading processes. In this respect, service quality assurance could become standard practice in Europe. In addition, waste management companies are increasingly developing the use of composted sludge, as compost has the advantage of reducing odours and of being a commercially viable product (European Commission, 2002).

Communities

Communities are in most cases seeking to maintain the existing disposal and recycling routes for sewage sludge that are both economically viable and safe in terms of health. In addition, communities

are subject to strong pressure from their voters and are therefore concerned about limiting the "water bill". The "NIMBY" factor is also an important element which makes a difference between acceptance or non-acceptance in rural and in urban communities (European Commission, 2002).

National authorities

In most cases national authorities have implemented policies supporting the use of sludge in agriculture as it is considered to be the best economic and environmental option to deal with the increasing quantities of sludge produced. In this context, national authorities are seeking to increase confidence in the quality and safety of products cultivated on sludge fertilised soils (European Commission, 2002).

Consumer associations

Consumer associations and nature protection associations have both played only a minor-role in national debates on sludge recycling. Most consumer organisations involved in the debate on the use of sludge in agriculture have been largely preoccupied with food safety. In this respect, some consumer associations are concerned that the use of sludge in agriculture does not offer sufficient guarantees. The limited participation of consumer associations and the general public in the debate on sludge recycling can be explained by the lack of information made available to the public on these issues (European Commission, 2002).

The analysis of the stakeholders' positions shows that the main areas of consensus on sludge disposal and recycling routes are that the growing quantities of sludge must be treated in the aims of keeping both environmental and economic costs as low as possible. Similarly, improving practices both with regard to the treatment and the use of sludge, is now considered as essential. In the context of uncertainties concerning the potential impacts on human health and the environment of the various disposal and recycling routes, all stakeholders are calling for additional research in order to increase confidence in the use of sludge in agriculture.

3.5 Factors Unique to South Africa

We ask ourselves the question: "Why can we not simply choose a suitable sludge guideline from the suite of legislative documents discussed in this document? It is obvious that the EU, USA, Australia and other developed countries have spent thousands of hours and millions of dollars (in terms of US\$) in the development and updating of these regulations and guidelines." The answer lies in the fact that South Africa has unique circumstances that should be considered in the development of the second edition of the sludge guidelines. Some of them have already been mentioned in the report but is included here for completeness. The list below is also not complete, as the ARC, Institute for Soil Climate and Water are currently reviewing soil and environmental data for South Africa to identify unique factors that should be considered. These will be added as soon as it becomes available.

The following factors have been identified that could affect deviation from the regulations adopted by developed countries:

1. Climate

South Africa is a semi-arid (subtropical along the east coast) country and often experiences prolonged droughts. In terms of pathogen kill in soil, South Africa has the advantage of soil solarisation (high UV exposure and rapid desiccation). It can therefore be argued that the climatic conditions favour the land application of sewage sludge.

2. Soil

In warm areas, such as Southern Africa, the process of organic matter decomposition by micro organisms is high and organic material build-up in soils to high levels is not common. The decrease in organic matter may lead to a deterioration of the soil physical properties that may in turn lead to accelerated erosion. The irreplaceable loss of agricultural soil due to soil erosion and the subsequent decrease in crop productivity is considered one of the main environmental problems on the African continent. The addition of sludge could provide a measure to maintain the organic status of soil and decrease the danger of runoff and erosion (Korentajer, 1991).

South African soils are also typically shallow, making it a limited resource that should be protected.

3. Prevalence of diseases

The prevalence of HIV infections is high in South Africa. In 2000, it was estimated that 2.5 million women (age 15-49), 2.2 million men (age 15-49) and 106 000 children were HIV positive. A large proportion (1/9) of the South African community is therefore immuno-compromised that should be considered during the development of sludge management guidelines.

Other diseases such as tuberculosis, malaria and cholera are also prevalent in South Africa and that should also be considered.

4. Socio-economic challenges

South Africa has a spread between developed and under developed regions, rich and poor, educated and illiterate, high density and rural areas. Locally, these challenges are well understood and documented. These factors should be considered when developing and implementing the sludge management guidelines.

Economically, the management of sewage sludge should be considered in relation to its priority in service delivery. The owners of wastewater treatment facilities are faced with huge challenges to treat wastewater effectively and to recover costs. The sludge stream is often neglected and very little (if any) financial allocations are made for the final use and/or disposal of sewage sludge. It is therefore crucial to develop sludge guidelines that can be practically and economically implemented.

5. Transport infra-structure

South Africa is a relatively big country. The problem is that a high percentage of sewage sludge is produced in the metropolitan areas, which are often a few hundred km away from the agricultural centres where the sludge should be utilised. In the US (New York), for example sewage sludge is transported over vast distances via a well-established and maintained railway system. In South Africa, the railway system is not geared for these type of practices and road transport is expensive.

6. National customs and believes

South Africans represent many cultures and customs that should be considered during the development of sludge guidelines and especially related to human exposure to pathogens. For example, some rural women deliberately ingest soil on a regular basis and raw meat ("biltong"), although dried and pickled, is widely consumed.

3.6 Conclusions and Recommendations emanating from the Literature Review

The following general approach was recommended:

In the development of the second edition of the sludge guidelines, it is proposed that sustainable management options be encouraged.

The guidelines of some countries support one or more of these options for that particular country. For example, in the US legislation that supports several options was developed including land application of sewage sludge, surface disposal of sewage sludge and sewage sludge incineration. It is recommended that South Africa adopt a similar approach to encourage the implementation of one of the above management options, rather than trying to develop a single guideline to address all the management options. This will also simplify the document (s) for the users, as each guideline will be dedicated to the management, technical and legislative aspects associated with a particular option.

Each of the management options have different regulatory requirements. Also, the characterisation requirements for each option would be different.

It is therefore proposed to follow a process similar to that adopted by the Water Research Commission, Department of Water Affairs and Forestry and Department of Health for the development of the series entitled: "Quality of Domestic Water Supplies" (WRC, 1998). All the documents were not developed at the same time.

4 SLUDGE CLASSIFICATION AND CHOICE OF PARAMETERS

4.1 The South African sludge classification system

The literature review of South African and international sludge management guidelines and legislation (Chapter 3) highlighted the fact that the South African Sludge classification system is not aligned with the general approach adopted internationally.

In South Africa, unstable sludge is classified as a Type A sludge and the most stable sludge that also complies with inorganic and organic limits is classified as Type D sludge. Internationally, the trend for sludge classification normally adopted is a two-tier system:

- (1) A classification system based on the pathogenic and/or stability of the sludge with a Type A sludge being the more stable and highest quality.
- (2) Classification system based on the contaminant issues (organic and inorganic).

The literature review detailed the classification systems adopted by other countries. Based on this review and public participation, the following classification system was adopted:

- (1) A two-tier system using capital and small letters, one for the Pathogen class and one for the Pollutant class. This is in line with the classification system used to classify hazardous landfill sites (HH and Hh) and should therefore be accepted more readily compared to another system.
- (2) Add a third classification criterion based on sludge stability (a number that ties in with the Pathogen class). Stable sludge is defined as a sludge that has been subjected to a vector attraction reduction option and does not cause odour nuisance. It is the opinion of the authors that the stability of sludge (especially the odour) is the single most objectionable factor to the public. In addition, the current South African guidelines allows for putrefied sludge to be disposed of on land without vector attraction reduction options applied prior to application. In many cases, the pathogen reduction methods will also increase the stability of the sludge (reduce odour and vector attraction) and therefore satisfy this criterion as well.
- (3) A classification system that allows for gradual/step-wise improvement and therefore ultimate compliance. For example, if the requirements of a certain class are seen to be stringent, the guidelines must not be viewed as unattainable, which will cause stockpiling or landfill options to persist in the industry.
- (4) A classification system that classifies the sludge in terms of:
 - Pathogen content
 - Stability
 - Organic and inorganic pollutants

The classification system includes a Microbiological and a Pollutant class. Due to the effect of odours on the perception of the public, a Stability class has now been included. Table 4 details the proposed classification system.

Table 4: Proposed South African sludge classification system

Use Quality	Best Quality intended for unrestricted use	General Quality intended for general use	Worst Quality intended for limited use
Microbiological class	A	B	C
Stability class	1	2	3
Pollutant class	a	b	c
<i>Notes:</i> Sludge needs to comply with all three criteria within the specific quality criterion to qualify for a "use quality". For sludge to comply with a certain quality class, the specific quality parameter must comply with a target value (threshold value) for at least 90 % of the time and may never exceed a specified maximum allowable level.			

The table can be explained using a few examples:

- (1) Class A:1:a - This sludge complies with the "Unrestricted use quality" as it complies with the pathogen, stability and pollutant quality criteria for a specific use.
- (2) Class A:2:c - This sludge will be classified as a "Limited use quality" as one of the quality criteria lies in the "Limited use quality". The user should therefore be aware that the pollutant levels could restrict the use of the sludge for certain applications. If this sludge is to be considered for the cultivation of vegetables on a commercial scale the following considerations would apply:
 - a. Microbiological class: This sludge is acceptable for the cultivation of vegetables on a commercial scale as the sludge complies with the microbiological class criteria (Microbiological class A). The risk of pathogenic infection is therefore acceptable (very low) and farm workers and consumers will not be infected even if they come in direct contact with the product or ingest some of the product/soil.
 - b. Stability class: The sludge is classified as a Stability class 2. In terms of this criterion, careful consideration should be given to the application of the sludge in areas close to communities (public) as this sludge could in some cases cause odours or attract vectors. Therefore, this classification (Stability class 2) does not restrict the vegetable farmer to apply the sludge, but merely alerts the farmer to possible odours or other nuisance potential.
 - c. Pollutant class: The sludge is classified as a Pollutant class c. As this application refers to agricultural use, the specific criteria and limits pertaining to organic and

inorganic constituents in Volume 2 "Requirements for the agricultural use of sludge" apply. A Pollutant class c rating indicates that the specified concentrations for metals are exceeded and the sludge generator should investigate the source and attempt to rectify this.

4.2 Motivation for the selection of the microbiological parameters

Two indicator organisms were proposed (*Faecal coliforms* and Helminth ova). The Steering Committee recommended that *Salmonella* would not be used as an indicator for the preliminary microbiological classification of sludge, as this would not add any additional information regarding the effectiveness of the disinfection process.

4.2.1 *Faecal coliforms*

As a result of the complex, expensive and time-consuming nature of many pathogen detection methods and of the large number of potential pathogens which may be associated with sludge, it is better to monitor microbiological quality of sludge on the basis of indicator organisms rather than the pathogens themselves. *Faecal coliforms* are the most common bacterial indicators of faecal pollution and refer to all bacteria which produce typical blue colonies on m-Fc agar within 20-24 hours of incubation at 44.5°C (including *E. coli*). Most of the laboratories in South Africa are equipped to analyse for *Faecal coliforms* and the presence and amount of *Faecal coliforms* in sludge give an indication of the effectiveness of the disinfection process of the wastewater treatment facility and therefore analyses for *E. coli* is not required. The decision to use faecal coliforms as a microbiological indicator was also confirmed with Prof W Grabow (Emeritus Professor, UP) in a personal communication.

4.2.2 Helminth ova

The previous South African sludge guidelines recommended the monitoring of viable *Ascaris* ova. We recommend that this be changed to total viable helminth ova. If we do continue measuring the *Ascaris* ova only, we stand a chance to underestimate the helminth ova concentrations. Table 4.2.2(a) shows the parasites most often found in sludge (Cabaret *et al.*, 2002). This table shows that *Taenia* (tape worm) is often the most prevalent. Table 4.2.2(b) show the prevalence of human taeniasis in different parts of the world. The viable helminth ova count will not only give an indication of the effectiveness of the disinfection process of the wastewater treatment facility but will also generate data on the prevalence of the different species. This method would still show the viable *Ascaris* ova which is believed to be resistant. For example, *Ascaris* eggs and certain larval stages can survive for over a year in soil that has been irrigated with sludge (Chale-Matsau, 2004). Table 4.2.2(c) shows the average survival time of pathogens in wet sludge at ambient temperature.

**TABLE 4.2.2(a): PARASITES FOUND IN SEWAGE SLUDGE IN SEVERAL COUNTRIES
(CABARET ET AL., 2002)**

Country	Helminths arranged in decreasing order of frequency*	Reference
Argentina		
Patagonia (4 sites)	<i>Hymenolepis</i> > <i>Ascaris</i> > <i>Trichuris</i> > <i>Toxocara</i>	Semenas et al., 1999 (87)
Bahrain	<i>Ascaris</i> > <i>Hymenolepis</i> > <i>Trichuris</i> > <i>Toxocara</i> > <i>Taenia</i>	Amin, 1988 (1)
Brazil		
Parana (Curitiba, 22 samples)	<i>Ascaris</i> > <i>Hymenolepis</i> > <i>Trichuris</i> > <i>Toxocara</i> > <i>Taenia</i>	Thomaz-Soccol et al., 1997 (95)
France		
Caen (21 samples)	<i>Trichuris</i> > <i>Taenia</i> > <i>Ascaris</i> > <i>Toxocara</i>	Barbier et al., 1989 (3)
Caen (6 samples)	<i>Taenia</i> > <i>Trichuris</i> > > <i>Toxocara</i> > <i>Ascaris</i>	Madeline et al., 2001 (68)
Falaise	<i>Taenia</i> > <i>Toxocara</i>	Madeline et al., 2001 (68)
Nancy (several sites)	<i>Ascaris</i> > <i>Trichuris</i> > <i>Hymenolepis</i> = <i>Toxocara</i> > <i>Taenia</i>	Collomb et al, 1983 (15)
Nancy (1 site)	<i>Trichuris</i>	Own unpublished data 2001
Reims (19 samples)	<i>Ascaris</i> > <i>Toxocara</i> = <i>Taenia</i>	Bouchet and Leger, 1986 (10)
Champagne (14 samples)	<i>Trichuris</i> > <i>Ascaris</i> > <i>Toxocara</i>	
Savoie (38 samples in several sites)	<i>Taenia</i> = <i>Ascaris</i>	Gauthier et al., 1991 (40)
Tours (4 sites)	<i>Taenia</i> = <i>Trichuris</i> > > <i>Ascaris</i> > <i>Hymenolepis</i>	Own unpublished data, 2001
Valenton (1 sample)	<i>Trichuris</i> > <i>Taenia</i> > <i>Ascaris</i> = <i>Toxocara</i>	Madeline et al., 2001 (68)
Morocco		
Agadir	<i>Trichuris</i> > > <i>Ascaris</i> > <i>Hymenolepis</i> > <i>Taenia</i>	Khallaayoune, 1996 (60)
Beni-Mellal	<i>Hymenolepis</i> > > <i>Ascaris</i> > <i>Trichuris</i> > <i>Toxocara</i>	Khallaayoune, 1996 (60)
Marrakech	<i>Ascaris</i> > <i>Hymenolepis</i> = <i>Trichuris</i> > <i>Taenia</i>	Khallaayoune, 1996 (60)
	<i>Ascaris</i> > <i>Trichuris</i> > <i>Toxocara</i> , <i>Hymenolepis</i> , <i>Taenia</i> , <i>Moniezia</i>	Bouhoum and Schwartzbrod, 1989 (11)
Ouarazate	<i>Hymenolepis</i> > <i>Ascaris</i> > <i>Moniezia</i> > <i>Trichuris</i>	Khallaayoune, 1996 (60)
Norway		
(1 site)	<i>Ascaris</i> > <i>Trichuris</i>	Bergstrom, 1981 (5)
Switzerland		
(11 sites)	<i>Trichuris</i> > <i>Ascaris</i>	Eckert and Birbaum, 1983 (25)
Tchekia an Slovakia		

Country	Helminths arranged in decreasing order of frequency*	Reference
(72 samples, Slovakia)	<i>Ascaris</i> >> <i>Toxocara</i> > <i>Trichuris</i> > <i>Taenia</i>	Plachy and Juris, 1994 (79)
(3 sites in Bohemia)	<i>Ascaris</i> > <i>Toxocara</i> > <i>Trichuris</i> > <i>Hymenolepis</i> > <i>Toxascaris</i>	Horak, 1992 (54)
United Kingdom		
East of England (7 sites)	<i>Ascaris</i> > <i>Trichuris</i> > <i>Taenia</i>	Watson et al, 1983 (100)
Ukraine		
(1 site)	<i>Ascaris</i> > <i>Trichuris</i>	Khizhnyak and Romanenko, 1975 (61)
USA		
(several sites in Illinois)	<i>Ascaris</i> > <i>Toxocara</i> > <i>Toxascaris</i> > <i>Trichuris</i> > <i>Hymenolepis</i>	

TABLE 4.2.2(b): PREVALENCE OF HUMAN TAENIASIS (*TAENIA SAGINATA*) IN DIFFERENT PARTS OF THE WORLD (CABARET ET AL., 2002)

Continents and Countries	Prevalence (%)
Europe	<0.01 - 10
Bulgaria, France*, United Kingdom	<0.01
Belgium, France, Germany, Hungary, Italy, Montenegro, Poland, Spain, The Netherlands, Turkey*	0.01-2
Slovakia, Turkey	>2-10
Americas	<0.01 - 10
Brazil, Canada, Chili, USA	<0.01
Argentina	<0.01-2
Honduras	2-10
Africa	<0.01 -7
Cameroon*, Egypt, Ivory coast, Morocco, Sudan, Tunisia	0.01-2
Cameroon*, Egypt	>2-10
Asia	0.02-36
India* (Uttar Pradesh, Iran, Pakistan)	0.01-2
Afghanistan, Azerbaidjan, India, (others), Malaysia	2-10
Dagestan	36

*Country appearing twice since two surveys gave different results

**TABLE 4.2.2(c): PATHOGEN SURVIVAL PERIODS IN FAECAL SLUDGE
(STRAUSS, 2000)**

Organism	Average Survival Time in Wet Faecal Sludge at Ambient Temperature ¹	
	In temperate climate	In tropical climate
Viruses	< 100	<20
Bacteria:		
Salmonellae	< 100	< 30
Cholera	< 30	< 5
Fecal coliforms ²	< 150	< 50
Protozoa:	< 30	< 15
Amoebic cysts	< 30	< 15
Helminths:		
Ascaris eggs	2 – 3 years	10 - 2 months
Tapeworm eggs	12 months	6 months

¹ When exposed to the drying sun, the survival periods are much shorter

² Faecal coliforms are commensal bacteria of the human intestines and used as indicator organisms for excreted pathogens

4.3 Motivation for the selection of stability parameters

In the previous sludge guidelines the stability of sludge did not receive much attention. It was implicated in old Type D sludge but, since most of the sludge in South Africa was Type B, it was never applied. Since the beneficial use of sludge is promoted in the new guidelines, the stability of the sludge is of utmost importance. The stability of sludge is management driven and should enable more wastewater treatment facilities to beneficially dispose of its sludge.

It is recommended that the vector attraction reduction criteria of the US EPA 503 Sludge rule (US EPA, 1993; US EPA 1994) be adopted. These criteria (or very similar) have been adopted by many other countries including Australia.

4.4 Motivation for the selection of pollutant criteria

4.4.1 Organic pollutants

The choice of whether organic pollutants should be included was subject to considerable debate, especially due to the costs involved. The organic pollutants in sludge could potentially pose a high risk to many receptors. The WRC funded research project entitled: "Methodology and survey of organic pollutants in South African sludges (K5/1339)" included the screening of sludge samples to determine the existence of the most persistent organic pollutants. The preliminary findings indicate that pesticides are not the main pollutants in the sludge. Phenols and Poly Aromatic Hydrocarbons (PAHs) are compounds that require further quantitative studies. The phenols are p-cresol and nonylphenols while the PAHs are acenaphthene, phenanthrene, fluorene, fluoranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene and indeno(1,2,3-c,d)pyrene. No

organic pollutant ceiling limits were developed for the agricultural application of sludge but it is recommended that action should be taken if the sum of the PAHs is $> 6\text{mg/kg}$.

This particular study did not do a comprehensive risk assessment to prove the associated risks with elevated PAHs for different disposal or use methods. We therefore recommend that we include the measurement of PAHs for the comprehensive characterisation stipulated in Volume 1 in order to develop a database. We recommend that a risk assessment then be done for each of the disposal/uses to establish whether it is indeed required to monitor and manage the organic pollutants.

4.4.2 Metals

The metal limits and load restrictions vary for different applications. For example, the pollutant limits applicable for agricultural use of sludge are completely different to those requirements pertaining to landfill or incineration. The requirements for sampling and analysis are also different for each option. For this reason, the development of the metal limits that pertain to a particular use or disposal option, are detailed in the particular scientific premise chapter.

5 PREMISE OF VOLUME 1: MANAGEMENT OPTIONS

This chapter is dedicated to the thought process followed during the development of Volume 1 of the South African Sludge Guidelines.

Volume 1 is intended to direct the reader to decide on the best management option(s) for the sludge streams generated on the specific plant. Once a suitable management option is decided upon, the relevant volume that deals with the selected management option should be referred to.

5.1 Part 1: Background

Volume 1 – Part 1 informs the reader of the background leading to the new guidelines. There are several reasons why the previous guidelines had to be updated, the main reason being the significant change in the regulatory environment during the last decade. Most of the South African laws and regulations documents pertaining to environmental, waste and water have either been replaced or updated in the last decade. The guidelines in this publication have been developed taking the updated regulatory framework into consideration.

Other reasons for updating of the wastewater sludge guidelines include:

- The principle of sustainability

The sludge guidelines that are presented in this Guidelines support the principles of sustainable use of resources. Wastewater sludge management options should not harm the environment by either the inefficient use of a non-renewable resources or the accumulation of a substance/compound in the environment to harmful levels. This is in line with the resolution of the World Summit on Sustainable Development held in South Africa in 2003.

- Choice of different options

The 1997 wastewater sludge guidelines focussed on the land application of wastewater sludge i.e. the use of wastewater sludge as a soil conditioner, but were not clear on the requirements for other options such as disposal to in a landfill facility. The addendum that followed in 2002 identified different management options based on the characteristics of the sludge. However, the addendum was intended to clarify the ambiguities of the 1997 guidelines in the interim, until the second edition of the guidelines (Volume 1-5) could be published and did not describe the alternative management options in general detail. This, the 2nd Edition of sludge guidelines, clearly differentiates between the different management options in a series of guideline volumes.

- Aligning South African guidelines with recent international trends.

These sludge guidelines introduce a new sludge classification system, which is more in line with recent international trends.

- Local research findings

The scientific basis of the previous sludge guidelines was based largely on international research guideline results. The WRC initiated a research programme to further develop the knowledge base for the management of wastewater sludge in the South African context. These research projects addressed the following aspects (reports available from the WRC):

- Quality of South African wastewater sludge (WRC Reports 1283/1/04 and 1339/1/05).
- Agricultural use of sewage sludge (WRC Report 1210/1/04).
- Sacrificial land disposal (WRC Report 1209/1/04).
- Sludge treatment technologies (WRC Report 1240/1/04).

Although the results of these research projects do not give all the answers, they do enable the formulation of an updated sludge guideline series. This sludge management series combine the knowledge gathered during the development of the addendum and research findings related to metals, nutrients and organic pollutants to ensure credibility and user acceptance.

- Ease of use and understanding

Users of the 1997 and 2002 / 1st Edition of the wastewater sludge guidelines required the assistance of experts or an in depth understanding of the basis of the guidelines to apply the principles correctly. These previous documents could be misinterpreted. This sludge guideline series was developed to explain the concepts in a simple user-friendly manner.

5.2 Part 2: Structure

Volume 1 – Part 2 describes the structure of the wastewater management series (see section 2.1 of this document).

5.3 Part 3: Good sludge management practices

The emphasis of Volume 1 – Part 3 is on good sludge management practices. In the past, the South African wastewater industry did not regard sludge as a resource. In addition operational performance of wastewater treatment plants were focussed on the effluent quality. Very little was done to monitor and manage sludge quality. In other words, the sludge quality was irrelevant and industrial effluents were accepted as long as it did not affect the final effluent quality. The contaminants end up in the sludge which is compromised to such an extent that it cannot be used beneficially. We therefore recommend that we start sensitising the wastewater industry that sludge is a resource and that the quality should be managed and continuously improved through stricter control of industrial wastewater. This applies not only for beneficial use, but also for disposal options.

Irrespective of the management option adopted, good sludge management practices are required. This includes understanding and managing the full life cycle of the sludge streams generated at a wastewater treatment plant to ensure acceptable and sustainable use and disposal.

Figure 5.3 illustrates how a life cycle assessment can be used to manage sludge from a wastewater treatment plant. It is particularly important to understand the source of possible pollutants that might restrict the use of the sludge. Equally important is the management and treatment of the wastewater treatment plant to generate a stable sludge, which does not generate any odours or attract vectors. If the resulting sludge is not meeting the required standards, this information should feed back to the operation of the plant and wastewater source control. Managing the full life cycle of the sludge generation, handling, use and disposal will ensure continuous improvement.

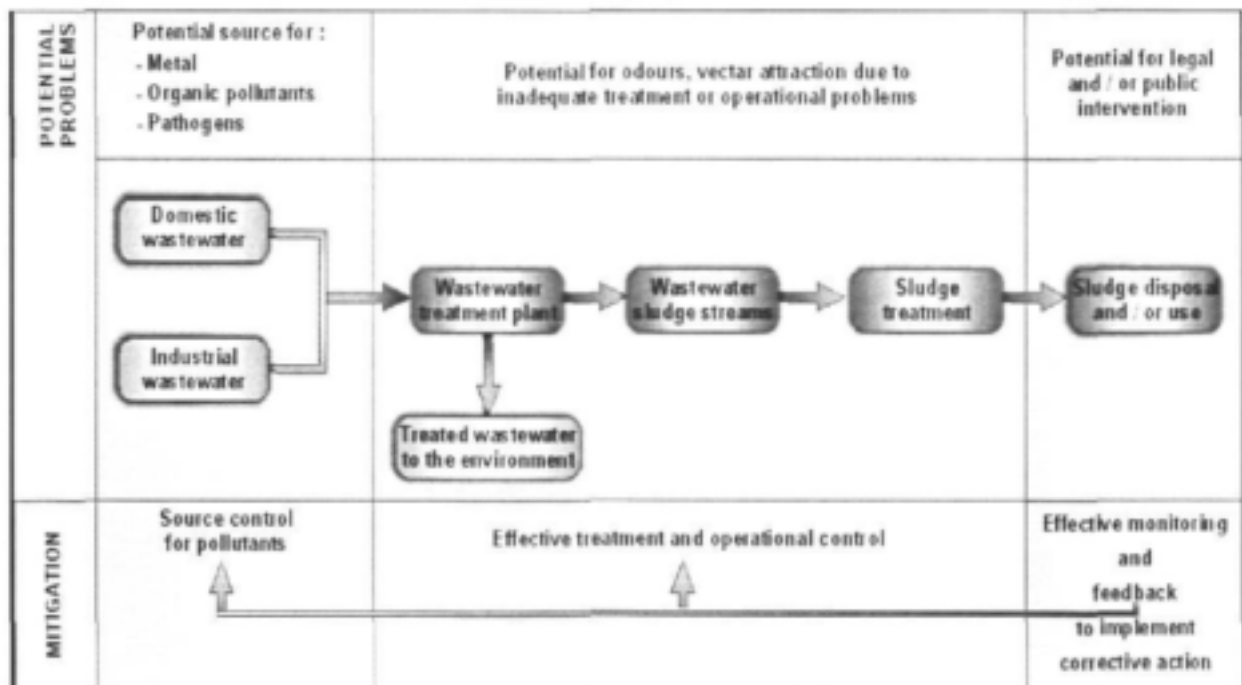


Figure 5.3: Effective use of life-cycle assessment to manage sludge quality

5.4 Part 4: Legal framework

Legally, sludge management could resort under several government departments including the Dept of Health, DWAF, DEAT and DoA. It obviously depends on the final use or disposal option selected. Volume 1 – Part 4 aims to simplify the legal complexities related to sludge use and disposal.

The use and disposal of sewage sludge **could** be influenced by the following acts, and guidelines, including:

- The National Water Act (Act 36 of 1998) (NWA)
- The Water Act (Act 54 of 1956) (WA)
- The Environmental Conservation Act (Act 73 of 1989) (ECA)
- Conservation of Agricultural Resources Act, 1983 (Act 43 of 1983) (CARA)
- The Fertilisers, Farm feeds, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947)
- National Health Act (Act 61 of 2003) (HA)
- The Water Services Act (Act 108 of 1997) (WSA)
- The National Environmental Management Act (Act 107 of 1998) (NEMA)
- Minimum Requirements: (Second Edition) 1998

This refers to the Waste Management Series published by DWAF, which establishes a reference framework of standards for waste management in South Africa in terms of section 20 of the ECA. This trilogy consists of:

- Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste
- Minimum Requirements for Waste Disposal by Landfill
- Minimum Requirements for Water Monitoring at Waste Management Facilities
- Water Use Authorisation and Registration Management System (WARMS). This is a registration system used by DWAF for water uses

The Department of Agriculture and the Department of Water Affairs and Forestry actively participated in the development of the Guidelines. Every effort was made to bring the Department of Health and the Department of Environment and Tourism to participate. We were however not successful. The final documents will be sent to the ministries as all the departments involved for approval. Although this is not ideal, as active participation enriches the documents, they will have taken note of the documents.

The matter is also complicated through the fact that the different legal documents are developed to protect different receptors and hence have different policies underpinning them. It is however, important to note that not all the acts and regulators are applicable for all the uses. For example, the

Minimum Requirements need to be consulted for the disposal of sludge in a landfill, but do not have to be considered if sludge is to be used beneficially as a soil amendment.

For this reason, the legal requirements and relevant acts will be detailed for each management option in the relevant volume that deals with that particular option.

However, irrespective of the management option selected, the Department of Water Affairs and Forestry will remain the lead regulatory agent and they will manage the sludge management options using the NWA. It should also be noted that, due to the dynamic nature of our environmental laws, the legal requirements and even the lead agent might change. It is therefore recommended that the legal requirements be re-assessed from time to time.

5.5 Part 5: Comprehensive characterisation of sludge

This part of Volume 1 deals with the initial characterisation of sludge. To establish which management options are suitable for the type and quality of sludge generated at a particular wastewater treatment plant, the different sludge streams need to be characterised. Due to the financial constraints, we cannot expect a wastewater treatment plant to do a comprehensive characterisation of wastewater sludge on a routine basis. It is recommended that the comprehensive characterisation required in Volume 1 should only be done once and will only be required again if the characteristics of sludge is likely to change due to extensions or change in the raw influent. The required characterisation and monitoring programme could differ for the different management options and once a particular management option has been selected, the characterisation and monitoring requirements pertaining to that particular management option should be followed.

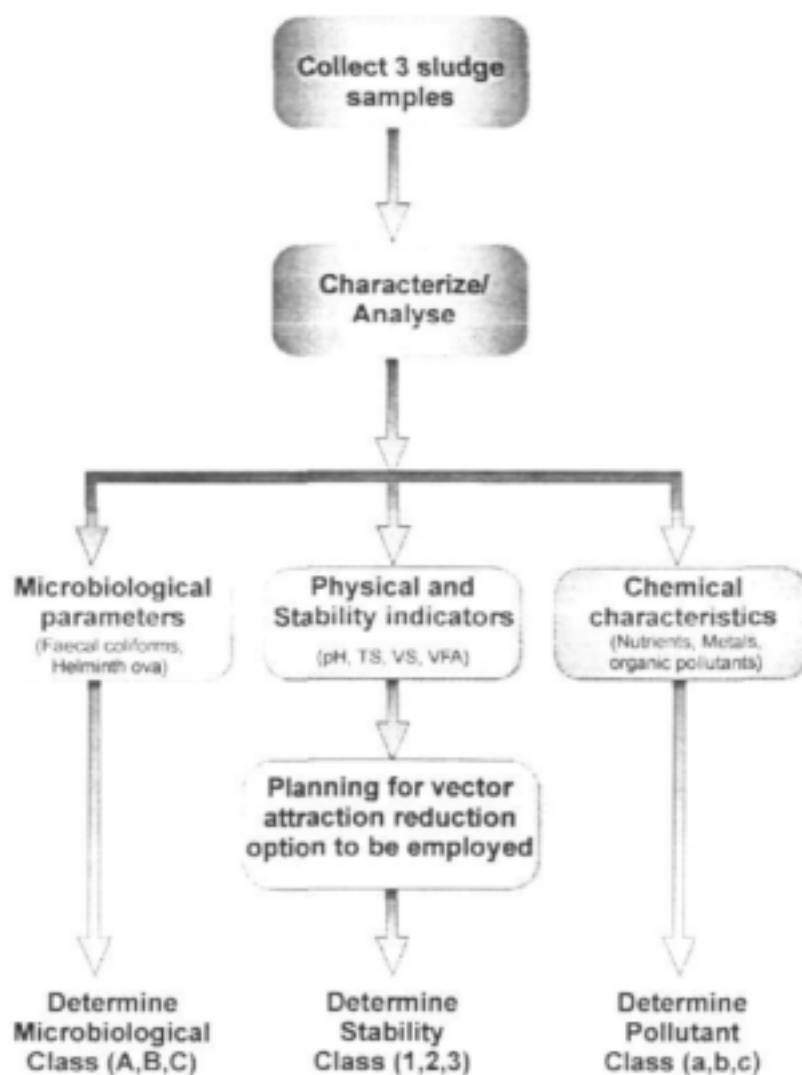


Figure 5.5: Initial characterisation and classification of sludge

Comprehensive characterisation of all the sludge streams destined for storage, further processing, and disposal is required. At least three composite sludge samples from each sludge stream considered for use/disposal should be collected in order to compensate for variation in sludge sampling and analyses. Table 5.5.1 details the recommended parameters to be determined.

Table 5.5.1: Parameters to be included in the comprehensive characterisation of sludge

Characteristic	Parameter		Guidance on methodology and / or recommended extraction method
Physical characteristics	pH		pH on saturated paste
	Total solids (TS)		Standard Method 2540B1
	Volatile suspended solids (VSS)		Standard Method 2540E2
	Volatile Fatty Acids (VFA)		Adapted from Standard Methods. The full method is detailed in Appendix 2.
Nutrients	Total Kjeldahl Nitrogen (TKN)		The suggested method description has been attached in Appendix 3.
	Total Phosphorus (TP)		The suggested method description has been attached in Appendix 3.
	Potassium (K)		The suggested method description has been attached in Appendix 2.
Metals and micro-elements	Compulsory	Optional	Compulsory method
	Arsenic Cadmium Chromium Copper Lead Mercury Nickel Zinc	Aluminium Antimony Boron Barium Beryllium Cobalt Iron Manganese Molybdenum Selenium Silver Sodium Strontium Thallium Vanadium	Extraction of trace elements soluble in aqua regia. International Standard ISO 11466 Method Reference number : ISO 11466:1995 (E) The metal limits are based on aqua regia extraction. Note : Remind the laboratory to manage the interferences on the ICP appropriately, especially for compounds such as Arsenic. A semi-quantitative ICP Scan would give concentration of all mentioned metals.
Organic pollutants	Poly-aromatic hydrocarbons (PAH) ¹		EPA Methods 3510C (Liquid-liquid extraction) for liquid sludge, 3540C (Soxhlet extraction) for solid sludge and EPA Method 3660B for sulphur clean-up.
Microbiological quality	Faecal coliforms		Membrane filter / m-FC medium
	Ascaris ova		Filtration/flotation and also determine viability

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

³ Acenaphthene, phenanthrene, fluorene, fluoranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1,2,3-c,d)pyrene.

5.5.1 Recommended analytical methods

Analytical methods are recommended for comparable results. Some laboratories use more sophisticated methods to measure the same parameter. It is not the intention to dictate to these laboratories to revert back to the older methods. However, it is recommended that these adopted updated methods be compared to the recommended methods to assess whether similar fractions are

extracted. For example, if the adopted method includes an acid extraction and ICP analyses in stead of AA analyses, it will still be within the same standard for total metal analyses. If, for instance, the adopted method uses an EDTA extraction for chromium, it is not comparable with the chromium recommended method and should therefore be changed. The following parameters are recommended. The detail of the specific analytical methods are included in Appendix 4.

Physical characteristics of the sludge (pH, total solids, volatile suspended solids and volatile fatty acids)

The methods recommended for the physical characteristic analyses are fairly standard. It's used to establish whether sludge is stable and could indicate operational problems and stability problems. For example, if the pH of the sludge is very low it indicates that odour will be a problem and that the sludge is not stable.

Chemical quality of the sludge (nutrients, organic pollutants, metals and micro-nutrients)

Nutrients

The recommended methods for nutrient determination are standard methods (Appendix 4) used by many laboratories in many countries to assess the nutrient contents of sludge and soil.

Metals and micro-nutrients

Standardisation of all analytical methods for regulatory compliance is vital. Many methods are presently being used and since analysis of a specific component by various methods yields significantly different data, standardisation would increase the applicability of the Guidelines.

A total method is best for the analyses of metals and micro-nutrients in sludge because, once the sludge is applied to the soil, the organic matter will decompose and all the trace elements in the sludge will eventually become available, although large portions thereof will be adsorbed by soil particles. Once adsorbed by the soil it will become available over time. Snyman, Herselman & Kasselmann (2004) compared EPA 3050 and *aqua regia* as total methods in their study and found *aqua regia* to give better results (better accuracy and precision). This method is widely used by laboratories as a standard method for total metal extraction of sludge. The metal limits are also based on *aqua regia* extractions; therefore it is the compulsory method to use for the extraction of metals and micro-nutrients from sludge.

Analyses for As, Cd, Cr, Cu, Pb, Hg, Ni and Zn are compulsory since limits were set for these elements, while analyses for the other metals and micro-nutrients are optional. A semi-quantitative ICP scan of all elements is recommended to ensure that all elements are within acceptable levels and will not pose an environmental risk.

Internationally another method, EPA Method 3051 is gaining acceptance. However, this method is not used routinely for the characterisation of wastewater sludge in South Africa. This method called the "Microwave Assisted Acid Digestion of Sediments, Soils and Oils" is provided as an alternative to Method 3050. It is intended to provide a rapid multi-element acid leach digestion prior to analysis so that decisions can be made about site clean up levels, the need for TCLP testing of as waste and whether a BDAT (Best Demonstrated Available Technology) process is providing acceptable performance. A representative sample of up to 0.5 g is digested in 10 ml of concentrated nitric acid for 10 min using microwave heating with a suitable laboratory microwave unit. The sample and acid are placed in a fluorocarbon (PFA or TFM) microwave vessel. The vessel is capped and heated in the microwave unit. After cooling the vessel contents are filtered, centrifuged, or allowed to settle and then diluted to volume and analysed by the appropriate SW-846 method. Due to the sophisticated microwave extraction required, the Steering committee decided to take note of this development but recommended that we continue using the *aqua regia* extraction method due to its cost effectiveness and reliability.

Organic pollutants

The only organic pollutant parameter that needs to be determined is Poly-aromatic hydrocarbons (PAH) and the analytical methods are standard methods used in industry. The reasoning and limits for the preliminary classification of sludge is detailed in section 4.2.2 of this document.

Microbiological quality of the sludge

For the purposes of the preliminary classification of sludge only 2 indicator organisms were proposed (Faecal coliforms and Helminth ova).

Faecal coliforms

The standard method for the determination of faecal coliforms in sludge should be used (Standard methods for the examination of water and wastewater 20th edition)

Helminth ova

In section 4.2.2 we recommended that we change from the monitoring of ascaris ova to helminth ova. The current method used in South Africa to measure ascaris ova was reviewed by Prof Jimenez (Tratamiento y Reúso Apdo. Pstal; Instituto de Ingeniería; Coyoacán, México, D.F), a recognized expert, who recommended that we change from the South African method to a method developed by the EPA. Our current method could underestimate the amount of helminth ova due to low recoveries. The new recommended method is detailed in Appendix 4.

Additional analyses

Sludge could be analysed for all the different parameters suggested by the US EPA, but this will only overburden the wastewater industry. It is therefore recommended that additional analyses should only be done if a problem is suspected.

The Department of Water Affairs and Forestry might require additional analyses, specifically with regards to additional organic pollutants such as phenolic compounds, pesticides, poly chlorinated biphenyls (PCBs), chlorinated hydrocarbons etc. It is also the responsibility of the producer to analyse for additional appropriate constituents if the sludge producer is aware of certain contributors that could influence the quality of the sludge. For example, if an industry discharge wastewater that contains aldehydes to the sewer, aldehydes should be measured in the sludge. Wastewater treatment plants that receive the leachate from hazardous landfills need to be specifically vigilant as the chemicals dissolved in the leachate often end up in the sludge.

Based on the results of the analysis, the sludge can be classified and appropriate management options can be selected

5.6 Part 6: Preliminary classification

Volume 1 – Part 6 lead the reader to the initial classification of sludge. The classification rational and procedures are discussed in chapter 4 of this document.

5.6.1 The generic classification system

As detailed in chapter 4, the table below show the generic classification system for South Africa.

Microbiological class	A	B	C
Stability class	1	2	3
Pollutant class	a	b	c

5.6.2 Microbiological class

At present, very few South African wastewater treatment plants disinfect their sewage sludge. Techniques commonly used in South Africa include anaerobic stabilisation by increasing the sludge age in the activated sludge process and anaerobic digestion in either mesophylic or heated digesters. These techniques are not capable of adequately disinfecting sewage sludge, resulting in a product that contains a large number of pathogens and can still have a high potential for vector attraction. Techniques such as lime stabilisation and composting which yield sewage sludge of improved microbiological quality (WRC, 1997), which can be safely applied to agricultural land are not

common practice in South Africa. Most environmental concerns about land application of sewage sludge have focused on effects of nutrients especially nitrogenous (N) and phosphorus-containing (P) compounds and effects of heavy metals. Microorganisms from sludge are often low on the priority list. To assess the threat posed by different microorganisms in sludge intended for soil conditioning, the types of organism present in the sludge must be determined.

In Section 3.3.5 of this document the international approach to the regulation of microbiological quality of sludge is discussed as well as a novel approach followed by Mexico. The pathogens that are generally subject to regulation are *Salmonella*, enteric viruses, helminth ova, and oocysts and oocysts of protozoa (NZWERF, 2003). Faecal coliforms are used as a general indicator for the presence of bacterial pathogens found in sewage sludges.

Salmonella spp. bacteria are subject to regulation because outbreaks of gastro-enteritis have in the past been relatively common and experience has shown that reducing *Salmonella* to a low level, as with faecal coliforms, provides a high degree of assurance that other bacterial pathogens do not constitute a health risk. *Salmonella* spp. are so common in the environment that the proper control of salmonellosis is through food hygiene, sewage sludge properly used in agriculture is not involved in the transmission of human salmonella (Smith, 1996 according to NZWERF, 2003). It was decided not to continue with the monitoring of salmonella species in South African sludge as this would add additional financial burden without adding value.

In chapter 4 we recommended that we change from the monitoring of ascaris to the monitoring of helminth ova. Helminths found in sewage sludge include nematodes (roundworms and hookworms), cestodes (tapeworms) and trematodes (flukes). Helminth ova are very resistant to the environmental factors that reduce the numbers of bacterial indicators or animal viruses in sludge. Because of their resistance, the presence/absence of viable helminth ova is used as a criterion for monitoring for the presence of helminths in sludge to be applied to land. *Taenia saginata*, the beef tapeworm, is a helminth of potential concern. It produces eggs that are resistant to environmental stresses. *T. saginata* has a cyst stage in cattle and a worm stage in humans. Problems have generally only arisen where cattle have been grazed on pasture irrigated with untreated human sewage sludge (thereby becoming infected with the larval stage of the tapeworm) and then people have eaten the raw or undercooked beef, becoming infected with viable larvae.

A comparison between the US, European and Australian sludge regulations – Pathogens

Table 5.6.1(a) summarises the microbiological criteria of several countries.

United States

The pathogen standards for the US 503 rule were based on operational experience and professional judgment, rather than a formal risk assessment process. The regulatory approach to classification is predominantly based on the previously described combination of validated technologies, ongoing monitoring of process control parameters and compliance with bacterial limits. The valid treatment processes included processes that conform to generic temperature-time curves, specific pH-

temperature-time criteria, processes that are listed in the regulations as Processes to Further Reduce Pathogens (PFRP's), or processes that have been more recently assessed and considered as 'equivalent' to PFRP's (Reid, 2003).

European requirements

As noted earlier, the Sludge Directive (86/278/EEC) currently provides the overarching legislative basis for sewage sludge treatment and reuse in Europe. Unfortunately, despite the significance of this document, it provides only qualitative criteria rather than quantitative standards for treatment. Not surprisingly, given the lack of definitive treatment criteria, the current directive is restrictive on acceptable uses of sludge. In contrast to the approach in the US of an 'unrestricted' microbiological grade, there are restrictions on all sludge use.

- **Draft EC directive**

Although the current EC directive does not provide detailed criteria on sludge treatment, working redrafts of the directive do include quantitative standards. The redraft describes an 'advanced' treatment grade that is proposed for unrestricted use. As per the US, this classification is based on a combination of prescribed treatment processes and microbiological standards.

- **United Kingdom**

The sludge management framework in the UK is currently of great significance. Recent redrafting of the legislation has been underpinned by a major research initiative. The research has involved three components: 1) development of methods for pathogen analysis and quantification, 2) assessment of pathogen reductions through key treatments, and 3) quantitative assessment of the resultant food safety risks.

National Australian guideline

The draft of the national guideline for sludge management *Guidelines for Sewerage Systems – Sludge Management* under the NWQMS makes an important structural distinction from the US and European approach, effectively dividing the 'intensive treatment' grade classification into two categories. However, the philosophy of linking the treatment process with microbiological criteria remains unchanged.

- **New South Wales**

The most widely recognised guidelines in Australia are the *Environmental Guidelines: Use and Disposal of Sludge Products* (NSW EPA, 1997 according to Reid, 2003). They specify similar treatment processes to the draft national guideline (albeit the presentation is altered). The microbiological standards for the unrestricted grade product are also comparable.

- **Victoria (Australia) microbiological standards**

Grade T1 represents the highest quality grade and from a microbiological perspective is suitable for unrestricted use. Since this guideline does not include regulatory controls on the end use of T1

products, there is a particular emphasis on ensuring adoption of treatment processes that can reliably achieve significant log reductions across a wide range of pathogens (EPA Victoria, 2002).

Table 5.6.1(A): The key international criteria for achieving an 'Unrestrictive Use' grade sludge product

Country	Microbiological Criteria			
	Faecal coliforms (MPN/g dw)	Salmonella (g dw)	Helminth including Ascaris	Other
US Part 503 rule	<1000 faecal coliform/g dw	or < 3 <i>Salmonella</i> /4 g dw	<1 viable helminth ova/4g dw	<1 PFU enteric viruses/4g dw
EC working redraft	<500 <i>E.coli</i> /g	No <i>Salmonella</i> /50 g (wet weight) ²		
UK proposed legislation	< 1000 <i>E. Coli</i> /g dw	No <i>Salmonella</i> /2g dw		
France		< 8 <i>Salmonella</i> MPN/ 10 g dw	<3 Helminth ova/10g dw	< 3 MPN enteric viruses /100 g dw,
Draft Australian national Guideline	< 100 <i>E. coli</i> /g dw	< 1 <i>Salmonella</i> /50 g dw		
NSW guideline 1 ³	< 1000 faecal coliforms/g dw < 100 <i>E.coli</i> /g dw	<1 <i>Salmonella</i> /25g dw	1 Helminth ova/4 g dw	<1 PFU enteric viruses/4g
Victoria (Australia)	<100 <i>E.coli</i> /g dw	<1 <i>Salmonella</i> /50g dw		
Mexico	<1000 MPN/g dw	<3 <i>Salmonella</i> /g dw	<1 viable helminth ova/g dw	

Table Notes:

1. The specific criteria listed for each treatment process may vary between frameworks. For example, heat drying in the US and in the EC draft directive requires heating to 90% solids content (10% moisture) at temperature >80°C, but the EC also proposes a requirement that the water activity is maintained above 0.9 for the first hour of treatment.
2. The EC Directive redraft lists *Salmonella* units as per gram wet weight, however, the *E.coli* units are not explicitly described. The majority of jurisdictions express sludge microbiological limits on a dry weight basis and therefore testing would require a sub-sample to be assessed for dry weight quantification.
3. The NSW guideline describes generic temperature time equations for different sludge moisture contents, but not prescriptive criteria for individual treatments such as heat drying.

Microbiological content of South African sludge

According to Jimenez *et al* (2003), the lack of sanitation in developing countries is the main environmental concern. The sanitation coverage of Africa is 76% in urban areas and 45% in rural areas. In developing countries, excreta-related diseases are very common, and sludge and wastewater contain correspondingly high concentrations of excreted pathogens – the bacteria, viruses, protozoa, and the helminths (worms) that cause gastro-intestinal infections in man (Strauss, 2000). Globally many wastewater treatment plants do not include sludge management within their treatment schemes and in many cases sludge is applied, disposed or discharged without any treatment.

About 33% of the population in developing countries is infected by intestinal worms (*ascaris* and *trichuris*). More than 61 million people in developing countries had infections caused by *ascaris* during 1990. *Ascaris* is one of the most resistant helminths and may survive for several years in the environment as directly related to the use of sludge on agricultural land (EPA 1991).

Results from the 'Metal content survey of South African sewage sludge' (Snyman *et al.* 2004) indicate that South African sludge contain 1.5-11.5 non-viable *Ascaris* ova/10g_{dw} (Figure 5.6(b)), >1.00E+06 Faecal coliforms/10g_{dw} (Figure 5.6(a)) and *Salmonella* was detected in 42% of South African sludge.

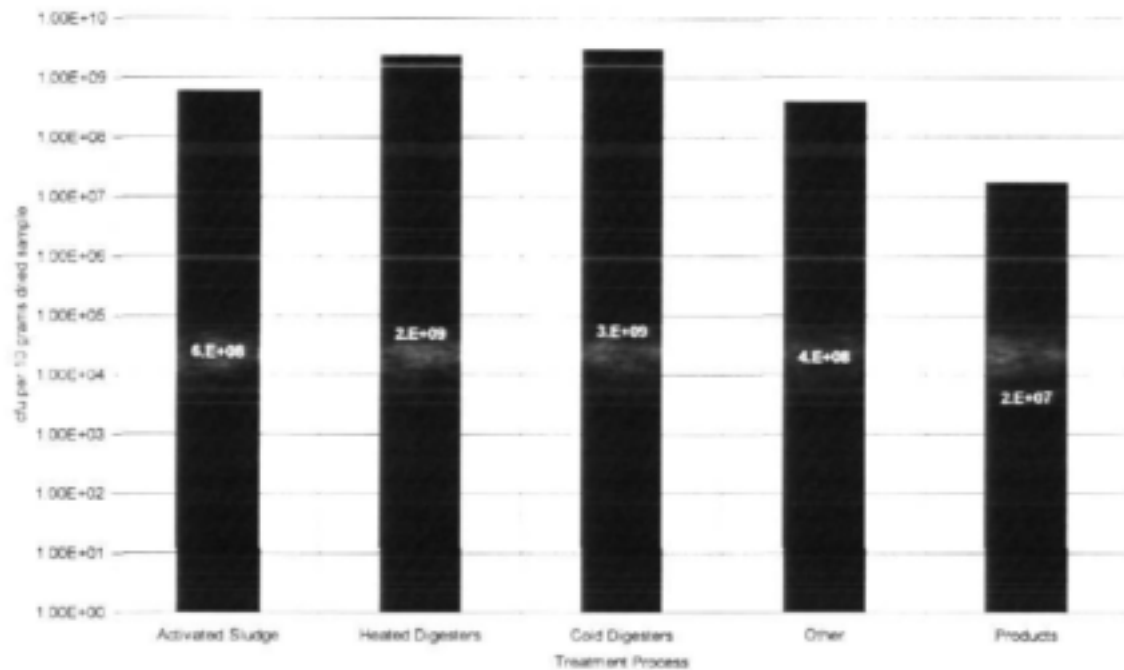


Figure 5.6(a): Faecal coliform (cfu (10 dry grams)⁻¹) results according to the treatment method

Comparisons between South African data and data for other developing countries (Jimenez *et al.*, 2003) indicate that South African sludge could have lower helminth ova than many other countries (Brazil 1-76; Egypt 8-124, Ghana 76 and Mexico 177 ova/g dw). However, as detailed in section 4.2.2 this method could have underestimated the total helminth concentrations. Research done in South Africa by Jimenez and Chale-Matsau in 2004 showed that the helminth concentrations are considerably higher and in line with other developing countries. As stated previously, the standards set by the first world countries (Table 5.6.1(a)) are easier to achieve when the starting concentration is low. Disinfection methods as detailed below are costly.

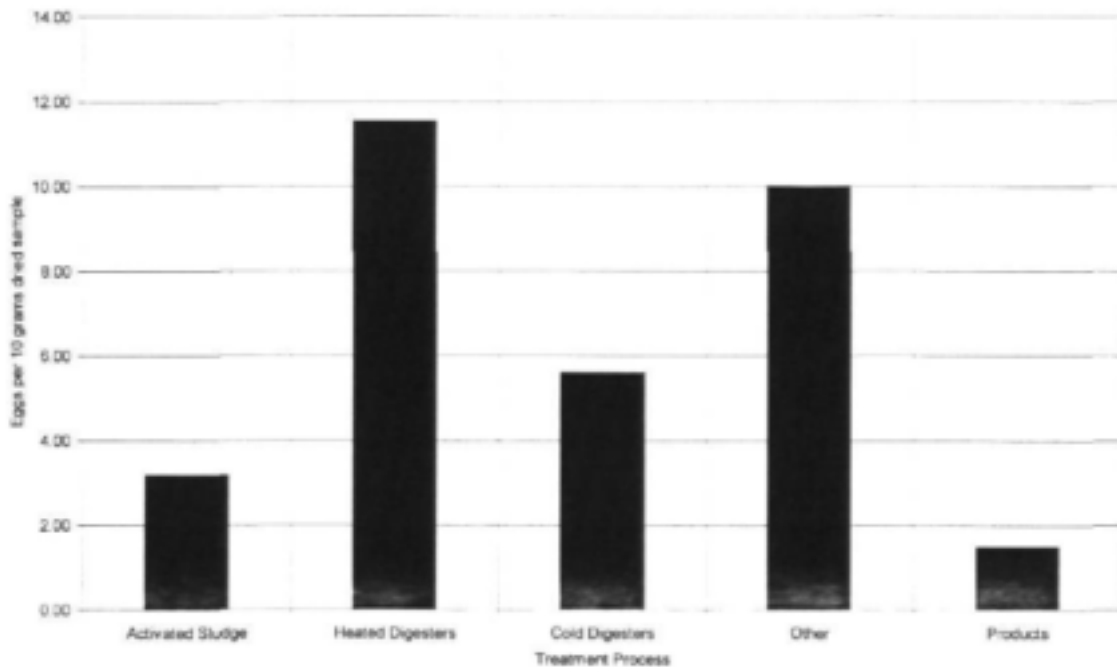


Figure 5.6(b): *Ascaris ova* (eggs (10 dry grams)⁻¹) results according to the treatment method.

Effect of treatment method on microbiological constituents in sludge

Research done by Lucero-Ramirez (2000) in Texas indicated that:

- Anaerobically digested sludge satisfied the EPA Part 503 requirements for Class B sludge; however, the Class A sludge requirements for faecal coliforms, *Salmonella*, and helminth ova densities in the digested sludge were exceeded.
- Air-dried sludge satisfied the Class A sludge criteria for bacteria and viable helminth ova. Airdrying of anaerobically digested sludge may be a potential alternative low-technology process for producing Class A sludge.
- Aerobically composted sludge satisfied the Class A sludge requirements for bacteria, and viable helminth ova.

The removal of helminth ova, faecal *coliforms*, *Salmonella* and protozoan cysts by the application of physicochemical treatment processes to municipal wastewater and sludge was studied by Jimenez *et al* (2001). The following results were documented:

- Advanced primary treatment (APT) process was studied, as well as filtration of the APT effluent. The APT sludge was treated with either lime or acid. After APT treatment, 96% of the helminth ova, 1 log of faecal *coliforms* and *Salmonella*, and 67% of the protozoan cysts were eliminated in the wastewater.

- A 97% reduction of the helminth and an 8.5 log reduction of faecal *coliforms* and *Salmonella* was achieved by alkaline stabilisation, compared with a 98% and 4.5 log reduction by acid treatment.

Strauss (2000) documented the pathogen removal efficiencies of various wastewater treatment systems as detailed in Table 5.6.1(b).

Table 5.6.2(b): Expected removal of helminth ova in various wastewater treatment systems (strauss, 2000)

Treatment process	Removal in log ₁₀ units of ____*
Primary sedimentation, plain	0-2
Primary sedimentation, coagulated	1-3
Activated sludge + secondary sedimentation	0-2
Trickling filter + sedimentation	0-2
Contact filtration of secondary effluent	1-2
Waste stabilisation ponds	1-3
Septic tank + anaerobic filter	1-2
Upflow anaerobic sludge blanket clarifier	1-2
* The higher numbers in the ranges relate to well-designed, non-overloaded and well operated WWTP	

It is clear from the above information that the microbiological constituents in sludge can be reduced significantly by stabilisation of the sludge, to such a degree that the sludge could safely be use for agricultural purposes.

Setting Microbiological standards for South Africa

In adopting standards, many countries tend to immediately adopt the strictest standards as they are in use in industrialised countries. This may satisfy the legal requirements of the enacting authorities and provide the prestige of "also having standards", but may often not be feasible in the local economic and institutional context. Instead of this, it would make much sense that countries would adopt a stepwise approach in setting standards, which would if followed and enforced, already achieve a considerable advancement in terms of pollution abatement and risk prevention. Even in industrialised countries standard setting has evolved gradually based on scientific and economic advancement (Strauss, 2000).

Intensive studies on the characterisation of sludge and demonstration projects would provide valuable information that will help support regulation. In South Africa the research data on the effects of sludge borne pathogens is extremely limited and very little research has been conducted in this field.

Table 5.6.1(a) details the recommended maximum permissible pathogen content for each microbiological class. In the US, the Committee on Toxicants and Pathogens in Sludge Applied to Land (National Academy of Science, 2002) found no documented scientific evidence that the Part 503 rule has failed to protect public health. No causal association between sludge exposures and adverse health outcomes has been documented. It was therefore recommended that South Africa adopt the US EPA maximum permissible values for Microbiological class A.

Snyman, Herselman & Kasselmann (2004) reported on the current situation in South Africa. The average faecal *coliform* count in South Africa sludge is in the order of 1×10^8 MPN or CFU/g_{dw}. In order to achieve a faecal *coliform* count of 1000 MPN or CFU/g_{dw} a 5 log reduction is required (99.999%). It is clear from the above mentioned study that this is currently not realistic for South Africa. However, we recommend that we set internationally accepted standards for our Microbiological class A sludge, especially in the light that a Class a product is intended for use by the public without restrictions. Thus all risks of microbiological infection need to be removed. More realistic targets is recommended for Microbiological class B sludge. In order to achieve a faecal *coliform* count of $< 2 \times 10^6$ MPN or CFU/g_{dw} (the US EPA standard for their Class B sludge) a 2 log reduction (99%) would be required.

The US EPA does not specify limits for Helminth ova for their Class B sludge. The current situation in South Africa have been reviewed by Snyman, Herselman & Kasselmann (2004) who found a maximum of 16 non-viable *Ascaris* ova/g_{dw}. It is recommended that for a Microbiological class B sludge a ceiling limit of 4 viable Helminth ova/g_{dw} will not be exceeded. For Microbiological class A and B two of the three samples must comply to the maximum permissible level while the other sample may not exceed the ceiling concentration.

Table 5.6.1(b): Preliminary classification: Microbiological class

Microbiological class	A		B		C
	All three samples comply with the following standard	The sample that failed does not exceed the following standard	Two of the three samples comply with the following standard	The sample that failed does not exceed the following standard	Two or more of the samples exceed the following standard
Faecal <i>coliform</i> (MPN/g _{dry})	1 000 (5 log reduction)	10 000 (4 log reduction)	1×10^6 (2 log reduction)	1×10^7 (1 log reduction)	$> 1 \times 10^7$ (no reduction)
Helminth (viable ova/g _{dry})	0.25	1	1	4	>4
Note: These requirements must be met immediately after treatment (disinfection/sterilisation), because of re-growth of indicator organisms in the sludge					

Continuous monitoring of the sludge will provide useful information on the actual situation experienced in South Africa over time and will enable the Guidelines to be updated in future with a better understanding of the reality in South Africa.

5.6.3 Stability class

In the previous sludge guidelines the stability of sludge did not receive much attention. It was implicated in old Type D sludge but, since most of the sludge in South Africa was Type B, it was never applied. Since the beneficial use of sludge is promoted in the new guidelines, the stability of the sludge is of utmost importance. The stability of sludge is management driven and should enable more wastewater treatment facilities to beneficially dispose of its sludge.

The vector attraction reduction criteria of the US EPA 503 Sludge rule (US EPA, 1993; US EPA 1994) was adopted. These criteria (or very similar) have been adopted by many other countries including Australia. Table 5.6.2 details the compliance criteria for the different stability classes based on the US EPA Sludge rule (US EPA, 1993). Note that the stability class is based on what is planned to do in future or currently done. It is possible to address stability issues at a later stage. It is therefore recommend that a worst case scenario is followed to assign the stability class based on the current situation or plan.

Table 5.6.2: Preliminary classification: Stability class

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

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

Option 1: Reduction in Volatile Solids Content

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

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

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

$$\% \text{VS reduction} = \{ (v_i - v_o) / v_i - (v_i \times v_o) \} \times 100$$

Where v_i = volatile fraction in feed sludge

v_o = volatile fraction in digested sludge

Example of calculation of VS reduction

Assume volatile solids in feed sludge	=	84%	
Therefore volatile fraction of feed sludge	=	0.84	= v_i
Assume volatile solids of digested sludge	=	68%	
Therefore volatile fraction of digested sludge	=	0.68	= v_o
% VS reduction =	$\{ (0.84 - 0.68) / 0.84 - (0.84 \times 0.68) \} \times 100$		
	=	59%	

Option 2: Additional Digestion of Anaerobically Digested Sludge

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

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

Option 3: Additional Digestion of Aerobically Digested Sludge

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

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

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

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

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

Option 5: Aerobic Processes at Greater Than 40 °C

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

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

Option 6: Addition of Alkaline Material

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

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

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

Option 7: Moisture Reduction of Sludge Containing no Unstabilised Solids

Under this option, vector attraction is considered to be reduced if the sludge do not contain unstabilised solids generated during primary treatment and if the solids content of the sludge is at least 75 percent before the sludge is mixed with other materials. Thus, the reduction must be achieved by removing water, not by adding inert materials.

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

Option 8: Moisture Reduction of Sludge Containing Unstabilised Solids

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

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

Option 9: Sludge Injection

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

The reason for this special consideration for Microbiological class A and B sludge (assuming vector attraction has not been reduced by some other means) is that pathogens could regrow and

Microbiological class A and B sludge have no site restrictions to provide crop, grazing, and access protection.

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

Injection of sludge beneath the soil places a barrier of earth between the sludge and vectors. The soil removes water from the sludge, which reduces the mobility and odour of the sludge. Odour is usually present at the site during the injection process but quickly dissipates once injection is complete.

Option 10: Incorporation of Sludge into the Soil

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

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

5.6.4 Pollutant class

Metals

The organic and inorganic pollutant limits and load restrictions vary for different applications. For example, the pollutant limits applicable for agricultural use of sludge are completely different to those requirements pertaining to landfill or incineration. The requirements for sampling and analysis are also different for each option. It is therefore recommended that the various volumes that deal with different applications address the premise for the pollutant limits that pertain to that particular use or disposal option. However, it is important that to at least have an indication of the pollutants class for planning purposes. In order to do a preliminary classification, it is recommended that we use the metal limits designed for the agricultural use of sludge because this is the most sensitive disposal. Use Table 5.6.4(a) to assign a preliminary Pollutant class for the 8 metals based on the average results from the three samples collected and analysed according to Table 1 in Volume 1 - Part 5. The metal limits have been adopted from the US EPA Rule 503 and the values in the table have been rounded off to the nearest 5.

The values for the optional metals included in Table 5.6.4(a) are based on the benchmark values of typical South African sludge values derived from data compiled by Snyman, Herselman & Kasselmann

(2004) on 78 wastewater treatment facilities. The benchmark values were calculated as the 20th and 80th percentile values of all the data at all wastewater treatment facilities that were sampled (See Appendix 5), rounded off to at least 3 significant digits. If the sludge samples have been assigned a Pollutant class a, the sludge quality falls in the top 20% in terms of metal content. Similarly, if the sludge samples have been assigned a Pollutant class c, the sludge quality falls in the bottom 20% in terms of metal content. This means that compared to the average metal content in South African sludges, these sludge samples show very high metals and should be investigated. The Pollutant class classification system is presented in Table 5.6.4(a).

Table 5.6.4(a): Preliminary classification: Pollutant class

Metal limits (mg/kg) for South African Wastewater Sludges			
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
Benchmark Metal Values			
Pollutant class	a	b	c
Aluminium (Al)	-	-	-
Antimony (Sb)	<1.1	1.1-7	>7
Boron (B)	<23	23-72	>72
Barium (Ba)	<108	108-250	>250
Beryllium (Be)	<0.8	0.8-7	>7
Cobalt (Co)	<5	5-38	>38
Iron (Fe)	-	-	-
Manganese (Mn)	<260	260-1225	>1225
Molybdenum (Mo)	<4	4-12	>12
Selenium (Se)	<5	5-15	>15
Silver (Ag)	-	-	-
Sodium (Na)	-	-	-
Strontium (Sr)	<84	84-205	>205
Thallium (Tl)	<0.03	0.03-0.14	>0.14
Vanadium (Va)	<85	85-430	>430

Notes:

- (1) The word "metals" include all inorganic constituents and could include both beneficial and potentially toxic elements depending on the application.
- (2) For sludge to comply with Pollutant class a, the specific quality parameter must comply with a target value (threshold value) for at least 90 % of the time and may never exceed a specified maximum allowable level
- (3) For sludge to comply with Pollutant class b, the specific quality parameter must comply with a target value (threshold value) for at least 75 % of the time and may never exceed a specified maximum allowable level
- (4) Sludge that is classified as a Pollutant class c, exceeds the specific quality parameter(s) of Pollutant class b for a specific use by either exceeding a target value (threshold value) for more than 25 % of the time and/or exceeding a specified maximum allowable level
- (5) The target values and maximum allowable limits for the applicable constituents vary for different applications and are detailed in the relevant volumes:
 - a. Volume 2: Requirements for the agricultural use of sludge
 - b. Volume 3: Requirements for the on-site and off-site disposal of sludge
 - c. Volume 4: Requirements for the beneficial use of sludge
 - d. Volume 5: Requirements for thermal sludge management practices and for commercial products containing sludge

Organic pollutants**Current local knowledge regarding organic pollutants in sludge**

Organic pollutants in sludge could potentially pose a high risk to many receptors. The previous South African sludge guidelines had limits for certain organic constituents in sludge (Table 5.6.3(b)). Seven (7) of the 11 constituents are classified and used as pesticides.

In order to determine the existence of the most persistent organic pollutants in South African sludge, the WRC funded a research project entitled: "Methodology and survey of organic pollutants in South African sewage sludges (K5/1339)" which included the screening of sewage sludge samples. The preliminary findings indicate that pesticides are not the main pollutants in the sludge. It would therefore not be advisable to continue monitoring the contaminants recommended in the previous guidelines. Phenols and Poly Aromatic Hydrocarbons (PAHs) are compounds that require further quantitative studies. The phenolic compounds are p-cresol and nonylphenols while the PAHs are acenaphthene, phenanthrene, fluorine, fluoranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene and indeno(1,2,3-c,d)pyrene.

Table 5.6.4(b): Maximum limits for organic and other pollutants in sewage sludge (Adapted from WRC 1997)

Pollutants	Use/Origin	Conc. mg/kg dry sludge	State of pollutant
Aldrin	Insecticide (Termite control)	0,202	Banned in 1992
Benzo(a)pyrene	PAH. They are not produced or used commercially but formed as a result of incomplete combustion of organic materials.	2,53	
Chlordane	Man-made chemical that was used as a pesticide in the United States from 1948 to 1988	3,5	Restricted to stem treatment of citrus and vineyards from 1993
DDT	Pesticide – Malaria control	0,35	Banned in 1983 except

Pollutants	Use/Origin	Conc. mg/kg dry sludge	State of pollutant
			for malaria control by Government
Dieldrin	Insecticide	0,303	Banned in 1983
Dimethyl nitrosamine	Formerly used in rocket fuels, as an antioxidant, and for other purposes	2,9	
Heptachlor	Termiticide and an insecticide used on seed grain and crops	0,35	Registration withdrawn in 1976
HCB (Hexachlorobenzene)	Most often used to make other compounds, but has also been used as a wood preservative, a fungicide on grains and grain seeds, and an additive in explosives, as well as a part of the production process for rubber, aluminium, and dyes. Its fungicide use was permitted in the U.S. until 1965.	16,2	Banned in 1983 (DEAT)
Lindane	Pesticide	1,36	Registration withdrawn in 1971. Used in some shampoos
PCB (Polychlorinated biphenyls)	Heat stable oils once used as transformer and hydraulic fluids.	1,0	
Trichloroethylene	Solvent	2020,0	

Table 5.6.4(c) indicates that pesticides were detected in very few sludge samples, probably due to the fact that the use of many of these pesticides is banned.

Table 5.6.4(c): The group frequency of the organic compounds detected in different province sewage works

Organic pollutants	No. of times detected								
	Gau (23)	Lim (7)	N-West (7)	F State (5)	Kw-Nat (11)	E-Cape (4)	N-Cape (4)	W-Cape (15)	Mpu (2)
Phenols	36	4	5	4	4	5	4	18	
Chlorinated phenols	-	-	-	-	-	1	-	-	
Pesticides	1	-	-	1	-	-	-	-	
PAHs	49	8	1	1	14	8	1	14	
Phthalates	5	1	-	1	-	-	-	5	
PCBs	6	-	-	-	1	-	-	-	
Furans	9	1	1	-	1	-	2	-	
Amines	21	6	4	2	11	3	4	12	
Aldehydes	33	4	2	-	7	2	2	9	
Esters	74	20	9	3	20	3	9	33	
Acids	174	69	41	11	58	18	27	165	
Alcohols	25	9	10	1	9	5	1	35	
Chlorinated hydrocarbons	21	4	2	2	8	-	4	6	
Hydrocarbons	410	97	95	18	176	45	50	185	
Others	248	66	35	16	52	18	22	100	

Very few wastewater operators (and their associated laboratories) have the expertise and resources to measure organic pollutants in sludge. Based on these findings as well as the international trends detailed in section 3.3.4, we recommend that only the screening of PAHs are included at this stage.

Table 5.6.4(d): Organic pollutants of concern in the sludge samples

Poly-aromatic hydrocarbon (PAH)	No action required	Action required
Acenaphthene	The sum of the concentrations of these constituents are below 6mg/kg	The sum of the concentrations of these constituents are above 6mg/kg
Phenanthrene		
Fluorene		
Fluoranthene		
Pyrene		
Benzo(b+j+k)fluoranthene		
Benzo(a)pyrene		
Benzo(ghi)perylene		
Indeno(1,2,3-c,d)pyrene		

5.6.5 Examples of classification of South African sludge

Table 5.6.4 shows actual data of 5 wastewater treatment plants in South Africa. The data was used to compare the classification criteria of the 1997 Guidelines with the classification criteria of the proposed new Guidelines.

The data indicate that only WWTP 5 could use agricultural application as a disposal method according to the 1997 Guidelines, but according to the proposed new Guidelines, WWTP 2, WWTP 4 and WWTP 5 can use agricultural application as a disposal route for sludge. If WWTP 3 can reduce its Faecal *Coliform* count and apply one vector attraction reduction option, it will also be able to apply the sludge on agricultural land. The sludge from WWTP 1 is not suitable for agricultural application due to the high metal content as well as the high *Ascaris* ova and Faecal *coliform* and the presence of *Salmonella* and should therefore choose another disposal route.

Table 5.6.4: Data of 5 South African wastewater treatment plants for classification

		WWTP 1	WWTP 2	WWTP 3	WWTP 4	WWTP 5
Sludge type		Anaerobic digested	Anaerobic digested	WAS	WAS	WAS
Sampling point		Wet sludge	Compost	Wet sludge	Belt press	Compost
Microbiological parameters	Helminth ova/g _{dw}	5.7	0	0	0.25	0.23
	Faecal <i>Coliform</i> /g _{dw}	1.79E+06	0.00E+00	3.66E+08	5.1E+04	0.9E+05

Metal content (mg/kg)	Cd	70.9	25.3	5.6	10.2	4.77
	Cr	2791	1109	125	113	133
	Cu	2920	810	260	343	269
	Hg	7.7	3.9	8.2	2.1	2.7
	Ni	600	381	141	188	171
	Pb	3758	838	150	100	78.1
	Zn	20533	5058	2157	1010	856.6
Vector attraction reduction options		-Anaerobic digestion with VS reduction of 40% -Drying beds	-Reduce moisture content to 75% solids -Make compost	-None	-Add lime in rainy season -Reduce moisture content to 20% solids	-Reduce moisture content to 75% solids -Make compost
1997 Guideline Classification		B	C	A	B	D
Proposed new Guideline classification		C1c	A1b	C3a	B2a	B1a

5.7 Part 7: Selection of appropriate management options

5.7.1 Decision-making matrix

The results from the comprehensive characterisation and classification detailed in Volume 1 - Part 5 and Part 6 can be used to determine the best appropriate management option. Table 5.6.4 shows a colour coded matrix that can be used to assess the appropriateness of a management option based on the Microbiological class, Stability class and the Pollutant class. These management options, the volumes that pertain to them as well as the major restrictions in terms of each different class are explained in Volume 1 – Part 6.

Table 5.7.1: Decision-making matrix

(i)	Yes	Recognising that no management option can ever truly be applied without any restrictions, these options only have minor restrictions.
(ii)	Qualified yes	The restrictions that apply do not have major complications and can be managed using good management practices.
(iii)	Maybe	This can only be effectively applied under strict conditions and major management and cost implications apply.
(iv)	Qualified no	Only under very unique conditions can this management option be applied for this class of sludge
(v)	No	This management option should not be considered for this class of sludge.

5.7.2 Examples of how to select appropriate management option/s from preliminary classification

Wastewater Treatment Plant 1

This Plant has waste activated (WAS) and anaerobic digested (AD) sludge. The WAS is pumped to the heated digester (sludge age 21 days). The AD has a sludge retention time of 19 days. The sludge is dried on drying beds. The analyses data of 3 grab samples (average) from the digester is shown in Table 5.6.4.

The microbiological parameters in the sludge are high and therefore it is Microbiological class C. The Stability class is 1 since the Plant comply with at least 1 vector attraction reduction options presumably 90% of the time. The Ni, Pb and Zn content of the sludge is high (Pollutant class c). This sludge is thus a Type C1c and the following management options apply:

- Agricultural use at agronomic rates – Not allowed due to pollutant content
- On-site or off-site disposal – Allowed with restrictions
- Beneficial use (not agriculture) – Allowed with restrictions
- Thermal treatment – Allowed with restrictions
- Produce saleable products – Not allowed due to microbiological content

Wastewater Treatment Plant 2

Plant 2 produces compost from AD sludge (heated digester) dried on drying beds and other organic waste materials. The analyses of 3 compost samples (average) are detailed in Table 5.6.4. The microbiological content of the sludge is low and falls in Microbiological class A. Since the sludge is

dried, the Stability class is 1. The Pb and Zn concentration of the sludge is too high for unrestricted use but still in Pollutant class b. The sludge produced at this Plant is type A1b. The following management options apply:

- Agricultural use at agronomic rates – Allowed with restrictions due to pollutant content (can be used if metal content of the soil is low)
- On-site or off-site disposal – Allowed, but should rather be used beneficially
- Beneficial use (not agriculture) – Allowed, but should rather be used in agriculture
- Thermal treatment – Allowed, but should rather be used beneficially
- Produce saleable products – Allowed with restrictions due to pollutant content

Wastewater Treatment Plant 3

Plant 3 is a WAS plant with nitrification, denitrification and biological P removal. There is no reduction in moisture content and currently the sludge is disposed on-site on dedicated land. The analyses of 3 grab samples of the WAS is presented in Table 5.6.4.

The faecal *coliform* count of the sludge is high and therefore it is Microbiological class C. the Stability class is 3 since no vector attraction reduction options are implemented at the Plant. The metal concentration of the sludge is low and the Pollutant class is a. Thus, the sludge is Type C3a. the following management options apply:

- Agricultural use at agronomic rates – Not allowed due to microbiological and stability classes. If a vector attraction reduction option is implemented agricultural application will be allowed with restrictions due to the Microbiological class.
- On-site or off-site disposal – Allowed with restrictions
- Beneficial use (not agriculture) – Allowed with restrictions
- Thermal treatment – Not allowed due to stability class. If a vector attraction reduction option is implemented thermal treatment will be allowed without restrictions
- Produce saleable products – Not allowed due to microbiological and stability classes.

Wastewater Treatment Plant 4

This is a WAS plant with a sludge age of 21 days. The sludge is de-watered with a belt filter press to 20% solids. Lime is added during the raining season. Analyses results of 3 samples from the belt filter press is detailed in Table 5.6.4.

The faecal *coliform* count of the sludge places it in Microbiological class C. Vector attraction reduction options is implemented and the Stability class is 2 (comply only on a 75% basis). The metal

concentration is low, therefore the Pollutant class is a. The following management options apply (sludge type C2a):

- Agricultural use at agronomic rates – Allowed with restrictions
- On-site or off-site disposal – Allowed, but should rather be used beneficially
- Beneficial use (not agriculture) – Allowed with restrictions due to microbiological class
- Thermal treatment – Allowed with restrictions
- Produce saleable products – Not allowed due to microbiological class.

Wastewater Treatment Plant 5

Plant 5 produces compost from WAS after de-watering with a belt filter press. Analyses results of samples from the dry compost heaps are shown in Table 5.6.4. Due to the faecal *coliform* count the sludge is Microbiological class B. The stability class is 1 and the low metal content place the sludge in Pollutant class a. This is a type B1a sludge. The following management options apply:

- Agricultural use at agronomic rates – Allowed with restrictions due to microbiological content
- On-site or off-site disposal – Allowed, but should rather be used beneficially
- Beneficial use (not agriculture) – Allowed with restrictions
- Thermal treatment – Allowed, but should rather be used beneficially
- Produce saleable products – Allowed with restrictions

Note that in this case it would be in the interest of the producer to sample the compost just after production in order to assess if Microbiological class A sludge cannot be achieved. If the compost sample still fails, small adjustments could be made to the composting operation and the microbiological quality re-assessed. If the producer can enhance the microbiological quality to the class A requirements, the product could be alienated and sold.

5.7.3 Choosing the suitable sludge management volume for a specific management option

Once you have decided on a suitable management option, you will need to refer to the relevant volume that deals with the selected management option (Figure 5.7.3).

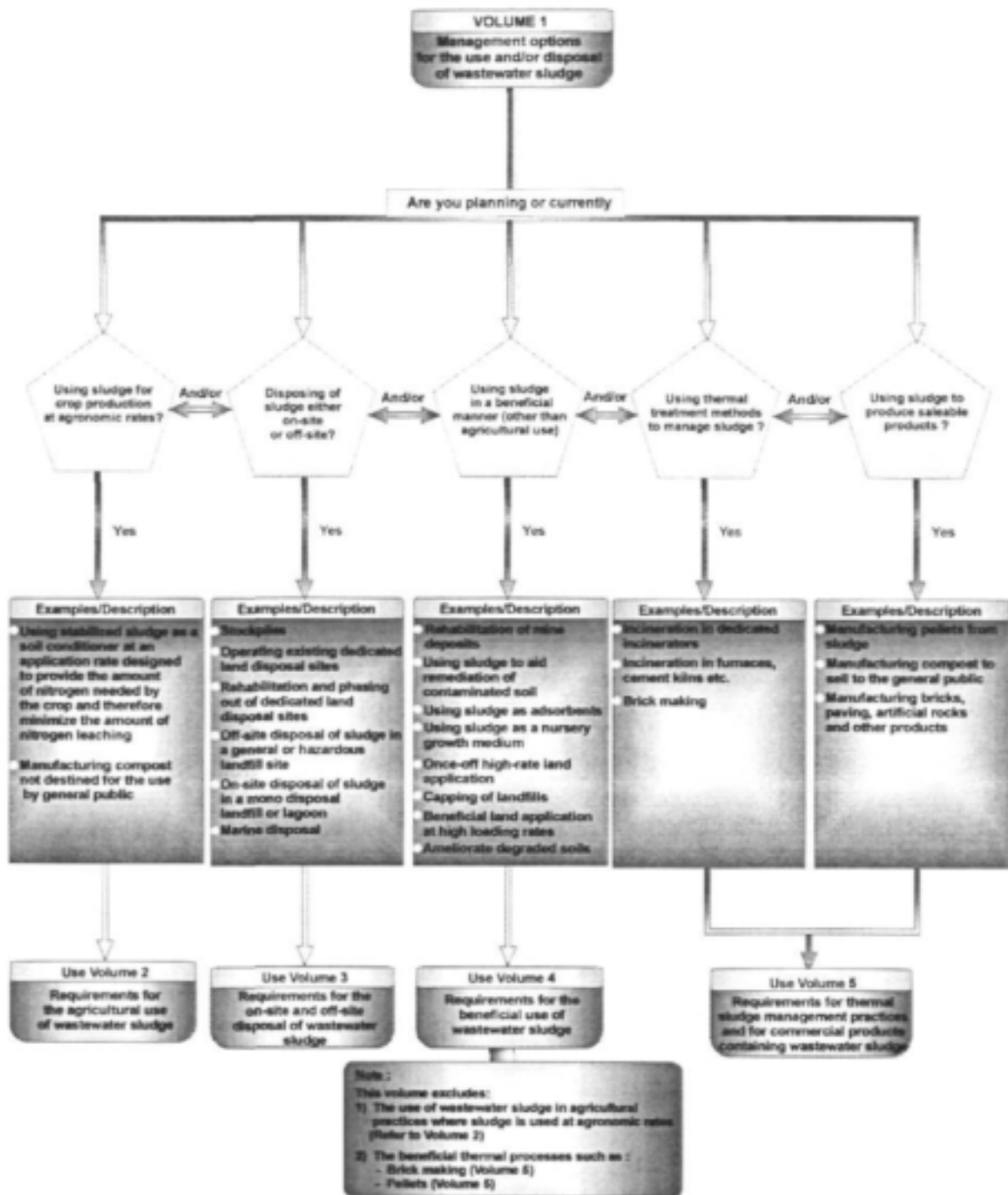


Figure 5.7.3: Choosing the suitable sludge management volumes for a specific management option

Appendix 3 details the essential items to be included in contractual agreement between the sludge producer and the sludge user.

6 PREMISE OF VOLUME 2: AGRICULTURAL USE

The agricultural use of sludge is defined as the beneficial use of certain constituents in sludge to benefit either the soil condition and/or enhance crop production in a sustainable manner without harming the environment. If this management option is considered, special care should be taken to accommodate the public in the surrounding areas (neighbour farmers, formal and informal settlements etc.). According to the "Regulations regarding control over the sale of organically produced products in the Republic of South Africa" (Agricultural Product Standards Act, 1990; Act No. 119 of 1990), organically produced products cannot be marketed or registered as such if sludge is applied in the vicinity. Therefore the agricultural practices on neighbouring farms should be accommodated. The odour and vector attraction properties of sludge are probably the single most important aspect that influences public perception. Special care should be taken of these aspects when agricultural application of sludge is considered near public areas.

This volume addresses the requirements for the agricultural use of sludge when applied beneficially at agronomic rates. It aims to assist the reader to:

- implement the requirements pertaining to the agricultural use of sludge at agronomic rates, including the operational and legal requirements (Volume 2 – Part1); and,
- implement the monitoring requirements for the agricultural use of sludge.

The scientific premise for this volume is based on a risk assessment and management process in which the following questions are answered:

- What is agricultural use of sludge?
- What are the possible benefits associated with the use of sludge in agricultural practices?
- What are the possible negative effects associated with the use of sludge in agricultural practices?
- Which receptors are sensitive and need to be protected for this particular application?
- Are these receptors more sensitive to some of these contaminants than others?
- Can these negative effects be avoided/mitigated by either:
 - Treating the sludge (elimination of the contaminant in the sludge/source); and/or
 - Preventing the contaminant from reaching the receptor by breaking the pathway between the source and the receptor?
- How should this be managed to minimise the risk to the sensitive receptors?

6.1 Benefits associated with the agricultural use of sludge

Sludge acts as a soil conditioner to facilitate nutrient transport, increase water retention and improve soil tilth (Ekama, 1993). Sludge also serves as a partial replacement for chemical fertilisers. The major plant nutrients (nitrogen, phosphorus and potassium) in sludge are not substantially removed

during sludge processing; therefore the nutrients could improve the soils nutritional status after sludge application. Sludge also contains essential plant micronutrients such as copper, zinc, manganese and boron (Ekama, 1993). However, the long-term benefit of sludge to land as an alternative source of plant nutrients is frequently limited by potentially toxic levels of heavy metals and human pathogens (Palmer, 1993). Therefore, the benefits of sludge should be weighed up against the limitations before and during sludge application.

6.2 Potential toxic and infectious aspects associated with sludge

Snyman *et al.* (2003) quoted several authors and studies detailing the possible risks associated with sludge use in agricultural practices. Pathogens, potentially toxic metals and elements, organic pollutants and nutrients and macro-elements could possibly impact the natural environment and other receptors negatively, if they are not managed adequately.

6.2.1 Pathogens

The pathogens that are generally subject to regulation are *Salmonella*, enteric viruses, helminth ova, and oocysts of protozoa. *Escherichia coli* (E.coli) are used as a general indicator for the presence of bacterial pathogens found in sludge (NZWERF, 2003).

Salmonella spp. bacteria are subject to regulation because outbreaks of gastro-enteritis have in the past been relatively common and experience has shown that reducing *Salmonella* to a low level, as with faecal coliforms, provides a high degree of assurance that other bacterial pathogens do not constitute a health risk. *Salmonella spp.* is so common in the environment that the proper control of Salmonellosis is through food hygiene, sludge properly used in agriculture is not involved in the transmission of human *Salmonella* (Smith, 1996). There is potential for regrowth of these organisms in sludge and sludge in storage or after application to land. This is one of the reasons this parameter has been omitted from the new South African sludge guidelines.

There are numerous types of enteric viruses that occur in sludge including Hepatitis A virus, Small Round Structured Viruses including Norwalk virus, and Adeno virus. Some enteric viruses, such as the Adeno virus, are more resistant to physical and chemical agents than others. The types and concentrations of viral agents in sludge are dependent on the presence of viral hosts in the associated community.

Helminths found in sludge include nematodes (roundworms and hookworms), cestodes (tapeworms) and trematodes (flukes). Helminth ova are very resistant to the environmental factors that reduce the numbers of bacterial indicators or animal viruses in sludge. Because of their resistance, the presence/absence of viable helminth ova is used as a criterion for monitoring the presence of helminths in sludge to be applied to land (NZWERF, 2003).

Protozoa found in wastewater include *Entamoeba histolytica* (amoebic dysentery) *Giardia entestinalis* (gastro-enteritis), *Cryptosporidium* (gastro-enteritis) and *Balantidium coli* (gastro-enteritis). These

organisms generally occur as cysts, which are inactivated by heat and/or lime treatment (NZWERF, 2003).

As stated previously, we recommend that faecal coliforms and total viable helminths ova be used as microbiological indicators.

6.2.2 Metals

The term "metals" generally refers to elements that occur in natural and perturbed environments in small amounts and that, when present in sufficient bio-available concentrations, are toxic to living organisms. The main metals of concern, from a human health perspective, are cadmium, lead and mercury (Smith, 1996). The US EPA found that the direct ingestion of sludge by children is the most critical pathway of exposure to cadmium, lead and mercury, with the greatest risk being for domestic gardens. Neither lead nor mercury are taken up to any extent by crops and consequently do not pose a risk through the dietary intake of plant foods.

Cadmium, on the other hand, can accumulate in crops. In practice it has been found that humans are protected from (sludge-related) cadmium toxicity because the high ratio of zinc to cadmium in sludge inhibits the uptake of cadmium in plants, plants take up zinc in preference to cadmium (Chaney and Ryan, 1994 according to the NZWERF, 2003). According to the NZWERF (2003), the US National Research Council (1996) found that although levels of cadmium in crops grown in sludge-amended soils can be elevated, there are no documented cases of human or animal poisoning from this source.

Copper, nickel and zinc can be translocated to the edible parts of crops. However, humans, like animals, are protected by the so called 'soil-plant barrier' (before metals in crops reach levels potentially harmful to humans, growth is so severely stunted that the crop or vegetable is not harvestable). According to the NZWERF (2003), the US National Research Council (1996) noted that no adverse human acute or chronic toxicity effects had been reported resulting from the ingestion of food plants grown in soils amended by sludge.

It is recommended that the specific metals considered be evaluated. Cadmium, copper, lead, mercury, nickel, zinc, arsenic, chromium are regulated by most countries. However, some countries regulate specific metals that do not form part of the list above. For example:

- South Africa and China are the only countries that have limits for boron;
- South Africa, Australia, Austria and Switzerland are the only countries that have cobalt limits;
- South Africa, USA (Wisconsin), France and Australia are the only countries with selenium limits.

The motivation to regulate some of these metals is not clearly understood and it is therefore recommended that the list of metals as presented in the 1997 guidelines be re-evaluated.

6.2.3 Organic pollutants

The organic contaminants generally considered when assessing risks from sludge are the persistent organochlorine pesticides (such as DDT and dieldrin), polychlorinated biphenyls (PCBs) and dioxins. These organochlorine chemicals are also known as persistent organic pollutants (POPs). Human exposure to POP is primarily via the food chain, especially from grazing animals, where the contaminants accumulate in body fat.

There would appear to be minimal risk to human health via dietary intake of organic contaminants from crops grown in sludge-treated soils because there is little or no plant uptake, except perhaps in the peel of carrot, which is generally removed during normal food production (Smith, 1996). Reviews of the possible environmental hazards by organic contaminants in sludge repeatedly identify surface application of sludge to grassland as the only potentially significant pathway of human exposure from the agricultural use of sludge, because of the possibility of persistent lipophilic compounds transferring to the tissue fat and milk of grazing livestock. Currently there would appear to be no reported examples where unacceptable concentrations of organic contaminants in foods are linked to the agricultural use of sludge (Carrington *et al.* 1998, according to the NZWERF, 2003).

6.2.4 Nutrients and macro-elements

Sludge contains nitrogen, phosphorus, potassium, calcium and magnesium that are generally regarded and actively applied in the inorganic form (fertilisers) as plant nutrients. These elements could be added in excess of that required and the excess could contaminate environmental receptors such as the soil, surface water and groundwater. Sludge also contains other macro-elements such as sodium and chlorine that could potentially increase the salinity of the soil.

Due to the low content of the other constituents, the nitrogen and phosphorus is potentially the only two elements that could impact the environment. However, the loss of nitrogen and phosphorus from soil by various biological processes and physical mechanisms is a common phenomenon in agricultural activities. These losses can result in pollution of the aerial environment by, for example ammonia volatilisation, and contamination of surface and groundwater resources through leaching of nitrate and surface run-off of both nitrate and phosphate (Smith, 1996). It was found that the application of sludge to soil decreased the run-off intensity and reduced soil erosion. This led to a decrease in the total phosphorus exported through surface run-off (Van den Bossche *et al.*, 1999). Very little research has been done concerning phosphorus losses after sludge applications to soil. Nitrate leaching has been investigated more thoroughly. Increased losses of nitrate by leaching following the application of sludge to soil have been frequently reported (Chang *et al.*, 1988; Wadman & Neeteson, 1992; Lotter & Pitman, 1997). The migration of NO_3^- is therefore the limiting factor when disposing of sludge.

Currently, strict legislation exists in South Africa for sludge application in terms of total nitrogen application, because of the possibility of NO_3^- leaching. According to the 'Permissible Utilisation and Disposal of Sludge' (WRC, 1997), the maximum loading rate of sludge to agricultural land is 8 tons of dried sludge per hectare per year. No equivalent legislation exists for commercial fertiliser. Unlike

sludge, which contains some nitrogen in an organic form, commercial fertiliser contains nitrogen only in the inorganic form. This means that nitrogen from fertiliser will be immediately available for plant uptake or leaching, whereas organic nitrogen from the sludge is only partly available and the remainder must be gradually mineralised by micro organisms, before it becomes available for plant uptake. In sludge the plant available nitrogen is about 30% of the total nitrogen in the first year, 15% becomes available in the second year, and 5% in the third (WRC, 1997). This assures a more balanced and constant supply of nitrogen to the plant over a longer time than commercial fertilisers. Commercial fertiliser can potentially contribute more to groundwater contamination than sludge. A local study done by Van Niekerk (2004) illustrated that the limit of 8 tons of dried sludge per hectare per year effectively protects the environment against the leaching of NO_3^- and preliminary results indicate that this could even be elevated to 20 tons of dried sludge per hectare per year. Her work illustrated a much higher mineralisation rate of the nitrogen, with levels up to 60% in the inorganic form after two months.

6.3 Risk analyses

Smith (1996) recorded an overall assessment of the potential impacts caused by recycling sludge to agricultural land (Table 6.3). The risk factor of using sludge in terms of metals, organic contaminants and pathogens is relatively low, with possible risk concerning ecosystems and soil fertility. It is also clear that the main nutrients (nitrogen and phosphorus) and organic matter present in sludge are beneficial for the use of sludge on agricultural land. There are, however, possible risks of groundwater or surface water nitrate or phosphate contamination (Smith, 1996). The following sections deal with the contamination risks of sludge applied to soil.

This assessment done by Smith (1996) was done before 1996 and a large amount of local information was since gathered. This multidisciplinary research programme includes the following projects:

- **WRC Project Number 1209:** An evaluation of dedicated land disposal practices for sewage sludge (WRC Report 1209/01/04)
- **WRC Project Number 1210:** Laboratory and field scale evaluation of agricultural use of sewage sludge (WRC Report 1210/01/04)
- **WRC Project Number 1240:** A technical and financial review of sludge treatment technologies (WRC Report 1240/01/04)
- **WRC Project Number 1283:** A metal content survey of South African sewage sludge and an evaluation of analytical methods for their determination in sludge (WRC Report 1283/01/04)
- **WRC Project Number 1339:** Survey and methodology for analysing organic pollutants in South African sewage sludge (WRC Report 1339/01/04)

A separate risk assessment was done to include the new data. This was done in a one-day brainstorming session held on 23 March 2004 at the ARC ISCW (Pretoria). The members were Dr HG Snyman (Golder Associates), Mr CE Steyn (ARC ISCW) and Mrs JE Herselman. The findings of this risk assessment are documented in the section below. Risks that could not be clearly defined

during this session were marked H (high risk) as a precautionary principle and specifically studied using risk models or international research findings.

Table 6.3: Environmental impact assessment for sludge recycling to agricultural land (Smith, 1996)

Environmental parameter	PTMEs	Organic contaminant	Pathogens	Nitrogen	Phosphorus	Organic matter
Human health	L	P(L)	L	B	B	B
Crop yield	L	L	L	B	B	B
Animal health	L	L	L	B	B	B
Groundwater	L	L	L	P	L	L
Surface water	L	L	L	P(L)	P(L)	B
Air quality	L	L	L	P(L)	na	na
Soil fertility	P	L	L	B	B	B
Natural ecosystems	P	P	L	P	P	B

(B = beneficial effect, L = low risk, P = possible risk, na = not applicable, PTEs = potentially toxic elements)

6.3.1 Qualifying the risks associated agricultural application of sludge

Source analysis

The following characteristics within the source (sludge) were considered:

- (1) Organic material
- (2) Nutrients (N, P, K, Ca, Mg)
- (3) Macro-elements (Na, Cl)
- (4) Metals (Beneficial micro-elements such as Zn, Cu, Co and Se and potentially harmful PTME's)
- (5) Organic pollutants
- (6) Pathogens
- (7) Odours and other nuisances such as vector attraction

Pathway analysis

The technical support document for land application of sludge that forms part of the Part 503 Regulations and core documents that deal with the management of sludge (US EPA, 1992), list the possible exposure pathways. These possible pathways (Table 6.3.1(a)) were considered.

Table 6.3.1(a): Environmental pathways of concern identified for the land application of sludge (US EPA, 1992)

Pathway	Description
1. Sludge – soil – plant – human	Consumer ingesting plants growth in sludge-amended soil
2. Sludge – soil – plant – human	Residential home gardener
3. Sludge – human	Children ingesting sludge
4. Sludge – soil – plant – animal – human	Farm households producing a major portion of the animal products they consume. It is assumed that the animals eat plants grown in sludge-amended soil
5. Sludge – soil – animal – human	Farm households consuming livestock that ingest soil while grazing
6. Sludge – soil – plant – animal	Livestock ingesting crops grown on wastewater-sludge amended soil
7. Sludge – soil – animal	Grazing livestock ingesting sludge amended soil
8. Sludge – soil – plant	Plants grown in sludge amended soil
9. Sludge – soil – soil biota	Soil biota living in sludge-amended soil
10. Sludge – soil – soil biota – soil biota predator	Animals eating soil biota living in sludge-amended soil
11. Sludge – soil – airborne dust – human	Tractor operator
12. Sludge – soil – surface water – human	Humans eating fish and drinking water
13. Sludge – soil – air – human	Humans breathing volatile pollutants
14. Sludge – soil – ground water – human	Humans drinking water from wells

Receptor analysis

The following receptors that could be affected by the application of sludge in agricultural practices were identified.

(1) Crops, plants

(2) Livestock, animals

(3) Humans

a. Public

b. Farm workers

-
- (4) Soil diversity/biota
 - (5) Surface water
 - (6) Groundwater

Risk matrix

Table 6.3.1(b) details the outcome of the brainstorming session in which the risks were qualified in terms of the source and receptors listed above. Note that the risk matrix does not assume any specific mitigation/management to reduce the risk to a specific receptor. The risks were quantified as follows:

- (B) This symbol indicates a beneficial effect. The effect can either be directly or indirectly.
- (na) Not applicable
- (L) This symbol indicates a low risk to the particular receptor.
- (M) This symbol indicates a medium risk to the particular receptor.
- (H) This symbol indicates a high risk to the particular receptor and needs to be managed.

The aspects noted as M and H were further investigated to include management recommendations in Volume 2.

Table 6.3.1(b): Qualified risks in terms of the agricultural use of sludge

Characteristics		Crops	Livestock	Public	Farm Workers	Soil diversity/ biota	Run-off to Surface water	Groundwater
Organic material		B	B	na	na	B	H	H
Nutrients (N,P,K, Ca, Mg)		B	B	na	na	B	H	H
Macro-elements (Na, Cl)		L	L	L	L	L	L	L
Metals	Beneficial micro- elements (Zn, Cu, Co, Se)	B	B	B	na	B	H	L
	Other metals	H	H	H	L	H	H	L
Organic pollutants		H	H	H	L	H	H	H
Pathogens		L	H	H	H	B	H	L
Odour and vector attraction		na	H	H	H	na	na	na
(B)		Beneficial effect. The effect can either be directly or indirectly.						
(na)		Not applicable						
(L)		This symbol indicates a low risk to the particular receptor.						
(M)		This symbol indicates a medium risk to the particular receptor.						
(H)		This symbol indicates a high risk to the particular receptor and needs to be managed.						

6.4 Proposed management criteria to reduce risks

Possible negative effects can be avoided by either:

- (1) Treating the sludge (elimination of the contaminant in the sludge/source); and/or
- (2) Preventing the contaminant from reaching the receptor by breaking the pathway between the source and the receptor.

All the risks identified as "H" in Table 6.3.1(b) can be reduced to an acceptable risk level by applying these management principles.

6.4.1 Organic material

Organic material is one of the beneficial characteristics of sludge and can be used as a soil conditioner. The improvement of the soil physical properties through the increase in organic carbon could play an important role in promoting the agricultural application of sewage sludge in the future in S.A. Generally, many soils in S.A. are low in organic matter due to rapid decomposition by micro organisms and the use of mineral fertilizers. This has led to the occurrence of widespread erosion and deterioration of soil physical status (Korentajer, 1991).

Organic material poses a risk to surface water due to run-off after accumulation in the topsoil and to groundwater because the decomposition of the organic material decreases the pH of the soil which can mobilise the metals in the soil. To manage this risk the following buffer zones can be introduced (taken from the 1997 guidelines):

- Maximum slope – 1:17
- Depth to aquifer – 2m
- Distance from dwelling - >200m
- Distance from surface water/borehole - >200m
- Soil pH >6.5

6.4.2 Nutrients

The nutrients (N, P and K) in sludge can be beneficial when added to soils (for plant uptake, livestock and soil biota). The risks associated with the nutrients are mainly due to N (P and K are bound by soil particles) contaminating surface and groundwater due to run-off and leaching. Nitrogen in sludge exists predominantly in an organically bound form. It must therefore first be transformed to inorganic forms by means of mineralisation prior to plant uptake. This means that the plant availability of N from sludge at any time is considerably lower than the N from commercial inorganic fertilizers. In certain situations the low rate of release of inorganic N from sludge could be a desirable feature, which may increase its availability. For example, when the efficiency of N fertilization is limited by factors such as high NO_3^- leaching losses or high volatilisation losses of NH_4^+ , the use of sludge as a slow release N material may decrease the N losses and increase N availability. It appears that sludge could also be used as a maintenance N fertilizer.

According to the previous guideline: Permissible Utilisation and Disposal of Sludge (WRC, 1997), the total amount of N in sludge that can become plant available is about 30% in the first year of application, 15% in the second year and 5% in the third year. Van Niekerk (2004) illustrated that the limit of 8 tons of dried sludge per hectare per year effectively protects the environment against the leaching of NO_3^- and results indicated that this could even be elevated to 20 tons of dried sludge per hectare per year. In a study done by Cripps et al. (1992) it was found that the mineralisation rate was 50% for the first year and 30% for the second year. Depending on the type of soil and type of sludge, the mineralisation rate of digested sludge can be 20-50% (Cripps et al., 1992). The true nutrient

quality of the sludge needs to be confirmed before each major planting season by determining the nitrogen, phosphorus and potassium concentration on at least four composite samples. Table 6.4.2 is illustrative of the typical nutrient load of South African sludge (assuming 3.2-4.5% total N, 1.5-1.7% total P and 0.2-0.3% total K).

Table 6.4.2: Typical nutrient loads at different application rates

Application rate	N application		P application		K application	
ton/ha/y	kg N/ha (Range)		kg P/ha (Range)		kg K/ha (Range)	
1	32	45	15	17	2	3
2	64	90	30	34	4	6
3	96	135	45	51	6	9
4	128	180	60	68	8	12
5	160	225	75	85	10	15
6	192	270	90	102	12	18
7	224	315	105	119	14	21
8	256	360	120	136	16	24
9	288	405	135	153	18	27
10	320	450	150	170	20	30
15	480	675	225	255	30	45
20	640	900	300	340	40	60

It is recommended that sludge be applied at an appropriate rate to satisfy the nutrient requirements of a specific crop and yield required (calculated on a crop basis) with the following limitations:

- (1) An absolute maximum load of **10 ton/ha/year** should not be exceeded for the first year and thereafter a sliding scale of maximum application should be implemented. At this rate, 320 kg of N is added per hectare per year which will deliver between 96 and 160 kg N/ha in the first year

Note: There may be cases where the maximum rate of 10 tonnes per hectare per year may not be sufficient for a specific crop's production. For these cases, a motivation supported by scientific proof can be submitted to the Department of Water Affairs and Forestry for consideration. Remember that the Pollutant class restrictions (Metal limits) may need to be adapted when the sludge is applied at rates higher than 10 tonnes per hectare per year

- (2) A monitoring programme should be adopted. (This is discussed in detail in: Specific requirements and restrictions for agricultural use of different sludge classes. Section 6.4.8 of this document)
- (3) An appropriate buffer zone between the source and receptor should be adopted. (This is discussed in detail in: Specific requirements and restrictions for agricultural use of different sludge classes. Section 6.4.8 of this document)

- (4) Soil properties (clay content and pH) for soil should be specified. If the agricultural use of sludge is considered on soil with clay content or pH below this limit, a specific site risk assessment investigation will need to be done and approval from the authorities will be required. (This is discussed in detail in: Specific requirements and restrictions for agricultural use of different sludge classes. Section 6.4.8 of this document)
- (5) A minimum groundwater level below the soil surface should be adopted.

6.4.3 Macro-elements (Na, Cl)

Results of WRC project K5/1209: "An evaluation of dedicated land disposal practices for sewage sludge" indicated that there is no accumulation of these elements in the soil profile, probably because it is present in low concentrations in the sludge. The concentrations of these elements were also present within acceptable levels in the groundwater samples. Therefore it was concluded that these elements have a low risk to all receptors.

6.4.4 Metals

The difference between beneficial micro-elements (Zn, Cu, Co and Se) and other metals should be stressed. According to research done by the ARC (Herselman & Steyn, 2001; Herselman, Steyn & Fey, 2005), the baseline concentrations of the beneficial micro-elements in South African soils are low (most soils have deficient levels for plant requirements) and therefore sludge could be used to increase these elements in the soil for plant uptake. Since these elements accumulate in the topsoil, it poses a high risk to surface water due to run-off. This risk can be managed by adopting an appropriate buffer zone between the source and receptor. Extensive research done by the ARC and WRC indicate that the risk for groundwater pollution is low since these elements are strongly adsorbed onto soil particles and not mobile in the soil profile below a depth of 300mm (Herselman, 1998; Herselman & du Preez, 2000; Herselman, Wade, Steyn & Snyman, 2005).

The other metals, both phytotoxic (Cr, Ni, As and B) and zoo-toxic (Cd, Hg, Mo, Pb and F), pose a higher risk to the environment (crops, livestock, public, soil biota and surface water) due to plant uptake (food chain contamination) as well as accumulation in the topsoil. The risk for groundwater pollution by these metals is low for the same reasons as for the beneficial micro-elements. The risks could be managed by setting the following limitations:

- (1) Adopt ceiling limits for soil and sludge in the agricultural use of sludge.
- (2) Determine the metal concentrations of sludge and soil before the application of sludge starts. If sludge is already applied (for agricultural purposes), the metal constituents in the soil should be regarded as the background values.
- (3) An application for a 5-year period should then be submitted to the relevant authority based on the status quo soil and sludge metal concentration.

- (4) A monitoring programme should be adopted.
- (5) An appropriate buffer zone between the source and receptor should be adopted.

The application will therefore typically include information such as:

- (1) Contact details
- (2) Metal concentrations of the soil
- (3) Metal concentration in the sludge
- (4) Soil properties (type, pH, clay content)
- (5) Crop to be used and yield expectations
- (6) Anticipated sludge loading rates and frequency
- (7) Monitoring plan
- (8) Storage methods
- (9) Application rate and method

Various extraction methods exist for the determination of metals in soils and sludge, both total and available (Table 6.4.4). The EPA 3050 and *aqua regia* methods were compared in two WRC studies (Snyman, Herselman & Kasselman, 2004; Herselman, Wade, Steyn & Snyman, 2004) for the extraction of total metals in soils and sludge. Both these studies concluded that the two methods gave very similar results but *aqua regia* is the best method for the determination of the total metal pool in sludge and soil since the results were more reliable (replicates were better for *aqua regia* than for EPA 3050). Methods need to be standardised in order to prevent confusion on metal concentrations and limits as were experienced in the previous guidelines.

In principle the *aqua regia* extraction method entails the extraction of a dried sludge sample with a hydrochloric/nitric acid mixture by standing for 16 hours at room temperature, followed by boiling under reflux for 2 h. The extract is then clarified and made up to a volume with nitric acid. The trace metal content of the extract can be determined using an appropriate analytical method. This extraction method was chosen because it's effective, reliable and all chemicals and apparatus are generally available. A full element analysis is required in Volume 1 to determine which elements could be of concern. Benchmark metal values are set for all elements although only 8 metal limits are set for South African sludge. These were specifically chosen as these are typically the elements that might be of concern. However, the sludge produced at a specific wastewater treatment plant could be compromised by other elements due to unique circumstances. In cases where an additional element(s)

was identified, these also need to be included in the analyses for classification and monitoring. A 90% compliance is required to comply with the requirements of a Pollutant class.

Table 6.4.4: Extraction methods that could be used for sewage sludge analysis (adapted from Steyn, 1994)

These are total methods to determine the total loading of metals in sewage sludge	Method	Chemicals	Fraction extracted*	Advantages	Disadvantages
	EPA 3050	HNO ₃ H ₂ O ₂ Heated to 95°C on hotplate	Water soluble Exchangeable Organically bound Part of residual fraction	Applicable for most metals Chemicals are generally available and not extremely expensive Little interference from substrates	Residual fraction not extracted completely Non-uniform digestion because of uneven temperature rises on hotplate
	EPA 3052	HNO ₃ H ₂ O ₂ Microwave digestion	Water soluble Exchangeable Organically bound Part of residual fraction	Applicable for most metals Chemicals are generally available and not extremely expensive Little interference from substrates	Residual fraction not extracted completely Special microwave oven needed, expensive
	Aqua regia	HNO ₃ HCl Heated on hotplate	Water soluble Exchangeable Part of residual fraction	Applicable for most metals Chemicals are generally available and not extremely expensive	Organically bound fraction not extracted The Cl may cause interference with Se, As and V on ICP-MS
	Digestion block method for organic material	HNO ₃ H ₂ O ₂ Heated in digestion block	Water soluble Exchangeable Organically bound Part of residual fraction	Applicable for most metals Chemicals are generally available and not extremely expensive	Non-uniform digestion because of uneven temperature rises on block Volatilisation of certain metals (Mo, Hg)
Immediate pollution danger before application to soil	TCLP	HNO ₃ HCl NaOH Acetic acid Distilled water	Water soluble Easily exchangeable	Good method to use for dump sites where soil is left on top of the soil	Extracts only a small part of the available fraction Procedure is relatively complicated, especially when solid and liquid phases need to be separated

*Different possible fractions

1. Water soluble (easily soluble)
2. Immediately exchangeable (easily exchangeable)
3. Exchangeable (non specifically adsorbed)
4. Organically bound
5. Residual fraction (PTMEs in the crystal structure of minerals and clays)

The specific ceiling limits for the sludge and soil were developed by the ARC-ISCW and derived from data compiled for various projects (Herselman & Steyn, 2001; Snyman, Herselman & Kasselmann, 2004; Herselman, Wade, Steyn & Snyman, 2005; Herselman, Steyn & Fey, 2005) and was also based on the EPA Part 503 Rule. The limiting concentrations for **inorganic pollutants in sludge** in Rule 503 were derived from separate risk assessments for agricultural land (14 pathways evaluated) and non-agricultural land (12 pathways evaluated). The pollutant limits generated under both scenarios were compared and the lower of the two used to create the pollutant limits for land-applied use, regardless of the end use and were adopted by the project team as the metal limits for Pollutant class a sludge. The metal limits for Pollutant class c sludge were also adopted from Rule 503, which are the 99th percentile concentrations of the National Sewage Sludge Survey (NSSS). To estimate the human health risk from exposure to metal contaminated soil, an international accepted model (RISC₄ Workbench, 2001) were used. The risk to human health via vegetable ingestion as well as direct ingestion of soil was determined. The input parameters of the model are detailed in Table 6.4.4(a). It was assumed that all the metals are present in the sludge at acceptable levels (Pollutant class a sludge). The metal load in the soil was determined as if sludge is applied 20tons/ha/y for 20 years and that all the added metals will be available for plant uptake (no adsorption by soil particles) (Table 6.4.4(b)). The risk analyses indicate that the carcinogenic risk after ingestion of vegetables and direct soil ingestion of both adults and children is within the acceptable range (Table 6.4.4(c)). The hazard quotients for both receptors and exposure routes are <1. If a Pollutant class c sludge is applied to soil at the same rate, the carcinogenic risk for adults and for children (for both exposure routes) are still within the acceptable levels and the hazard quotients for both receptors and exposure routes are <1. These results indicate that the receptors are protected.

Table 6.4.4(a): Human health risk input parameters

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

The **benchmark values** of typical South African sludge values were derived from the WRC funded project (K5/1283): 'A metal content survey of South African sewage sludge and an evaluation of analytical methods for their determination' (Snyman, Herselman & Kasselmann, 2004). The quality of sludge samples assigned a Pollutant class a falls in the top 20% in terms of metal quality. Similarly, if the sludge samples have been assigned a Pollutant class c, the sludge quality falls in the bottom 20% in terms of metal quality. This means that compared to the average metal content in South African sludges, your sludge samples show very high metals and this should be investigated. The

classification should be based on the average result of the three collected samples analysed according to recommended methods (Table 1 in Volume I - Part 5).

Table 6.4.4(b): Metal content of soil after 20 years of sludge application (no attenuation)

Metal	Pollutant class a metal limit	Metal content of soil after 20t/ha for 20 years	Pollutant class c metal limit	Metal content of soil after 20t/ha for 20 years
As	40	4.1	75	7.7
Cd	40	4.1	85	8.7
Cr	1200	123.1	3000	307.7
Cu	1500	153.9	4300	441
Pb	300	30.8	840	86.2
Hg	15	1.54	55	5.6
Ni	420	43.1	420	43.1
Zn	2800	287.2	7500	769.2

Table 6.4.4(c): Risk analysis of Pollutant class a and c sludge to adults and children after 20 years of sludge application

		Adults		Children	
	Risk type	Vegetable ingestion	Direct soil ingestion	Vegetable ingestion	Direct soil ingestion
Pollutant class a sludge	Carcinogenic risk (As)	$1.4:10^5$	$5:10^8$	$2.1:10^6$	$1.1:10^6$
	Hazard Quotients	<1	<1	<1	<1
Pollutant class c sludge	Carcinogenic risk (As)	$2.7:10^6$	$9.4:10^8$	$4.1:10^6$	$2.1:10^6$
	Hazard Quotients	<1	<1	<1	<1

In formulating recommendations for an improved set of guidelines for **maximum permissible limits of metals in soil**, account was taken of natural background levels as well as the degree to which current guidelines are unrealistic in the context of new local data. The upper limit of the baseline concentration suggests that the 1991 South African guidelines are fairly realistic and could be used as total investigation levels above which sludge application to the soil is permitted with monitoring, except for Ni which could safely be raised to 50 mg kg^{-1} . New **total maximum thresholds** (Table 6.4.4(d)) are proposed where the existing levels have been adjusted to bring them into line with the maximum expected natural concentrations, taking into account overseas norms. This should better accommodate geochemical reality. If the total metal content of the soil exceed this maximum threshold level, then sludge application is not permissible. These maximum threshold levels were used as input into RISC Workbench (same input parameters as before) and the results (Table 6.4.4(e)) indicated that the receptors are still protected, even at these maximum concentrations at 20t/ha/year for 20 years..

Table 6.4.4(d): New limits for metals in soils (mg kg⁻¹)

Total investigative level [#] (TIL)		Total maximum threshold [#] (TMT)	Maximum available threshold* (MAT)
Cd	2	3	0.1
Cr	80	350	0.1
Ni	50	150	1.2
Pb	56	100	3.5
Zn	185	200	5.0
Cu	100	120	1.2
Hg	0.5	1	0.007
As	2	2	0.014
Compliance criteria			
	90% compliance	Samples not allowed to exceed these values	Samples not allowed to exceed these values

[#] - Total digestion method (*Aqua regia*)* - NH₄NO₃ extraction method

Table 6.4.4(e): Risk analysis of the total maximum threshold metal limit

		Adults		Children	
	Risk type	Vegetable ingestion	Direct soil ingestion	Vegetable ingestion	Direct soil ingestion
Pollutant class a sludge	Carcinogenic risk (As)	6.8:10 ⁷	2.4:10 ⁸	1:10 ⁶	5.5:10 ⁷
	Hazard Quotients	<1	<1	<1	<1

Since the available fractions of these metals are very low, the need arose to investigate the possibilities of adopting metal limits based on the available metal fraction in the soil. Prüß *et al.* (1997) published such acceptable maximum concentrations of metals in NH₄NO₃ extracts for the assessment of polluted soils. These concentrations were based on correlations between elemental concentrations in soil extracts and elemental concentrations in plants grown on the corresponding soils, and since they were established to protect the environment (humans, soil, plants and water), they could be adopted for South Africa for the interim until further research proof otherwise. By introducing this **maximum available threshold** (MAT) level for soils (Table 6.4.4(d)) it could be ensured that the available metal concentration in soils stays below toxic levels and that leaching into the groundwater will not occur.

A schematic presentation of the system to be followed for sludge application on agricultural land is represented in Figure 6.4.4(a). Protocols on sampling methods and sample preparation form part of the guideline documents. The first step will be to analyse (after *aqua regia* digestion) and **classify the**

sludge to be used for agricultural application. If the Pollutant class of the sludge qualifies for unrestricted use (total metal content $\leq$ unrestricted use guideline, Pollutant class **a**), the sludge may be used unrestricted in terms of its Pollutant class, irrespective of the soil metal content. Agricultural use of the sludge is not permissible if the total metal content of the sludge is higher than the total maximum permitted concentration (Pollutant class **c**), irrespective of the soil metal content. Sludges classified as Pollutant class **b** (total metal content $>$ unrestricted use guideline and $<$ total maximum permitted concentration) may only be used once the soil metal content is determined.

The first step for **soil analysis** is the determination of the **total metal content** of the soil (*aqua regia* method). If the total metal content of the soil is below the total investigation level (TIL; Table 6.4.4(d)), the soil may be used for agricultural sludge application with 5-year monitoring intervals to ensure that the total soil metal content stays below the investigation level. Sludge application is not permissible on soils with total metal content higher than the total maximum threshold (TMT) level. Soils with a total metal content between the TIL and the TMT have to be analysed for their **available metal content** with the NH_4NO_3 extraction method. If the available metal content of the soil is higher than the maximum available threshold level then the soil may not be used for sludge application. In cases where the available metal content of the soil is lower than the MAT, the soil may be used for agricultural sludge application with monitoring every two years. Both total and available metal contents of the soil should be determined during the monitoring phase. If either of these results exceeds the TMT or MAT, the application should be terminated.



Figure 6.4.4: Schematic presentation of the system to be flowed for agricultural application of sludge

6.4.5 Organic pollutants

The organic pollutants in sludge could potentially pose a high risk to many receptors (Table 6.4.1(b)). The WRC funded research project entitled: "Methodology and survey of organic pollutants in South African sludges (K5/1339)" included the screening of sludge samples to determine the existence of the most persistent organic pollutants. The preliminary findings indicate that pesticides are not the main pollutants in the sludge. Phenols and Poly Aromatic Hydrocarbons (PAHs) are compounds that require further quantitative studies. The phenols are p-cresol and nonylphenols while the PAHs are acenaphthene, phenanthrene, fluorene, fluoranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene and indeno(1,2,3-c,d)pyrene. No organic pollutant ceiling limits were developed for the agricultural application of sludge but it is recommended that action should be taken if the sum of the PAHs is $> 6\text{mg/kg}$.

If the sum of PAHs in the sludge are $>6\text{mg/kg}$ and sludge is applied at 20tons/ha/y the concentration in the soil after 20 years is 0.615mg/kg . To estimate the human health risk from exposure to PAH contaminated soil, RISC Workbench were used. The risk to human health via vegetable ingestion and direct soil ingestion was determined. The input parameters are detailed in Table 6.4.4(a). The risk analyses indicate that, if all the PAHs are present in the soil at a concentration of 0.6mg/kg each, the carcinogenic risk for adults and for children (both exposure routes) is within the acceptable range. The hazard quotients for both receptors are <1 . Even at PAH concentrations of 6mg/kg in the soil (no dilution effect) the carcinogenic risk are within the acceptable levels and the hazard quotients for both receptors are <1 . This low risk is due to the adsorption of the organic pollutants by the soil organic material, rendering it immobile and unavailable for plant uptake.

Note that for the purposes of **domestic sludge** used in agricultural practices, the routine analysis of organic pollutants in sludge is not required. This decision was based on the fact that, apart from one local research project; we do not have enough information to justify routine organic analyses that are often costly. It is therefore recommended that the monitoring of organic pollutants be omitted from volume 2 of the sludge guidelines.

Table 6.4.5(f): Risk analysis of PAHs (No attenuation)

	Risk type	Adults		Children	
		Vegetable ingestion	Direct soil ingestion	Vegetable ingestion	Direct soil ingestion
PAH concentration in soil = 0.615mg/kg	Carcinogenic risk	$1.9:10^7$	$4.2:10^5$	$2.7:10^7$	$9.6:10^7$
	Hazard Quotients	<1	<1	<1	<1
PAH concentration in soil = 6mg/kg	Carcinogenic risk	$1.9:10^6$	$4.2:10^7$	$2.7:10^6$	$9.6:10^6$
	Hazard Quotients	<1	<1	<1	<1

6.4.6 Pathogens

While the value of sludge use in agriculture is clearly understood, in South Africa, the potential persistence of microorganisms in agricultural soil has not been fully investigated. Studies done elsewhere on different crops have indicated the contamination of fruits and vegetables following irrigation with sewage sludge or wastewater (Chale-Matsau, 2004).

Measures to reduce pathogen load in sludge such as composting are not always successful in completely inactivating these microorganisms from sludge. For instance, *Salmonella* spp and *E.coli* can survive the composting process and then regrow in soil following amendment. As the regrowth potential is affected by a number of different inherent and environmental factors the regrowth of pathogens appears difficult to predict. It has been reported that *E.coli* survived for more than a year in a non-aerated manure pile that was exposed to environmental conditions, and it was pointed out that this organism is capable of surviving for four months in soil. *Salmonella* spp may survive over one year in slurry and may still be isolated in soil for up to 20 weeks following application to land. It has been shown that even processed sewage sludge still contains considerable proportions of viral, bacterial, protozoan and helminthic agents of disease (Chale-Matsau, 2004).

One of the major routes of exposure to sludge is by ingestion, although other routes such as respiratory and ocular routes can be involved. If untreated or inadequately treated sewage sludge is used in the production of food crops, particularly those that are eaten raw, a chance of exposure to pathogenic microorganisms through ingestion exists. In South Africa, most studies on sewage sludge focused on the effects of nutrients and heavy metals. The effects of sewage sludge-borne microorganisms have not been studied in detail.

Recent research in South Africa

Research done by Chale-Matsau (2004) in South Africa showed that pots amended with high metal sludge (HMS) at 8 tons/ha, had fewer faecal coliform organisms than the pots amended with HMS at 16 tons/ha and that these organisms were not detected from week eight until the end of the experiment. An increase of faecal coliforms observed in both the 8 and 16 tons/ha pots up until week six was probably due to sufficient food and moisture as these pots were watered regularly. There was a significant reduction in the number of organisms after week six. The organisms in the soil that received a dose of 16 tons/ha showed complete die-off after week ten.

The low metal sludge (LMS) treatment showed persistence of Faecal coliforms throughout the duration of the experiment, although a decline was observed in weeks eight and ten for both 8 tons/ha and 16 tons/ha. The greatest survival of organisms was observed with LMS 16 tons/ha. In this treatment, although a decline in weeks eight and ten was noted, by the twelfth week, both faecal coliforms and *E. coli* had increased when compared to their initial values (week = 0) at the onset of the experiment. This could probably be due to out competition of some microorganisms over others. *E. coli* were detected throughout the study period with the exception of the LMS8 samples taken in week 6.

It appears that doubling the concentration of sludge (from 8 to 16 tons/ha) in the soil did not yield a large number of microorganisms from these pots. Instead, in some weeks there were more organisms in the 8 tons/ha than in the 16 tons/ha. For instance, the number of *E.coli* counted in LMS 8 tons/ha for weeks two, eight and ten were more than those counted in samples from pots containing LMS 16 tons/ha. However, the number of *E.coli* for LMS 16 tons/ha samples in the twelfth week were higher than those counted in the LMS 8 tons/ha samples. In South Africa guidelines for use of sewage sludge require that the application rate should not exceed 8 tons/ha (WRC, 1997). Despite a decline in the number of microorganisms from the time of planting (time zero) to the harvest time (twelfth week), there was a clear persistence of bacteria studied.

In this study it was shown that microorganism can persist for a period of three months in soil amended with sewage sludge and thus may be a source of pre-harvest contamination of food crops growing in the field. In some countries such as the United States, sewage sludge is allowed to stand for up to three months before use to encourage bacterial die-off (EPA, 1999). Although counts were minimal by the twelfth week (at harvest), it is likely that microorganisms will prevail in soil for a period well exceeding duration of the three months period. None of the microorganisms tested were detected in the potato core. However, Faecal coliforms and *E.coli* were detected on the potato peel at the end of the experiment, in the treatment LMS at 16 tons/ha.

The persistence of *Salmonella* spp throughout the experiment suggests their prolonged survival in soil. *Salmonella* spp have been indicated by other researchers as surviving in soil for a long period. For instance Strauch (1991) has reported that *Salmonella* spp could survive on and in the soil after a single application of sludge in summer for 424 to 820 days, and in winter the survival times were reported to be 104 to 350 days.

Other than at zero time and in the fourth week, there appeared to be no *Ascaris* detected in the soil sampled. Most *Ascaris* were found in samples collected in the fourth week. For instance, a total of four (4) *Ascaris* were counted in LMS 16 tons/ha samples.

It has been shown that *Ascaris* and microorganisms studied, namely faecal coliforms, *E.coli* and *Salmonella* spp will survive in soil for 3 months following a single application of sludge at planting. The presence of *E.coli* and Faecal coliforms on the potato peel indicates that use of untreated sewage sludge for growing vegetables that come into contact with soil could be potentially hazardous to public health.

Although there is a clear distinction between the LMS and HMS, there does not appear to be any appreciable difference in terms of the numbers of microorganisms between the two concentrations (8 tons/ha and 16 tons/ha) explored. It appears that doubling the application rate from the 8 tons/ha to 16 tons/ha does not significantly affect the persistence of microorganisms. The high metal sludge at an application rate of 8 tons/ha, had a quicker die off (week eight) of microorganisms. Generally microorganisms do not thrive in high metal sludge probably due to inhibition caused by these metals (Tsai and Olson, 1990).

Due to the presence of potentially dangerous pathogens in the sewage sludge, it is recommended that sewage sludge need to be adequately decontaminated prior to use in agricultural land if sewage sludge is to be used for soil amendment when growing crops meant for human consumption.

International findings

The agricultural or aquacultural use of excreta and wastewater can only result in an actual risk to public health if all of the following occur.

- (a) That either an infection dose of an excreted pathogen reaches the field or pond, or the pathogen multiplies in the field or pond to form an infective dose;
- (b) That this infective dose reaches a human host;
- (c) That this host becomes infected; and
- (d) That this infection causes disease or further transmission.

(a), (b) and (c) constitute the **potential risk** and (d) the **actual risk** to public health. If (d) does not occur, the risks to public health remain potential only. The sequence of events required for an actual health risk to be posed is illustrated in Figure 6.4.6 together with the pathogen - host properties and interactions that influence each step in the sequence. If the sequence is broken at any point, then the potential risks cannot combine to constitute an actual risk. This is the rationale behind the various methods of public health protection.

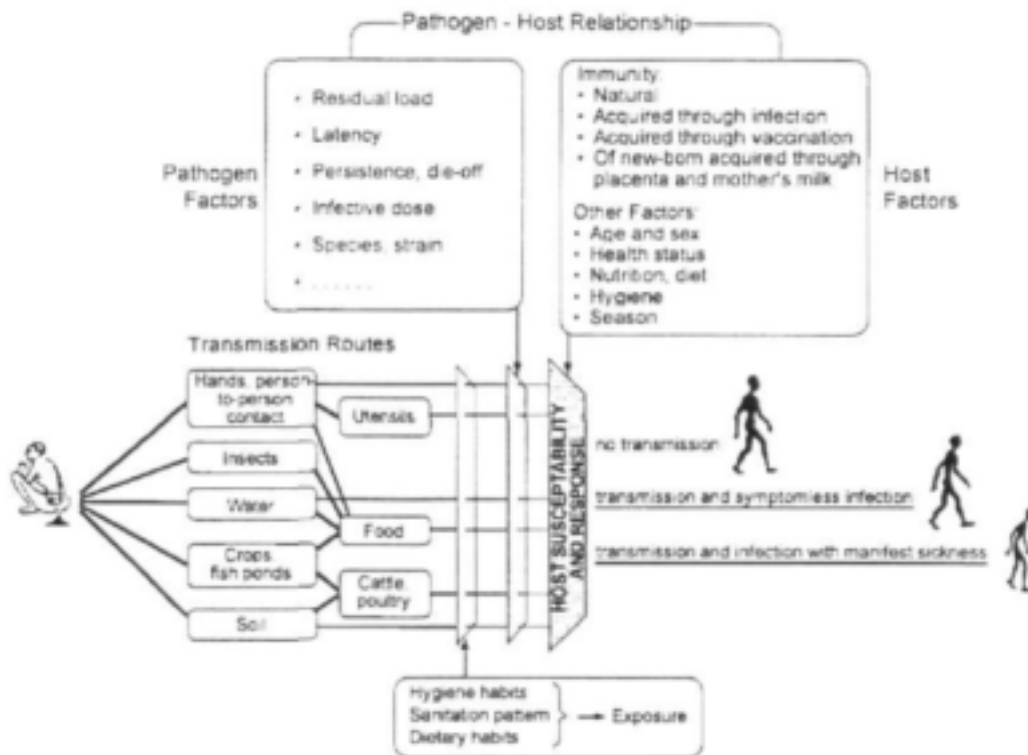


Figure 6.4.6: Pathogen-Host relationship for the transmission of excreta related infections from an infected to a new host

The actual risks to public health that occur through waste use can be divided into three broad categories - those affecting consumers of the crops grown with the waste (**consumer risk**), those affecting the agricultural and pond workers who are exposed to the waste (**workers', farmers' or fishermen's risk**), and those affecting populations living near to a waste reuse scheme (**nearby population risk**). Where nightsoil use and wastewater irrigation are unrestricted, so that all types of edible crops can be grown, then both consumer risk and worker risk are of interest. If use is restricted to certain crops, such as crops eaten cooked or processed, then this prevents the risk to consumers; in this situation, only the worker risk needs to be considered.

In wastewater reuse, the risks for farmers to contract gastro-intestinal infections (GI) is greatest when flood or furrow irrigation is practiced. The risks for consumers are greater, though, when the wastewater is applied by spray or sprinkler irrigation. For children under 15 years exposed to wastewater through work or play, the risk is always elevated. **Die-off or survival** of excreted pathogens is an important factor influencing transmission. In principle, all pathogens die off upon excretion. Prominent exceptions are pathogens whose intermediate stages multiply in intermediate hosts as the miracidia of e.g. *Clonorchis* or *Schistosoma* which multiply in aquatic snails and are later released into the water body. Some bacteria (Salmonellae, Shigellae and Campylobacter, e.g., have the potential to multiply outside the host predominantly on food and at warm temperature. The pathogens have varying resistance, and worms are among the more resistant with *Ascaris* surviving longest. The main factors influencing die-off are temperature, dryness and UV-light. Die-off rates increase in proportion to the level or intensity of these variables. Urea (H_2NCONH_2), ammonium bicarbonate (NH_4HCO_3) and carbamide ($\text{HNC}(\text{NH}_2)_2$) have also been found to enhance egg die-off in faecal sludges. Table 6.4.6(a) lists survival periods in faecal sludges for temperate and tropical climates.

Another important factor is the **infective dose** of a pathogen. It is the dose required to create disease in a human host. For helminths, protozoa (e.g. amoeba) and viruses, the infective dose is low ($< 10^2$). For bacteria, it is medium ($\approx 10^4$) to high ($> 10^6$).

Table 6.4.6(a): Pathogen survival periods in faecal sludge

Organism	Average Survival Time in Wet Faecal Sludge at Ambient Temperature ¹	
	In temperate climate	In tropical climate
Viruses	< 100	<20
Bacteria:		
Salmonellae	< 100	< 30
Cholera	< 30	< 5
Faecal coliforms ²	< 150	< 50
Protozoa:	< 30	< 15
Amoebic cysts	< 30	< 15
Helminths:		
Ascaris eggs	2 - 3 years	10 - 2 months
Tapeworm eggs	12 months	6 months

¹ When exposed to the drying sun, the survival periods are much shorter

² Faecal coliforms are commensal bacteria of the human intestines and used as indicator organisms for excreted pathogens

It is possible to design, implement or upgrade human waste use schemes that do not pose any risk to public health, but this requires an understanding of the occurrence of excreted infections in the area of concern, of the epidemiological or quantitative risk assessment in relation to the use practice and exposure patterns. In this way, sound and appropriate measures may be drawn up in a collaborative manner by the various stakeholders based on standards for the microbiological and parasitological quality of excreta and wastewater intended for reuse or based on appropriate measures to be implemented at critical control points (e.g. waste treatment or crop restriction) as suggested in the guidelines.

Summarising the evidence of transmission risks for excreted pathogens available to date, a relative ranking such as the one presented in Table 6.4.6(b) may be set up.

Table 6.4.6(b): Relative health risks form use of untreated excreta and wastewater in agriculture and aquaculture

Class of pathogen	Relative amount of excess frequency of infection or disease
1. Intestinal nematodes:	High
<i>Ascaris</i>	
<i>Trichuris</i>	
<i>Ancylostoma</i>	
<i>Necator</i>	
2. Bacterial infections:	Lower
Bacterial diarrhoeas (e.g. cholera, typhoid)	
3. Viral infections:	Least (but not insignificant under specific circumstances)
4. Trematode and cestode infections:	
Schistosomiasis	From high to nil, depending upon the particular excreta use practice and local circumstances
Chlonorchiasis	
Taeniasis	

Microbiological classification

Microbiological analysis is expensive and many wastewater laboratories are not equipped to perform complex microbiological analysis, but pathogens poses a high risk to livestock and the public as well as to surface water due to run-off. Table 6.4.6 recommends the monitoring of two indicator organisms, i.e., *Faecal coliforms* and helminth ova. These parameters were specifically selected since these have been used in the past and the wastewater industry is accustomed to these indicator organisms. In order to protect the receptors, certain restrictions must be placed on the use of class B sludge and strict restriction placed on the use of a class C sludge. It is recommended that no restrictions be applied to class A sludge. It is recommended that Table 2 of the 1997 sludge guidelines (WRC, 1997) be used as a starting point for these restrictions. The restrictions pertaining to the old Type A and B sludge will therefore apply to the new class C sludge.

Table 6.4.6: Determining the microbiological class

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

6.4.7 Odour and vector attraction

Odours and vectors pose a high risk to livestock and the public. Table 6.4.7 detail the compliance criteria for the different stability classes based on the US EPA Sludge rule (US EPA, 1993) and it was recommended that these criteria be adopted. It is recommended that no restrictions be applied to class A and B sludge, but that the agricultural use of a class C sludge be forbidden unless certain management criteria are met. class C sludge would typically include raw sludge and septic tank sludge. Although the treatment requirements for class A and B sludge do not disinfect the sludge completely, these processes often reduce pathogen numbers significantly adding a second buffer in the sludge guidelines. Allowing the application of raw sludge in agricultural practices will constitute an unacceptable risk to some receptors such as farm workers.

It is more important to constantly comply with a vector attraction reduction option, than the actual initial Stability class Classification. The stability class were specifically introduced in the sludge guidelines, as the potential to generate odours and attract vectors are potentially the aspects that influence public perception. It is important to confirm the classification at the start of implementing the management option addressed in this volume to avoid non-compliance once the monitoring programme starts. Realising shortcomings at that stage could be costly and unnecessarily expose the sludge producer.

Table 6.4.7: Determining the Stability class

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

6.4.8 Specific requirements and restrictions for agricultural use of different sludge classes

It is important to realise that all classes that permit agricultural use of sludge is equally protective of the environment and human health. However, the restrictions and management requirements increase with the decrease in class quality. For example, due to the presence of pathogens in Microbiological class C, this class may not be sold to the public for general use and the sludge producer and/or user need to have strict access control when this class is applied in order to protect the public adequately. Table 6.4.8(a) gives an overview of which sludge classes may be used for agricultural practices

Table 6.4.8(a): An overview of the permissible utilisation of sludge in agricultural applications

Note: Sludge that complies with all the requirements of class A1a may be sold or alienated to the public for unrestricted use.

South African Sludge Classification		Is agricultural use an option?	Any additional restrictions and requirements?	Notes
Microbiological Class	A	Yes (i)	No	Could potentially be used as a saleable product
	B	Qualified yes (ii)	Yes	Crop restrictions and buffer zones apply (refer to Part 4)
	C	Maybe (iii)	Yes	Only permissible if Stability class 1 or 2 is achieved. Crop restrictions and buffer zones apply (refer to Part 4)
Stability Class	1	Yes (i)	No	Could potentially be used as a saleable product
	2	Qualified yes (ii)	Yes	Additional management systems may be required to encourage compliance with Class 1
	3	No (v)	Not applicable	Stability class 3 may not be used in agricultural practices
Pollutant Class	a	Yes (i)	No	Could potentially be used as a saleable product
	b	Qualified yes (ii)	Yes	If the soil analysis permits it
	c	No (v)	Not applicable	Pollutant class c may not be used in agricultural practices

Table 6.4.8(b): Examples of crops impacted by site restrictions

Harvested / edible parts that :		
Usually do not touch the soil/sludge mixture	Usually touch the soil/sludge mixture	Are below soil/sludge mixture
Fruit growing on trees like peaches, apples, oranges, grapefruit, grapes, bananas, pineapple, avocados. Grains like corn, wheat, oat, barley, cotton, soybeans.	Fruit and vegetables like melons, strawberries, eggplant, squash, tomatoes, cucumbers, celery, cabbage, lettuce, spinach.	Fruit and vegetables like potatoes, sweet potatoes, peanuts, onions, leeks, radishes, turnips, beets.

Microbiological class use restrictions

Microbiological class A: Restrictions for Agricultural Use

No restrictions and requirements apply.

Microbiological class B: Restrictions for Agricultural Use

Operators are encouraged to achieve a Microbiological class A classification to reach a "no restriction" status in terms of the Microbiological class.

The following crops may not be cultivated on soils amended with Microbiological class B sludge:

- Household vegetables consumed raw
- Household vegetables that touch or are below the soil/sludge mixture (see Table 8)

Management practices and site restrictions

- Crops whose edible parts that do not touch the soil/sludge mixture, shall not be harvested until 30 days after sludge application
- Crops with harvested parts that touch the soil/sludge mixture and are directly above the soil surface shall not be harvested until 14 months after sludge application
- Crops with harvested parts below the soil surface where:
 - Sludge remain on the surface for 4 months or longer before incorporation into the soil shall not be harvested until 20 months after sludge application
 - Sludge remain on the surface for less than 4 months before incorporation into the soil shall not be harvested until 38 months after sludge application
- Animals shall not be grazed on land until 30 days after sludge application
- Access to land with low public exposure (private farmland) is restricted for 30 days after sludge application

Microbiological class C: Restrictions for Agricultural Use

Only suitable for agricultural use if stability class 1 or 2 is achieved.

The following crops may not be cultivated on soils amended with Microbiological class C sludge:

- Household vegetables consumed raw
- Household vegetables that touch or are below the soil/sludge mixture (see Table 9)
- Household vegetables with harvested parts below the soil surface (see Table 9)

Management practices and site restrictions

- Crops whose edible parts do not touch the soil/sludge mixture, shall not be harvested until 90 days after sludge application
- Crops with harvested parts that touch the soil/sludge mixture and are directly above the soil surface shall not be harvested until 14 months after sludge application
- Animals shall not be grazed on land until 90 days after sludge application
- Access to land with low public exposure (private farmland) is restricted for 90 days after sludge application

Stability class use restrictions**Stability class 1**

No restrictions and requirements apply.

Stability class 2

Due to the reliability of the vector attraction reduction measures implemented, additional management systems might be required. The potential to generate odours and attract vectors are potentially the single most important aspects that influence public perception. It is more important to constantly comply with a vector attraction reduction option, than the actual initial Stability class classification.

Stability class 3

Not suitable for agricultural use. At least one vector attraction reduction option should be implemented.

Pollutant class use restrictions**Pollutant class a**

No restrictions and requirements apply.

Pollutant class b

Note that sludge that does not comply with a Pollutant class a can still be used in agricultural practices.

However, additional analyses will be required to assess whether the receiving soil can accommodate the load (Figure 6.4.4). The first step for soil analysis is the determination of the total metal content of the soil (*aqua regia* method). If the total metal content of the soil is below the total investigation level (TIL; Table 6.4.4(d)), the soil may be used for agricultural sludge application with 5-year monitoring intervals to ensure that the total soil metal content remain below the investigation level. Sludge application is not permissible on soils with total metal content higher than the total maximum threshold (TMT; Table 6.4.4(d)) level.

Soils with a total metal content between the TIL and the TMT (Figure 6.4.4) have to be analysed for their available metal content with the NH_4NO_3 extraction method. If the available metal content of the soil is higher than the maximum available threshold level then the soil may not be used for sludge application. In cases where the available metal content of the soil is lower than the MAT, the soil may be used for agricultural sludge application with monitoring every two years. Both total and available metal contents of the soil should be determined during the monitoring phase. If either of these results exceeds the TMT or MAT, the application should be terminated. Buffer zone restrictions apply as detailed in the Microbiological class B restrictions.

Pollutant class c

The sludge metal content is too high for agricultural use. Source control should be implemented to improve the Pollutant class classification.

6.5 General restrictions and requirements

Irrespective of the classification, certain restrictions apply for the agricultural application of sludge.

6.5.1 Restriction/Requirement 1: Sludge storage before agricultural use

It is recognised that not all sludge produced can be utilised immediately after production and treatment. Treated sludge destined for agricultural application must be stored in a properly designed facility that minimises the impact on the environment. Maximum storage period of 90 days is permissible and adequate precautions must be taken not to generate odours or attract vectors. If sludge is stored for periods longer than 90 days, the activity falls under the Minimum Requirements (1998) and will require a permit.

6.5.2 Restriction/Requirement 2: Sludge application rates

Sludge should be applied to land at rates that do not exceed those which are needed to supply required plant nutrients (agronomic rates). In addition, an application rate of **10 tonnes dry mass per hectare per year** may not be exceeded.

Note: There may be cases where the maximum rate of 10 tonnes per hectare per year may not be sufficient for a specific crop's production. For these cases, a motivation supported by scientific proof can be submitted to the Department of Water Affairs and Forestry for consideration. Remember that the Pollutant class restrictions (metal limits) may need to be adapted when the sludge is applied at rates higher than 10 tonnes per hectare per year.

The true nutrient quality of the sludge needs to be confirmed before each major planting season by determining the nitrogen, phosphorus and potassium concentration on at least four composite samples.

Table 6.4.2(a) is illustrative of the nutrient load of South African sludge (assuming 3.2-4.5% total N, 1.5-1.7% total P and 0.2-0.3% total K). Note that the nutrients are not immediately available, but is released slowly over time. For example, between 30 and 50 % of the nitrogen becomes available during the first year after application. At an application rate of 10 tonnes per hectare per year, 320 kg of N is added per hectare per year which will deliver between 96 and 160 kg N/ha in the first year.

6.5.3 Restriction/Requirement 3: Prevention of soil erosion

Topography (slope) influence the amount of soil erosion and potential run-off of applied sludge. The application method of sludge should not contribute to soil erosion. It is for this reason that maximum slope restrictions have been proposed. Minimum slope 1:17

Note: The slope restrictions may be relaxed on condition that no contaminated run-off and seepage water will pollute any surface or ground water as agreed with the Department of Water Affairs and Forestry.

6.5.4 Restriction, Requirement 4: Depth to groundwater/surface water

Buffer zones adopted from 1997 Guidelines

6.5.5 Restriction/Requirement 5: Distance from dwelling

Buffer zone adopted from 1997 Guidelines

6.5.6 Restriction/Requirement 6: Monitoring programme

A monitoring programme should be implemented to protect the different receptors. The amount of monitoring samples and the frequency of monitoring would be influenced by the sludge class that is applied to the soil.

Sludge monitoring programme

Sludge streams should be monitored to determine continuous compliance to the guidelines. The monitoring programme detailed in the EPA 503 Rule was recommended.

Table 6.5.4(a): Sludge monitoring and sampling for monitoring

What should be monitored?	Microbiological quality Physical characteristics Chemical characteristics		
	Amount of sludge produced (t dry weight)		Monitoring frequency
How often should samples be taken?	Daily average	Yearly average	
	<1	<365	Once per year
	1-5	365-1 825	4 times per year
	5-45	1 825-16 500	6 times per year
	>45	>16 500	Monthly
Type of samples	Grab samples for pathogens and composite samples for metals.		
How many samples should be taken?	At least 4 samples of each sludge stream disposed each time		
When to sample?	Before use or disposal		
Where to collect samples?	Anaerobic digested	Collect from taps on the discharge side of positive displacement pumps	
	Aerobic digested	Collect from taps on discharge lines from pumps	
	Thickened	Collect from taps on the discharge side of positive displacement pumps	
	Heat treated	Collect from taps on the discharge side of positive displacement pumps after decanting	
	Dewatered, dried, composted	Collect from material collection conveyors and bulk containers	
	Dewatered by belt filter press, centrifuge	Collect from discharge chute	
	Dewatered by sludge press	Collect from storage bin (combine 4 samples)	
	Dewatered by drying beds	Divide bed into quarters, sample from each quarter and combine samples	
	Compost piles	Collect from front-end loader while sludge are transported	
Sample sizes	At least 500g dry mass		
Analyses methods	See Appendix 4		

Soil monitoring programme

A soil monitoring programme is introduced for the agricultural use of sludge. Monitoring should be done in the following cases:

- Take soil samples from all agricultural fields and analyse to determine the fertilizer requirement for the particular crop to be cultivated to ensure sludge application at agronomical rates

For sites receiving **Pollutant class b** sludge:

- Soils which total metal content exceed the investigative level (TIL) but are lower than the total maximum level (TMT), with an available metal content below the maximum (NH_4NO_3) available threshold (MAT)
- Soils which total metal content (TMC) not yet exceed the total investigative level (TIL)

Table 6.5.4(b): Soil monitoring and sampling for monitoring

What should be monitored and how often?	Which soils to monitor	What to monitor	Frequency
	All agricultural fields receiving sludge	Soil nutrient content (N, P, K)	Yearly
	TMT > Total metal content > TIL and Max available threshold < MAT	Total and available metals	Every 2 years
	Total metal content < TIL	Total metals	Every 5 years
Type of samples	Composite samples of total area where sludge is applied		
How many samples should be taken?	At least 4 composite samples of each area where sludge is applied		
When to sample?	After planting season, before next sludge application		
How to sample?	Divide area into quarters, sample from each quarter (plough layer, 30cm) and combine samples.		
Sample sizes	1kg dry mass		
Analyses methods	See Appendix 4		

6.5.7 Restriction/Requirement 7: Record keeping

Once the applicable permits and licences have been granted the Sludge Guidelines essentially become self-regulatory. This means that certain records need to be kept by the sludge producer.

Note: The sludge user also have a responsibility to keep certain records for certain sludge classifications. It is however, not a general requirement for all sludge types. For example, the sludge user using class A1a sludge do not require any records.

Table 6.5.5 summarises the general record keeping requirements for the producer (irrespective of the class of sludge produced).

Table 6.5.5: Record keeping requirements for the sludge producer applying sludge to agricultural land

Nr	Description of records to be kept
	Sludge records
1	Mass, solids content and volume of each sludge stream produced and a supporting wastewater mass balance

Nr	Description of records to be kept
	Sludge records
2	Detail description of sludge management process
3	Classification of each sludge stream that leaves the plant
4	Results supporting classification in terms of the: • Microbiological class (Table 6.4.6) • Stability class (Table 6.4.7) • Pollutant class (Table 6.4.4)
5	The original or certified copy of the contract between the sludge producer and user (if applicable)
6	A copy of applicable permits and licences
7	Monitoring data pertaining to the: • Microbiological class (Table 6.4.6) • Stability class (Table 6.4.7) • Pollutant class (Table 6.4.4)
8	Operational problem register: It is recognised that no plant runs smoothly 100% of the time. Document any operational problems that could affect the sludge management by detailing: • The nature of the problem • Duration of the problem • What was done with off-spec sludge • How was the problem rectified
9	Complaints register (This includes complaints by the user as well as the public or other I&AP) which includes the: • Date, time, complainant • Nature of the complaint • A description of steps taken
Soil records	
	Monitoring data pertaining to the: • Nutrient status of the soil (N, P and K) • Metal content of the soil (total and/or NH_4NO_3 extractable) where applicable

7 CONCLUSION

This document details an extensive literature survey on South African and International sludge guidelines. The guidelines and management systems applied by the US, Europe, Australia, Mexico, Canada and New Zealand are included and compared to each other. The history of sludge management and legislation in South Africa is detailed and compared to that of the other countries.

The premise of the new South African sludge guidelines is also discussed extensively. New maximum permissible levels for microbiological constituent as well as metals are proposed for South Africa. Since the US EPA assessed the risks of land application of sludge to all receptors through all pathways and could as yet not find any evidence that they endanger the environment, many of these levels are taken from the US EPA Rule 503 and adapted for South Africa. These maximum permissible levels were fed into a risk assessment programme to determine what the risks will be for receptors in South Africa.

Comments of all workshops were included and served as the basis for this document as well the rest of the sludge guidelines.

8 RECOMMENDATIONS

The results of several South African studies on sludge (Kasselman, 2003; Herselman, Wade, Steyn & Snyman, 2004; Jaganyi, 2005) have indicated that the metals and organic pollutants in sludge is associated with the liquor phase. However, this could not yet be proven conclusively. It is recommended that dry sludge rather than wet sludge be used for agricultural purposes in order to ensure the safe production of foodstuffs and to limit ground- and surface water pollution.

It is also recommended that the sludge guidelines be reviewed every 5 years. To ease the review process, all the monitoring data from the sludge producers and sludge users should be kept in a database at the lead agent. These data will then be available to interpret during the guideline review process.

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APPENDIX 1: INTERNATIONAL LIMITS FOR METALS IN SLUDGE

The international trends in total metal limits for application of sewage sludge on agricultural soil is presented in Figures A 1 (a to l). The figures represent the total metal limits for various countries. There are two values for South Africa; one originates from the Global Atlas (Matthews, 1996) while the other is from the 2002 Addendum (WRC, 2002). The Global Atlas (Matthews, 1996) value is indicated with an asterisk (*) on the y-axis and the bar is shaded grey. For some metals the Global Atlas had no value. The PUDSS Addendum value (WRC, 2002) is marked with an □ on the y-axis and the bar is white with black dots.

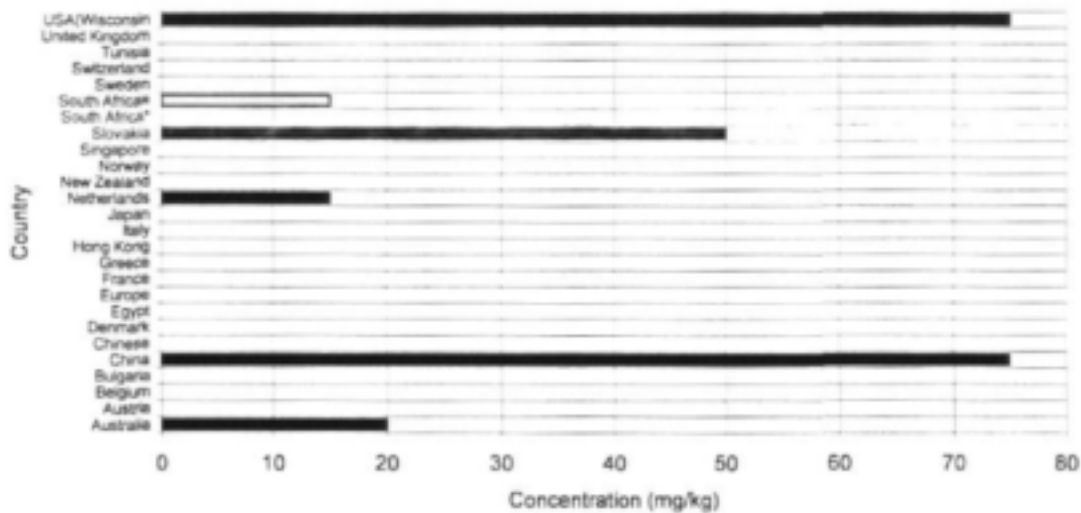


Figure A 1(A): International Arsenic limits for sewage sludge

* Global Atlas (Matthews, 1996)
 □ PUDSS Addendum 1 (WRC, 2002)

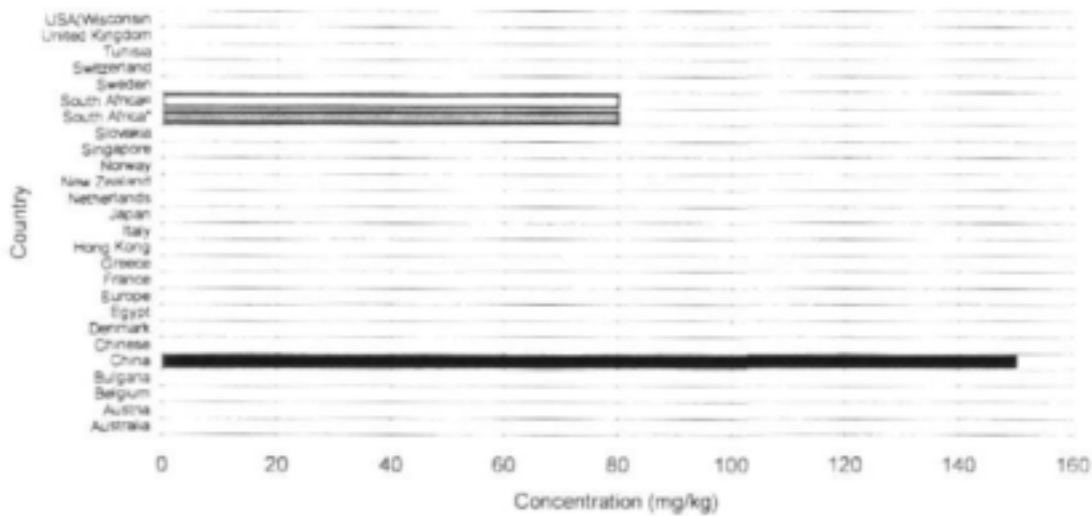


Figure A 1(B): International Boron limits for sewage sludge

* Global Atlas (Matthews, 1996)
 □ PUDSS Addendum 1 (WRC, 2002)

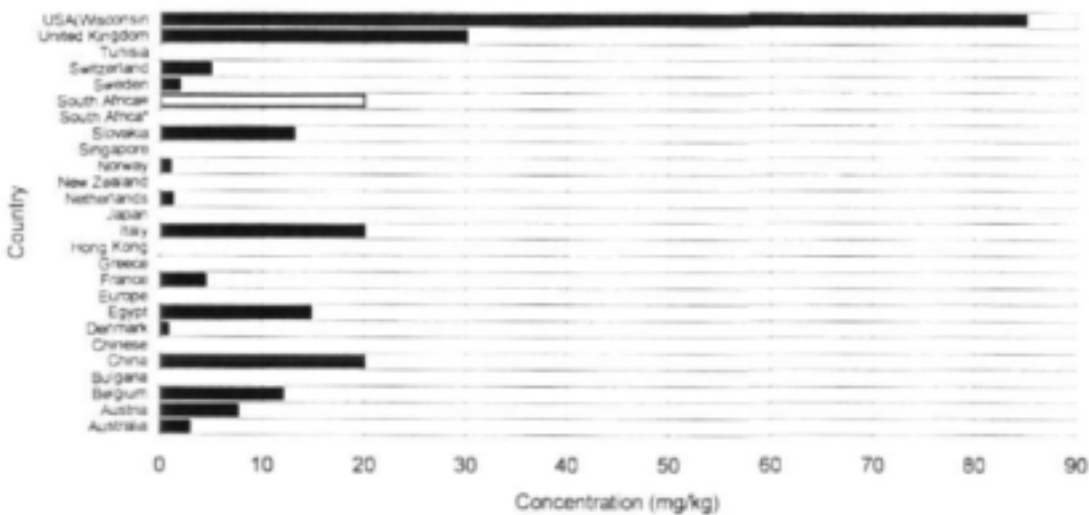


Figure A 1(C): International cadmium limits for sewage sludge

*Global Atlas (Matthews, 1996)

□ PUDSS Addendum 1 (WRC, 2002)

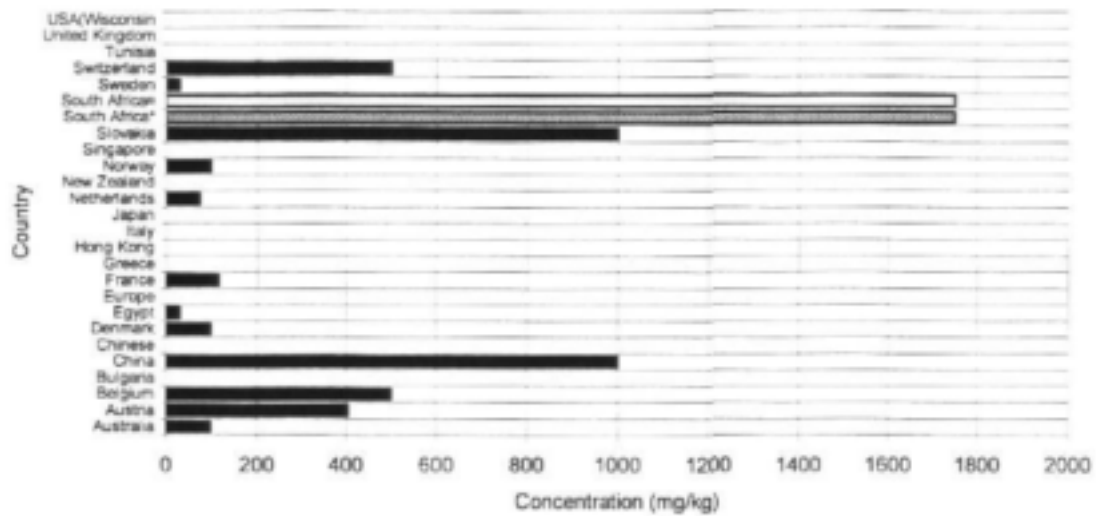


Figure A 1(D): International chromium limits for sewage sludge

* Global Atlas (Matthews, 1996)
 □ PUDSS Addendum 1 (WRC, 2002)

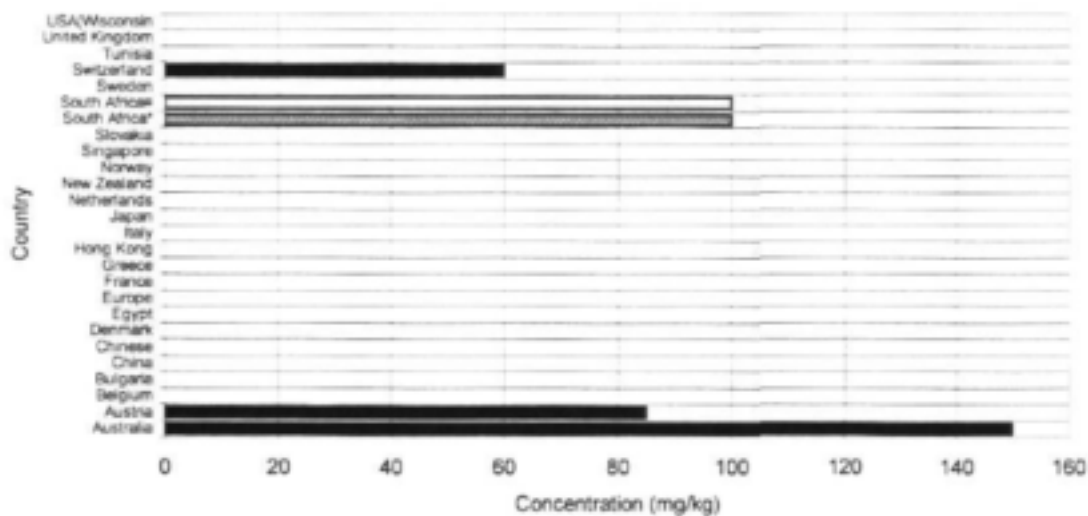


Figure A 1(E): International cobalt limits for sewage sludge

* Global Atlas (Matthews, 1996)

□ PUDSS Addendum 1 (WRC, 2002)

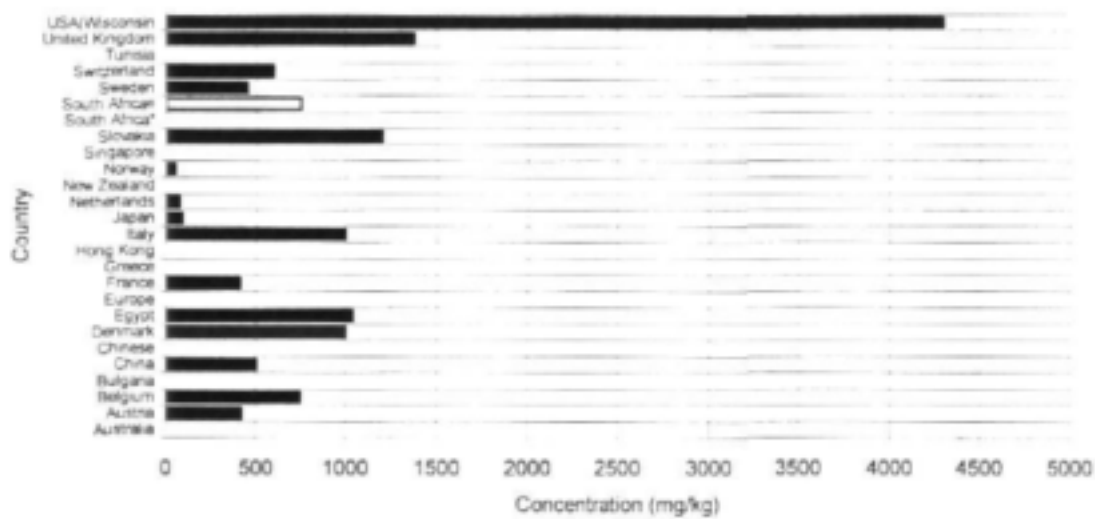


Figure A 1(F): International copper limits for sewage sludge

* Global Atlas (Matthews, 1996)
□ PUDSS Addendum 1 (WRC, 2002)

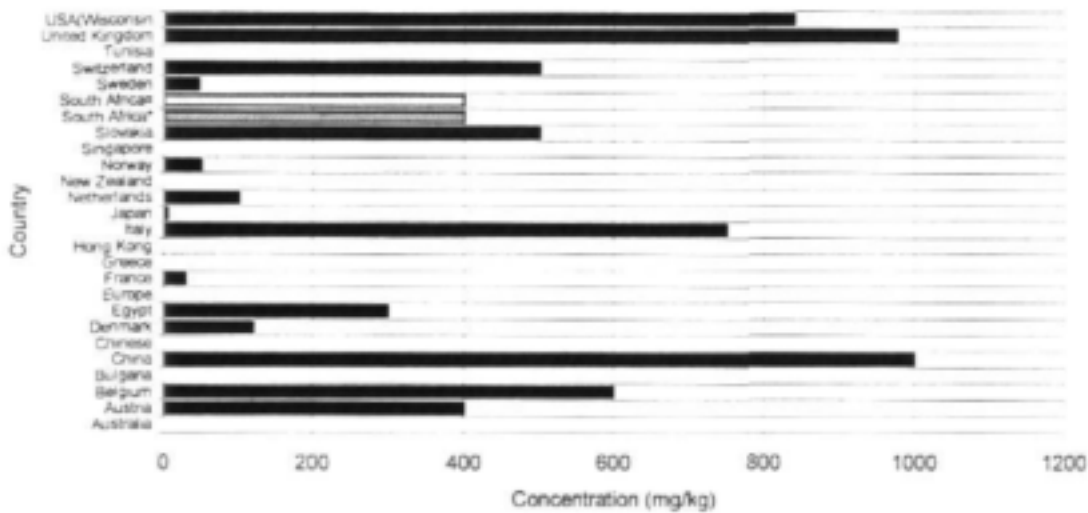


Figure A 1(G): International lead limits for sewage sludge

* Global Atlas (Matthews, 1996)
□ PUDSS Addendum 1 (WRC, 2002)

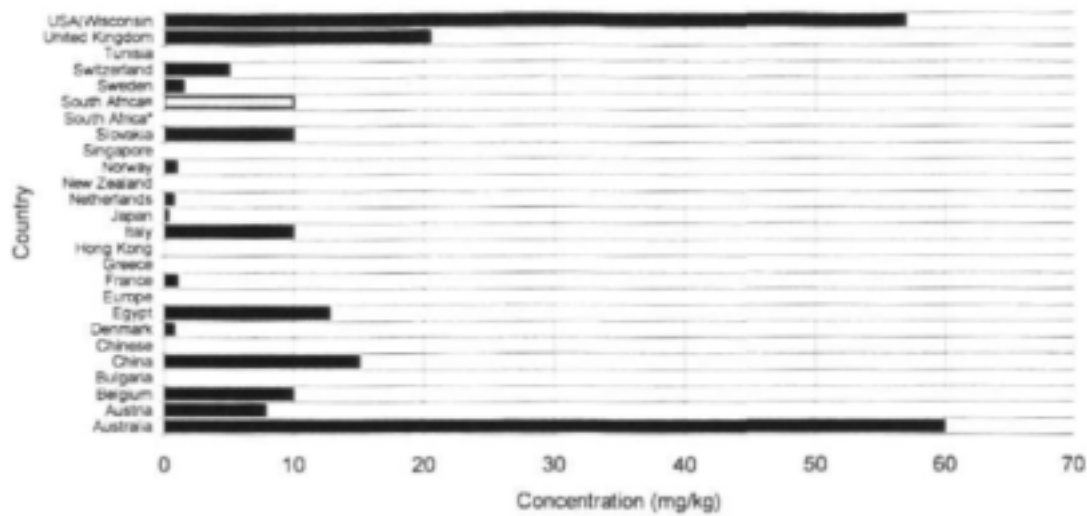


Figure A 1(H): International mercury limits for sewage sludge

* Global Atlas (Matthews, 1996)
 □ PUDSS Addendum 1 (WRC, 2002)

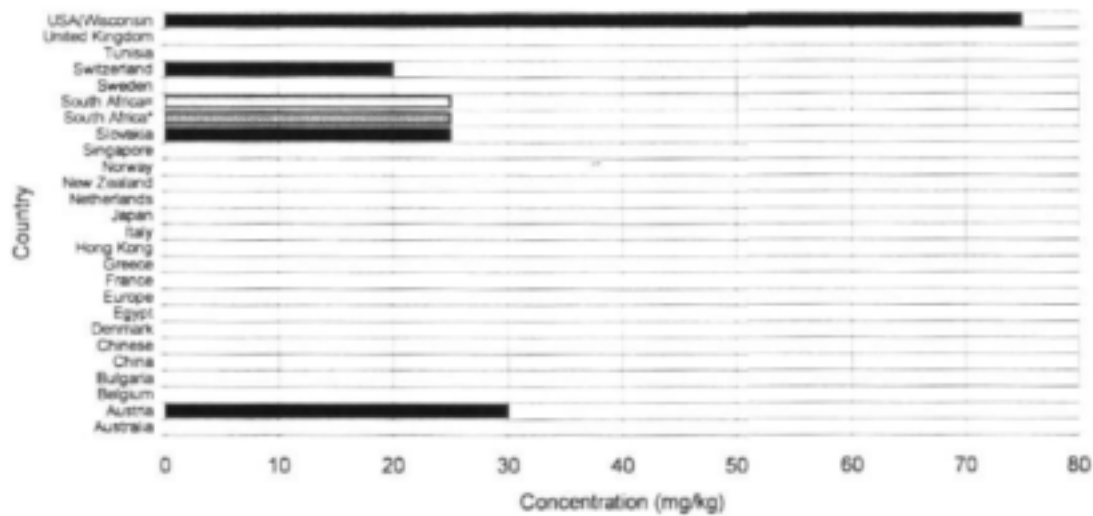


Figure A 1(I): International molybdenum limits for sewage sludge

* Global Atlas (Matthews, 1996)
 □ PUDSS Addendum 1 (WRC, 2002)

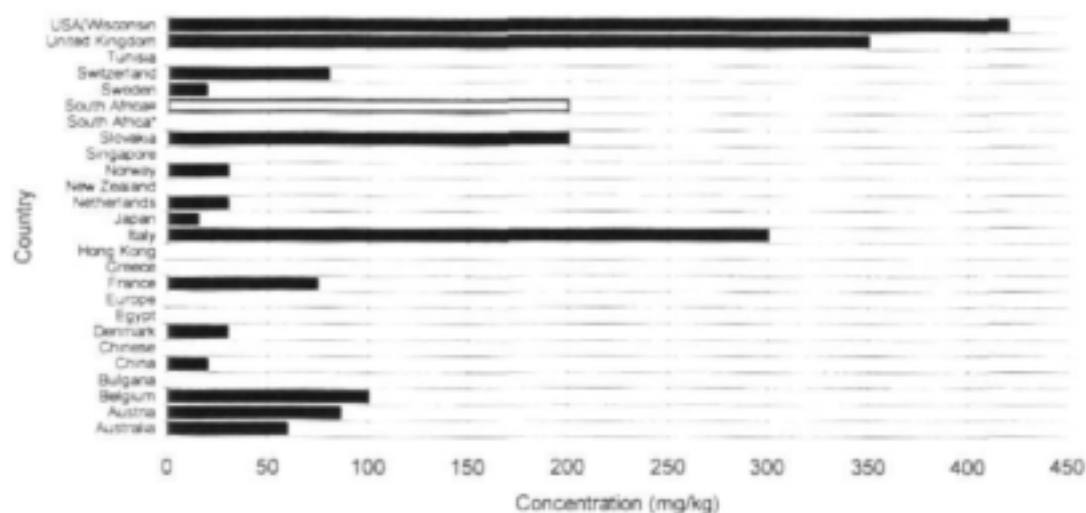


Figure A 1(J): International nickel limits for sewage sludge

* Global Atlas (Matthews, 1996)
 □ PUDSS Addendum 1 (WRC, 2002)

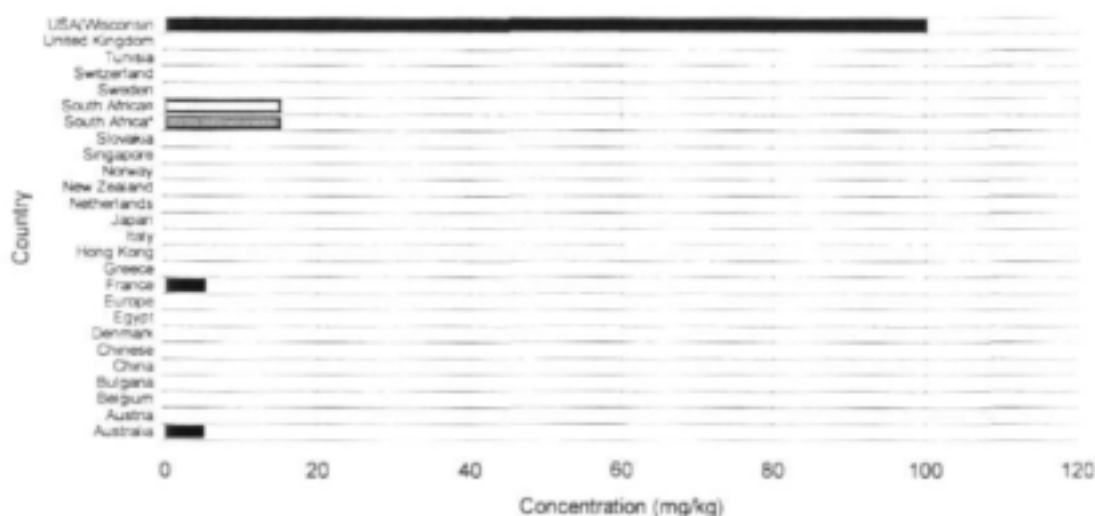


Figure A 1(K): International selenium limits for sewage sludge

* Global Atlas (Matthews, 1996)
 □ PUDSS Addendum 1 (WRC, 2002)

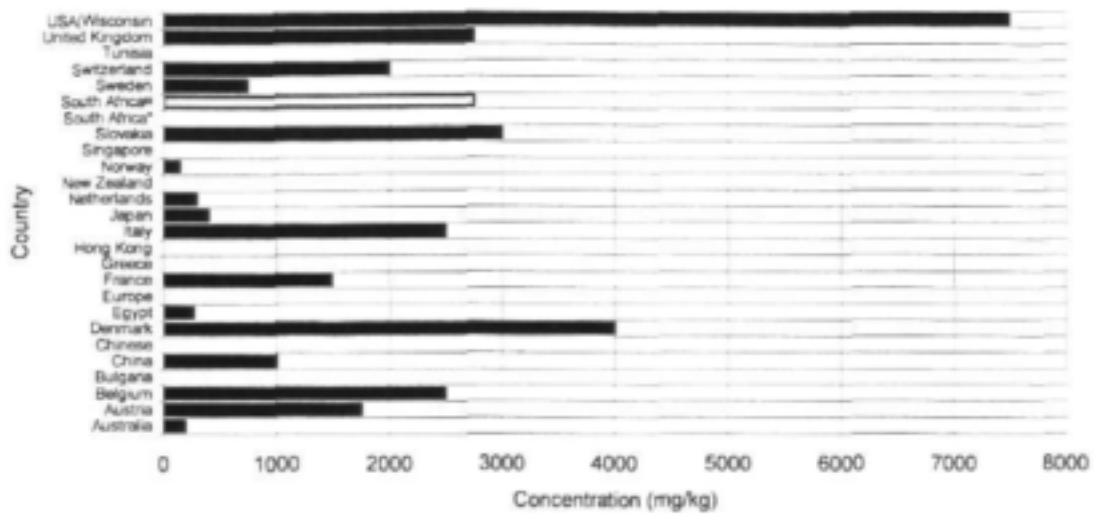


Figure A 1(L): International zinc limits for sewage sludge

* Global Atlas (Matthews, 1996)
 □ PUDSS Addendum 1 (WRC, 2002)

APPENDIX 2: TREATMENT PROCESSES CAPABLE OF RELIABLY REDUCING PATHOGENS TO LOW LEVELS

Table A2.1: Treatment grades based on treatment process, microbiological criteria and other suggested controls

Treatment Process	Associated controls
Treatment Grade T1 very low pathogen levels with minimum re-growth potential <u>Verification Monitoring</u> is based on <1 <i>Salmonella</i> /50 (dw) and <100 <i>E.coli</i> MPN/g (dw) with sampling undertaken immediately post treatment process and of the final product. Verification of inhibition of pathogen re-growth is also required (4.2.1). <u>Routine Monitoring</u> is based on <100 <i>E.coli</i> MPN/g (dw) with sampling undertaken of the final product (4.2.2).	
<u>Composting processes that simultaneously heat all material (e.g. invessel)</u> Temperature of all compost material to be maintained at $\geq 55^{\circ}\text{C}$ for ≥ 3 continuous days with process control as per AS-4454.	Relevant vector attraction reduction controls (refer Table 4) e.g. composted product to be matured for ≥ 30 days before use.
<u>Composting windrow method</u> Temperature of compost material maintained at $\geq 55^{\circ}\text{C}$ for ≥ 15 continuous days, including 5 tunings of the windrow. Process control as per AS-4454.	Relevant vector attraction reduction controls (refer Table 4) e.g. composted product to be matured for ≥ 30 days before use.
<u>High pH and high temperatures</u> Sludge pH raised to ≥ 12 for ≥ 72 continuous hours and during this period, maintained at $\geq 52^{\circ}\text{C}$ for ≥ 12 continuous hours. Final sludge product to be air-dried to a solids content of $\geq 50\%$.	Relevant vector attraction reduction controls (refer Table 4), e.g. alkali treatment and heating, final product to be kept dry ($\geq 90\%$ solids for unstabilised product), or for undigested products aeration in a windrow.
<u>Heating and drying</u> Sludge dried by heating particles to $\geq 80^{\circ}\text{C}$ to a final solids content of $\geq 90\%$.	Relevant vector attraction reduction controls (refer Table 4), e.g. final product to be kept dry ($\geq 90\%$ solids) until mixed with other materials or used.
<u>Long term storage</u> Sludge is digested, dewatered to $>10\%$ w/w solids and stores for >3 years.	Product must be stored in manner that ensures no recontamination, and shall demonstrate minimum re-growth by approved pathogen testing procedure(s)

Treatment Process	Associated controls
<u>Thermophilic digestion processes</u> Processes operating at greater than 55°C may be considered for inclusion, however, EPA endorsement will be considered on a case-by-case basis depending on retention time, the number of process stages and batch versus continuous feed/draw.	Relevant vector attraction reduction controls (refer Table 4), and shall demonstrate minimum re-growth by approved pathogen testing procedure(s).
Treatment Grade T2 Low pathogen levels but with some pathogen re-growth potential. Microbiological criteria: <10 Salmonella/50 grams of final product (dry wt), <1000 E.Coli MPN/g (dry wt)	
<u>Composting method</u> The temperature of all compost material to be ≥53°C for ≥5 continuous days or ≥55°C for ≥3 continuous days. (NB although this criteria is comparable to the T1 provisions, it is also included as a T2 process to reflect that composting processes without detailed management procedures may not regularly achieve T1 microbiological grading.)	Relevant vector attraction reduction controls (see Table 4) e.g. volatile solids reduction of ≥38%, or incorporation into soil within 6 hours. Weed seed controls may be needed in landscaping or agricultural applications.
<u>Heating and drying</u> Sludge are heated to ≥70°C and dried to a solids content of at least 75% w/w.	Relevant vector attraction reduction controls (see Table 4) e.g. final product to be kept dry (≥90% solids for unstabilised product or ≥75% for stabilised product) until mixed with other materials or used/applied to land.
<u>Aerobic thermophilic digestion</u> Aerobic conditions at 55-60°C maintained for ≥10 continuous days. Final product dried to ≥50% solids.	Relevant vector attraction reduction controls (see Table 4) e.g. Volatile solids reduction of at least 38% from the original, soil incorporation within 36 hours.
Treatment Grade T3 Established processes with pathogen reduction Microbiological criteria: <2 000 000 E.Coli MPN/g (dw).	
<u>Aerobic digestion</u> ≥15 days at ≥35°C or ≥60 days at ≥15°C.	For all Grade T3 treatment processes: Relevant vector attraction reduction controls (see Table 3) e.g. ≥38% volatile solids reduction, incorporation into soil within 6 hours. Weed seed controls may be needed in landscaping or agricultural applications.
<u>Aerobic digestion</u> ≥40 days at ≥20°C or ≥60 days at ≥15°C.	
Alternative processes – all treatment grades. A case-by-case assessment by EPA and other Government departments is required (for T1 refer 4.2.3).	Product shall comply with relevant re-growth, vector attraction reduction and odour management controls for the proposed treatment grade.

Table A2 2: Suggested Vector Attraction Reduction Requirements (USEPA 1999)

No.	Suggested VAR Requirements	Sludge most suited
1	Sludge treatment process reduces volatile solids by $\geq 38\%$	All biological anaerobic or aerobic processes
2	Sludge containing stabilised solids only, dried to $\geq 75\%$ solids content	Fully stabilised by anaerobic or aerobic process
3	Sludge containing un-stabilised solids, dried to $\geq 90\%$ solids content	Heat dried sludge
4	Aerobic treatment for ≥ 14 days at minimum 40°C and average $>45^{\circ}\text{C}$	Composted
5	Sludge pH raised to ≥ 12 , and without addition of further alkali pH maintained at ≥ 12 for 2 hrs and then at pH ≥ 11.5 for an additional 22 hours	PH (alkali/lime addition) and temperature
6	Injection or incorporation of sludge into soil within 6 hours of surface application	Partially stabilised or unstabilised sludge, liquid sludges

APPENDIX 3: ESSENTIAL ITEMS TO BE INCLUDED IN CONTRACTUAL AGREEMENT BETWEEN A SLUDGE PRODUCER AND SLUDGE USER

Supplier/Producer

1. Name and address
2. Classification of sludge
3. Quality: Hygienic - stability and micro-organisms
Moisture content
Nitrogen, phosphate and potassium content
Maximum metal and inorganic content
(Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Zn, As, Se, B, F)
4. Limiting metal and maximum application rate in dry t/ha/yr
5. Recommended maximum application rate in t/ha/yr in terms of nitrogen demand of crop
6. Notification of local authorities involved.

Receiver/user

1. Name and address
2. Name of transporter of sludge
3. Name of farm or site where sludge will be stored and used
4. Size of sludge application area
5. Crops to be fertilised or alternative use
6. Previous sludge application – annual rate and frequency
7. Metal and inorganic content of soil (Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Zn, As, Se, B, F). Soil to be analysed before commencing sludge application and monitored according to the Restriction/Requirement 6 discussed in this document
8. Details of sludge processing, addition of other materials or chemical and quality of final product, if produced for selling.

Agreement

1. Sludge to be used in terms of guide
2. Inspection of user's activities by local authority
3. Breach of contract – termination of sludge supply and punitive measures.

APPENDIX 4: PARAMETERS AND ANALYSES METHODS TO BE INCLUDED IN SLUDGE AND SOIL MONITORING

Characteristic	Parameter		Guidance on methodology and/or recommended extraction method
Physical characteristics	pH		pH on saturated paste or solution
	Total solids (TS)		Standard Method 2540B ¹
	Volatile suspended solids (VSS)		Standard Method 2540E ²
	Volatile Fatty Acids (VFA)		Adapted from Standard Methods. The full method is attached
Nutrients	Total Kjeldahl Nitrogen (TKN)		The suggested method description has been attached
	Total Phosphorus (TP)		The suggested method description has been attached
	Potassium (K)		The suggested method description has been attached
Metals and micro-elements	Compulsory Arsenic Cadmium Chromium Copper Lead Mercury Nickel Zinc	Recommended Aluminium Antimony Boron Barium Beryllium Cobalt Iron Manganese Molybdenum Selenium Silver Sodium Strontium Thallium Vanadium	Compulsory method – Extraction of trace elements soluble in <i>aqua regia</i> . International Standard ISO 11466 Method Reference number: ISO11466:1995 (E) The metal limits are based on <i>aqua regia</i> extraction Note: Remind the laboratory to manage the interferences on the ICP appropriately, especially for compounds such as Arsenic. A semi-quantitative ICP Scan would give concentration of all mentioned metals
Organic pollutants	Poly-aromatic hydrocarbons (PAH) ³		EPA Methods 3510C (Liquid-liquid extraction) for liquid sludge, 3540C (Soxhlet extraction) for solid sludge and EPA Method 3660B for sulphur clean-up.
Microbiological quality	<i>Faecal coliforms</i>		Membrane filter/ m-FC medium (Standard method)
	Helminth ova		Method attached

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

³ Acenaphthene, phenanthrene, fluorene, fluoranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1,2,3-c,d)pyrene.

Volatile acids and alkalinity

1. Scope

This method is applicable to the determination of volatile acids and alkalinity in sludge.

2. Principle

Hydroxyl ions present in a sample as a result of dissociation or hydrolysis of solutes react with additions of standard acid to a pH 4.0. Evaporation of volatile material and titration to pH 6.2.

3. Interferences

Do not dilute, concentrate or alter sample. (Soaps, oily matter, suspended solids, or precipitates may coat the glass electrode and cause a sluggish response).

4. Equipment

- 4.1 Where applicable use only class A volumetric glassware.
- 4.2 Centrifuge with centrifuge tubes.
- 4.3 Digital burette.
- 4.4 Pipette.
- 4.5 100 mL Erlenmeyer flask.
- 4.6 pH meter.
- 4.7 Magnetic stirrer with stirring bars.

5. Reagents and Standard Solutions

- 5.1 *Distilled water:* Conductivity should be less than $\leq 0.5 \text{ mS m}^{-1}$.
- 5.2 *Standard 0.1 mole per litre sulphuric acid H_2SO_4 .*
 - 5.2.1 Prepare a 0.1 mL H_2SO_4 solution by diluting 5.6 mL concentrated H_2SO_4 (sg = 1.84) to 1000 mL with distilled water.
- 5.3 *Standardisation of 0.1 mole per litre H_2SO_4 .*
 - 5.3.1 Standardise against $0.1 \text{ mol L}^{-1} \text{Na}_2\text{CO}_3$. Dissolve 10.599 g Na_2CO_3 in 1000 mL of distilled/de-ionised water. Retention time: 3 months. Store in fridge.
 - 5.3.2 Pipette 25 mL of the $0.1 \text{ mol L}^{-1} \text{Na}_2\text{CO}_3$ in an Erlenmeyer flask.
 - 5.3.3 Dilute with $\pm 25 \text{ mL}$ distilled/de-ionised water.
 - 5.3.4 Add 3 drops BDH "4.5" indicator.
 - 5.3.5 Titrate with $0.1 \text{ mol L}^{-1} \text{H}_2\text{SO}_4$, colour change from blue to orange.
 - 5.3.6 Determine the H_2SO_4 concentration. See section 8.1.
- 5.4 *0.05 M/litre Sodium hydroxide (NaOH) solution.*
 - 5.4.1 Prepare a 0.05 mol L^{-1} sodium hydroxide (NaOH) solution by dissolving 2.0 g NaOH in about 800 mL distilled water. Cool down and make up to 1 L.
- 5.5 *Standardisation of 0.05 mol L^{-1} sodium hydroxide (NaOH).*
 - 5.5.1 Standardise against $0.1 \text{ mol L}^{-1} \text{H}_2\text{SO}_4$.

- 5.5.2 Pipette 25 mL of the 0.05 mol L⁻¹ NaOH in an Erlenmeyer flask.
- 5.5.3 Dilute with $\pm$ 25 mL distilled/de-ionised water.
- 5.5.4 Add 3 drops BDH "4.5" indicator.
- 5.5.5 Titrate with 0.1 mol L⁻¹ H₂SO₄.
- 5.5.6 Determine the NaOH concentration. See section 8.1.
- 5.6 *Quality Control solutions for alkalinity: (QC 1: 1500 mg/L)*
- 5.6.1 Dissolve 1.65 g Na₂CO₃ (dried for 4 hours at 105°C $\pm$ 2°C) in an A grade 1L Volumetric Flask and bring to the mark with distilled/de-ionised water. Store in the fridge in a polyethylene bottle. Retention time: 1 month.
- 5.7 *Quality Control solutions for alkalinity: (QC 2: 1500 mg/L)*
- 5.7.1 Pipette 333 mL from QC solution 1 into an A grade 1 L Volumetric flask and fill to the mark with distilled/de-ionised water. Store in the fridge in a polyethylene bottle. Retention time: 1 month.

6. Sampling and Storage:

Collect samples in polyethylene or borosilicate glass bottles and store at a low temperature. Fill bottles completely and cap tightly.

7. Analytical Procedure

- 7.1 Centrifuge the sludge sample for about 5 minutes at 4000 r.p.m.
- 7.2 Measure out 50 mL of the water into a 100 mL Erlenmeyer flask.
- 7.3 Titrate with 0.1 mol L⁻¹ H₂SO₄ solution to pH 4.0 and determine alkalinity by noting amount of acid titrated.
- 7.4 Add acid to bring pH to 3.2 to 3.5.
- 7.5 Evaporate on water bath for 30 minutes. Cool to room temperature and titrate with 0.05 mol L⁻¹ sodium hydroxide to a pH of 4.0. Zero the burette.
- 7.6 Titrate to a pH of 6.2 with 0.05 mol L⁻¹ sodium hydroxide and note titration volume needed.

8. Calculation of Results

- 8.1 Standardisation of acid or base

$$C_a V_a = C_b V_b$$

C_a = Concentration of acid

V_a = Volume of acid titrated

C_b = Concentration of base : $\frac{\text{mass primary standard}}{\text{molar mass}} = \text{mol}$

V_b = Volume of base used

MF = Multiplication factor

8.1.1

$$\begin{aligned}
 \text{Concentration of acid} &= \frac{C_b V_b}{V_a} \\
 &= \frac{\text{concentration} \times 2.5 \text{ mL}}{V_a \text{ (mL)}} \\
 &= \pm 0.1 \text{ mol L}^{-1}
 \end{aligned}$$

8.1.2

$$\begin{aligned}
 \text{Concentration of base} &= \frac{2(C_a V_a)}{V_b} \\
 &= \frac{2(\text{concentration} \times V_a)}{25 \text{ mL}} \\
 &= \pm 0.05 \text{ mol L}^{-1}
 \end{aligned}$$

8.1.3

$$\begin{aligned}
 \text{Multiplication factor for alkalinity} &= \frac{\text{Concentration of acid calculated in 8.1.1}}{\text{Actual concentration of acid}} \\
 &= \frac{\pm 0.1000 \text{ mol L}^{-1}}{0.1000 \text{ mol L}^{-1}} \times 200 \\
 &= \pm 200
 \end{aligned}$$

8.1.4

$$\begin{aligned}
 \text{Multiplication factor for acid} &= \frac{\text{Concentration of base calculated in 8.1.2}}{\text{Actual concentration of base}} \\
 &= \frac{\pm 0.05 \text{ mol L}^{-1}}{0.05 \text{ mol L}^{-1}} \times 200 \\
 &= \pm 1
 \end{aligned}$$

8.1.5

$$\begin{aligned}
 \text{Alkalinity Determination} &= \frac{\text{Concentration of acid calculated in 8.1.1} \times \text{Normality} \times 50\,000}{\text{Volume of sample}} \\
 &= \frac{\text{Titrated (mL)} \times (\pm 0.2\text{N}) \times 50\,000}{50 \text{ mL}} \\
 &= \text{Titrated (mL)} \times (\pm 2000)
 \end{aligned}$$

$$8.2 \quad \text{Total alkalinity} = (\text{acid titration to pH 4}) \times (\pm 200)$$

To convert from molarity to normality:

$$\begin{aligned} M &= D \times V \\ &= 1.84 \times (5.6 \text{ mL}) \\ &= 10.304 \text{ g} \end{aligned}$$

$$\text{BUT equivalent mass} = \frac{\text{molar mass}}{Z}$$

Z is the factor that depends on the chemical context (chemical reaction involved). For acids the value of z is equal to the number of moles of H^+ . Displaceable from one mole of acid, e.g. for HCl , = 1, while for H_2SO_4 , $Z = 2$.

$$\text{Molar mass of } \text{H}_2\text{SO}_4 = 89.08 \text{ g mol}^{-1}$$

$$\text{The equivalent mass of } \text{H}_2\text{SO}_4 = \frac{89.08 \text{ g mol}^{-1}}{2} = 49.04 \text{ g mol}^{-1}$$

The normality when 5.6 mL of H_2SO_4 is used will then be:

$$\begin{aligned} \text{Normality} &= \frac{\text{mass used}}{\text{g/equivalent}} \\ &= \frac{10.304 \text{ g}}{49.04 \text{ g/equivalent}} \\ &= 0.21 \text{ N} \\ \therefore 0.1 \text{ M } \text{H}_2\text{SO}_4 &= 0.21 \text{ N } \text{H}_2\text{SO}_4 \end{aligned}$$

If NaOH titration from 4.0 to 6.2 < 3.7, then x 50.

If NaOH titration from 4.0 to 6.2 $\geq$ 3.7, then x 75.

9. Reporting of Results

9.1 Express results as Total Alkalinity in $\text{mg CaCO}_3 \text{ L}^{-1}$.

9.2 Express results as Volatile Acid in $\text{mg CH}_3\text{COOH L}^{-1}$.

The above method is sourced from:

Standard Methods. 1995. American Public Health Association, American Water Works Association, Water Environment Federation. *Standard methods for the examination of water and wastewater*. Edited by M.A.F. Franson, A.D. Eaton, L.S. Clesceri, and A.E. Greenberg. 19th Edition. Washington DC. USA. American Public Health Association

Procedure to determine Helminth ova in wastewater sludge

The method below was developed for the determination of *Ascaris* ova in wastewater and sludge samples. The method can also be used for the determination of all helminths' ova. The method is currently being optimised and adapted to ensure better recovery (Jimenez-Cisneros, 2005). The updated method will be communicated as soon as it becomes available. In the interim laboratories are urged to adopt the method detailed below (adapted from EPA/625/R-92/013).

Test Method for Detecting, Enumerating, and Determining the Viability of *Ascaris* Ova in Sludge

1. Scope

This test method describes the detection, enumeration, and determination of viability of *Ascaris* ova in water, wastewater, sludge, and compost. These pathogenic intestinal helminths occur in domestic animals and humans. The environment may become contaminated through direct deposit of human or animal faeces or through sewage and wastewater discharges to receiving waters. Ingestion of water containing infective *Ascaris* ova may cause disease.

This test method is for wastewater, sludge, and compost. It is the user's responsibility to ensure the validity of this test method for untested matrices.

This standard does not purport to address all the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the liability of regulatory limitations prior to use.

2. Terminology

The normal nematode life cycle consists of the egg, 4 larval stages and an adult. The larvae are similar in appearance to the adults; that is, they are typically worm-like in appearance.

Molting (*ecdysis*) of the outer layer (*cuticle*) takes place after each larval stage. Molting consists of 2 distinct processes, the deposition of the new cuticle and the shedding of the old one or ecdysis. The cuticle appears to be produced continuously, even throughout adult life.

A molted cuticle that still encapsulates a larva is called a *sheath*.

Ascarid egg shells are commonly comprised of layers. The outer tanned, bumpy layer is referred to as the *mammillae* layer and is useful in identifying *Ascaris* eggs. The *mammillae* layer is sometimes absent. Eggs that do not possess the *mammillae* layer are referred to as *decorticated* eggs.

A potentially infective *Ascaris* egg contains a third stage larva encased in a sheath of the first larval stage.

3. Summary of Test Method

This method is used to concentrate pathogenic *Ascaris* ova from wastewater, sludge, and compost. Samples are processed by blending with buffered water containing a surfactant. The blend is screened to remove large particulates. The solids in the screened portion are allowed to settle out and the supernatant is decanted. The sediment is subjected to density gradient centrifugation using magnesium sulfate (specific gravity 1.20). This flotation procedure yields a layer likely to contain *Ascaris* and some other parasitic ova if present in the sample. Small particulates are removed by a second screening on a small mesh size screen. Proteinaceous material is removed using an acid alcohol/ethyl acetate extraction step. The resulting concentrate is incubated at 26°C until control *Ascaris* eggs are fully embrocated. The concentrate is then microscopically examined for the categories of *Ascaris* ova on a Sedgwick-Rafter counting chamber.

4. Significance and Use

This test method is useful for providing a quantitative indication of the level of *Ascaris* ova contamination of wastewater, sludge, and compost.

This test method will not identify the species of *Ascaris* detected nor the host of origin.

This method may be useful in evaluating the effectiveness of treatment.

5. Interferences

Freezing of samples will interfere with the buoyant density of *Ascaris* ova and decrease the recovery of ova.

6. Apparatus

- 6.1 A good light microscope equipped with bright field, and preferably with phase contrast and/or differential contrast optics including objectives ranging in power from.
- 6.2 Sedgwick-Rafter cell.
- 6.3 Pyrex beakers, 2 L. Coat with organosilane.
- 6.4 Erlenmeyer flask, 500 mL. Coat with organosilane.
- 6.4 A centrifuge that can sustain forces of at least 660 X G with the rotors listed below.
 - 6.4.1 A swinging bucket rotor to hold 100 or 250 ml centrifuge glass or plastic conical bottles.
 - 6.4.2 A swinging bucket rotor to hold 15 ml conical glass or plastic centrifuge tubes.
- 6.5 Tyler sieves.
 - 6.5.1 20 or 50 mesh.
 - 6.5.2 400 mesh, stainless steel, 5 inch (12.7 cm) in diameter.
 - 6.5.3 A large plastic funnel to support the sieve. Coat with organosilane.
- 6.6 Teflon spatula.
- 6.7 Incubator set at 26°C.

- 6.8 Large test tube rack to accommodate 100 or 250 mL centrifuge tubes.
- 6.9 Small test tube rack to accommodate 15 mL conical centrifuge tubes.
- 6.10 Centrifuge tubes, 100 or 250 mL. Coat with organosilane.
- 6.11 Conical centrifuge tubes, 15 mL. Coat with organosilane.
- 6.12 Stoppers.
- 6.13 Wooden applicator sticks.
- 6.14 Pasteur pipettes. Coat with organosilane.
- 6.15 Vacuum aspiration apparatus.
 - 6.15.1 Vacuum source.
 - 6.15.2 Vacuum flask, 2 L or larger.
 - 6.15.3 Stopper to fit vacuum flask, fitted with a glass or metal tubing as a connector for 1/4 inch tygon tubing.
- 6.16 Wash bottles (500 mL), label "Water".
- 6.17 Spray bottles (16 fl oz.) (2).
 - 6.17.1 Label one "Water".
 - 6.17.2 Label one "1% 7X".

7. Reagents and Materials

- 7.1 Purity of Reagents - Reagent grade chemicals shall be used in all tests. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.
- 7.2 Purity of Water - Unless otherwise indicated, references to water shall be understood to mean reagent water.
- 7.3 Preparation of Reagents
 - 7.3.1 Phosphate buffered water (1 L = 34.0 g KH_2PO_4 , pH adjusted to 7.2 ± 0.5 with 1 N NaOH).
 - 7.3.2 1% (v/v) 7X ("Limbro" laboratory detergent) (1 L = 999 ml phosphate-buffered water, 1 ml 7X "Limbro", Adjust pH to 7.2 ± 0.1 with 1 N NaOH).
 - 7.3.3 Magnesium sulphate, sp. gr. 1.20. (1 L = 215.2 g MgSO_4 check specific gravity with a hydrometer; adjust as necessary to reach 1.20).
 - 7.3.4 Acid alcohol. 0.1 N H_2SO_4 , made in 35% ethyl alcohol. (100 ml = 35 ml EtOH, 0.9807 g H_2SO_4)
 - 7.3.5 Ethyl Acetate, reagent grade.
- 7.4 Organosilane. For coating glassware (This is to prevent the Helminth Ova from adhering to the glass). Coat all glassware according to manufacturer's instructions. (Alternatively, only use only plastic equipment)
- 7.5 Fresh *Ascaris* ova for positive control, either dissected from *Ascaris suum* gravid adult female worms or purified from *Ascaris* infected pig faecal material. (Other Helminth ova can also be used)

8. Precautions

- 8.1 When harvesting *Ascaris* ova (or any other Helminth ova) from gravid female worms, the analyst must wear latex gloves, a surgical mask and protective goggles or full face mask, and laboratory coat before dissecting the worms. Moreover, it is recommended that the *Ascaris* ova (or any other Helminth ova) (or any other Helminth ova) harvest be carried out either in a biological safety cabinet or minimally a chemical hood. These precautions are designed to prevent the development of an allergy to *Ascaris* pseudocoelomic fluid. If infective *Ascaris* ova are ingested they may cause disease.

9. Sampling

- 9.1 Collect 1 litre of compost, wastewater, or sludge in accordance with standard sampling methodology.
- 9.2 Place the sample container(s) on wet ice or around chemical ice and transport back to the laboratory for analysis within 24 hours of collection.
- 9.3 Store the samples in the laboratory refrigerated at 2 to 5°C. Do not freeze the samples during transport or storage.

10. Preparation of Apparatus

Follow the manufacturer's instructions

11. Calibration and Standardisation

Follow the manufacturer's instructions

12. Procedure

- 12.1 The percentage moisture of the sample is determined by analysing a separate portion of the sample, so the final calculation of ova per gram dry weight can be determined. The concentration of ova in liquid sludge samples may be expressed as ova per unit volume.
- 12.2 Initial preparation:
- 12.1.1 Dry or thick samples: Weigh about 300 g (estimated dry weight) and place in about 500 ml water in a beaker and let soak overnight at 4 - 10°C. Transfer to blender and blend at high for one minute. Divide sample into four beakers.
- 12.1.2 Liquid samples: Measure 1,000 ml or more (estimated to contain at least 50 g dry solids) of liquid sample. Place one half of sample in blender. Add about 200 ml water. Blend at high speed for one minute transfer to a beaker. Repeat for other half of sample.

- 12.3 Pour the homogenised sample into a 1000 ml tall form beaker and using a wash bottle, thoroughly rinse blender container into beaker. Add 1% 7X to reach 900 ml final volume.
- 12.4 Allow sample to settle four hours or overnight at 4 - 10°C. Stir occasionally with a wooden applicator, as needed to ensure that material floating on the surface settles. Additional 1% 7X may be added, and the mixture stirred if necessary.
- 12.5 After settling, vacuum aspirate supernatant to just above the layer of solids. Transfer sediment to blender and add water to 500 ml, blend again for one minute at high speed. (Aspiration can also be done manually using plastic pipettes)
- 12.6 Transfer to beaker, rinsing blender and add 1% 7X to reach 900 ml. Allow to settle for two hours at 4 - 10°C, vacuum aspirate supernatant to just above the layer of solids.
- 12.7 Add 300 ml 1% 7X and stir for five minutes on a magnetic stirrer.
- 12.8 Strain homogenised sample through a 20 or 50 mesh sieve placed in a funnel over a tall beaker. Wash sample through sieve with a spray of 1% 7X from a spray bottle.
- 12.9 Add 1% 7X to 900 ml final volume and allow to settle for two hours at 4 - 10°C.
- 12.10 Vacuum aspirate supernatant to just above layer of solids. (Aspiration can also be done manually using plastic pipettes). Mix sediment and distribute equally to 50 ml graduated conical centrifuge tubes. Thoroughly wash any sediment from beaker into tubes using water from a wash bottle. Bring volume in tubes up to 50 ml with water.
- 12.11 Centrifuge for 10 minutes at 1000 X G. Vacuum aspirate supernatant from each tube down to just above the level of sediment. (Aspiration can also be done manually using plastic pipettes). The packed sediment in each tube should not exceed 5 ml. If it exceeds this volume, add water and distribute the sediment evenly among additional tubes, repeat centrifugation, and vacuum aspirate supernatant.
- 12.12 Add 10 to 15 ml of MgSO_4 solution (specific gravity 1.20) to each tube and mix for 15 to 20 seconds on a vortex mixer. (Use capped tubes to avoid splashing of mixture from the tube.)
- 12.13 Add additional MgSO_4 solution (specific gravity 1.20) to each tube to bring volume to 50 ml. Centrifuge for five to ten minutes at 800 to 1000 X g.
- 12.14 Allow the centrifuge to stop without the brake. Pour the top 25 to 35 ml of supernatant from each tube through a 400 mesh sieve supported in a funnel over a tall beaker.
- 12.15 Using a water spray bottle, wash excessive flotation fluid and fine particles through sieve.
- 12.16 Rinse sediment collected on the sieve into a 100 ml beaker by directing the stream of water from the wash bottle onto the upper surface of the sieve.
- 12.17 After thoroughly washing the sediment from the sieve, transfer the suspension to the required number of 15 ml centrifuge tubes, taking care to rinse the beaker into the tubes. Usually one beaker makes one tube.
- 12.18 Centrifuge the tubes for three minutes at 800 X G, then discard the supernatant.
- 12.19 If more than one tube has been used for the sample, transfer the sediment to a single tube, fill with water, and repeat centrifugation.

- 12.20 Resuspend the pellet in 7 ml acid alcohol solution and add 3 ml ethyl acetate.
- 12.21 Cap the tube with a rubber stopper and invert several times, venting after each inversion.
- 12.22 Centrifuge the tube at 660 x G for 3 minutes.
- 12.23 Aspirate the supernatant above the solids.
- 12.24 Resuspend the solids in 4 ml 0.1 N H₂SO₄ and pour into a 220-mL polyethylene scintillation vial or equivalent with loose caps.
- 13.25 Before incubating the vials, mark the liquid level in each vial with a felt tip pen. Incubate the vials, along with control vials containing *Ascaris* or other Helminth ova mixed with 4 ml 0.1 N H₂SO₄ at 26°C for three to four weeks. Every day or so, check the liquid level in each vial. Add reagent grade water up to the initial liquid level line as needed to compensate for evaporation. After 18 days, suspend, by inversion and sample small aliquots of the control cultures once every 2 - 3 days. When the majority of the control *Ascaris* ova are fully embryonated, samples are ready to be examined.
- 12.26 Examine the concentrates microscopically using a Sedgwick-Rafter cell to enumerate the detected ova. Classify the ova as either unembryonated, embryonated to the first, second or third larval stage. In some embryonated *Ascaris* ova the larva may be observed to move.

See Figures below for examples of various *Ascaris* egg categories.

13. Calculation

- 13.1 Calculate % total solids using the % moisture result:

$$\% \text{ Total solids} = 100\% - \% \text{ Moisture}$$

- 13.2 Calculate categories of ova/g dry weight in the following manner:

$$\text{Ova/g dry wt} = \frac{(\text{NO}) \times (\text{CV}) \times (\text{FV})}{(\text{SP}) \times (\text{TS})}$$

Where:

NO = no. ova

CV = chamber volume(= 1 mL)

FV = final volume in mL

SP = sample processed in mL or g

TS = % total solids

14. Report

- 14.1 Report the results as the total number of *Ascaris* ova, number of unembryonated *Ascaris* ova, number of 1st, 2nd or 3rd stage larva; reported as number of *Ascaris* ova and number of various larval *Ascaris* ova per g dry weight. Representative reporting forms are shown in Figures below.

Reference: EPA Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge. EPA/625/R-92/1013, Revised October 1999

Note: This method is currently being revised and adapted and the most recent version will be communicated to interested parties as soon as it becomes available.



Figure 1. *Ascaris ovum*: potentially non-fertile, note smooth.



Figure 2. *Ascaris ovum*: fertile, note the bumpy outer mammillated layer.

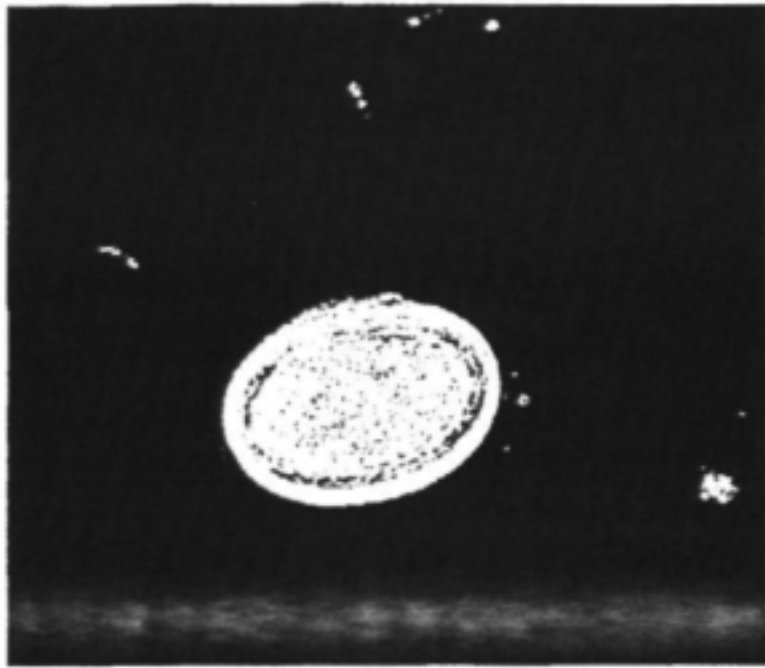


Figure 3. *Ascaris* ovum: decorticated, unembryonated. Note the outer mammilated layer is gone.

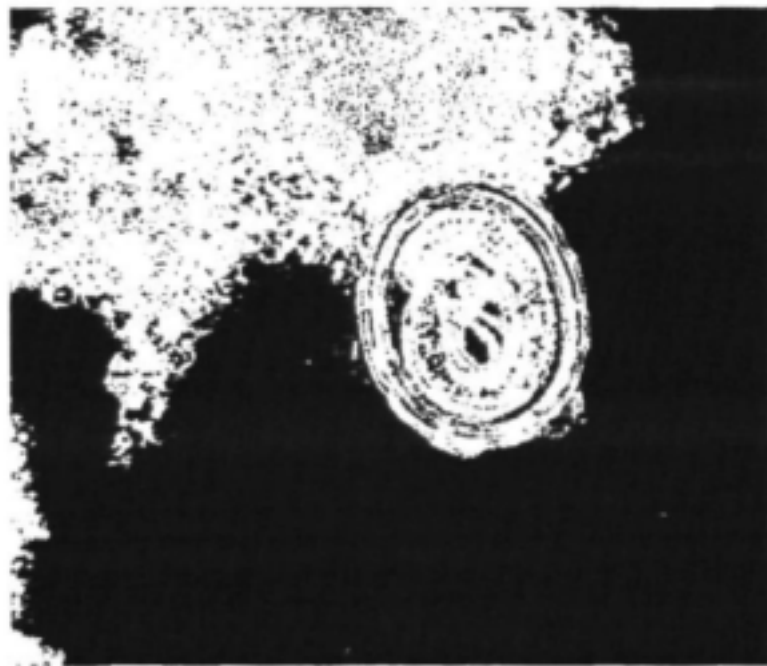


Figure 4. *Ascaris* ovum: decorticated and embryonated.



Figure 5. *Ascaris* ovum: decorticated, embryonated.

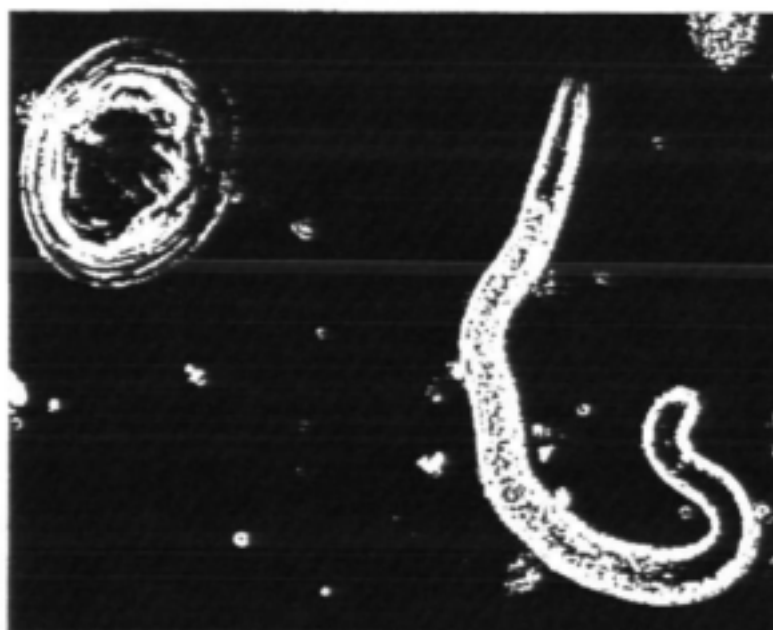


Figure 6. *Ascaris* ovum with second stage or potentially third stage larva; note the first stage larval sheath at the anterior end of the worm.

Methods for the determination of total Kjeldahl nitrogen and total phosphorus in sludge samples

Kjeldahl digestion to determine N

REAGENTS: Concentrated Sulphuric Acid, (H_2SO_4) Digestion Mixture: Potassium sulphate (AR) very finely ground (1500g) mixed with 4g finely ground (AR) $\text{Cu SO}_4 \cdot 5\text{H}_2\text{O}$.

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

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

Method for Digestion and Determination of P and K

Sample Digestion: 1g of sample is digested with 7ml HNO_3 (conc. nitric acid) and 3ml HClO_4 (perchloric acid) at temperature up to 200°C and brought to volume in a 100ml vol. flask. (Adapted from method for plant digestion at ISCW).

P and K Determination

The P and K can then be determined by ICP-AES (Inductively Coupled Plasma – Atomic Emission Spectroscopy). Values can also be confirmed by DCP (Direct Current Plasma Emission Spectroscopy) at a wavelength of 253.565 nm.

Reference: Zasoski, RJ and Burau, RG. 1977. A Rapid Nitric-Perchloric Acid Digestion Method for Multi-Element Tissue Analysis. *Communications in Soil Science and Plant Analysis*. vol. 8. iss.5 p.425-436.

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

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

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

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

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

Minimum concentrations which have to be quantified accurately with the ammonium nitrate extraction method (DIN 19730) for good results in the field of soil protection

		1 mol/l ammonium nitrate solution (µg/l)	ammonium nitrate extractable in the air dry soil (µg/kg)
Ag	Silver	< 0,4	< 1
As	Arsenic	10	25
Be	Beryllium	1	2,5
Bi	Bismuth	< 0,4	< 1
Cd	Cadmium	2	5
Co	Cobalt	20	50
Cr	Chromium	4	10
Cu	Copper	100	250
Hg	Mercury	< 0,4	< 1
Mn	Manganese	2000	5000

Mo	Molybdenum	10	25
Ni	Nickel	100	250
Pb	Lead	< 8	< 20
Sb	Antimony	10	25
Tl	Thallium	4	10
U	Uranium	1	2,5
V	Vanadium	10	25
Zn	Zinc	100	250

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

APPENDIX 5: BENCHMARK VALUES OF METALS IN SOUTH AFRICAN SLUDGE

Element	Symbol	Number of rounds	Mass of sludge (tonnes)	20 % (mg kg ⁻¹)	80 % (mg kg ⁻¹)
Lithium	Li	3	534.2	7.8	2.37
Beryllium	Be	3	534.2	6.6	0.8
Boron	B	3	534.2	72	22.5
Titanium	Ti	3	534.2	320	110
Vanadium	Va	2	498.09	427	85
Chromium	Cr	3	534.2	900	112
Manganese	Mn	3	534.2	1225	263
Cobalt	Co	3	534.2	37.5	5
Nickel	Ni	3	534.2	236	62
Copper	Cu	3	534.2	860	270
Zinc	Zn	3	534.2	4550	145
Bromine	Br	3	494.19	64	20
Selenium	Se	3	526.07	15	5
Arsenic	As	0	n/a	n/a	n/a
Rubidium	Rb	1	384.2	7.3	3.5
Strontium	Sr	3	534.2	205	84
Molybdenum	Mo	3	534.2	12	4
Palladium	Pd	1	459.3	0.55	0.24
Cadmium	Cd	3	534.2	165	19.5
Tin	Sn	3	534.2	67	14
Antimony	Sb	3	534.2	7	1.14
Tellurium	Te	1	207	0.418	0.17
Iodine	I	3	531.9	16	5.4
Cesium	Ce	1	384.2	0.61	0.17
Barium	Ba	3	534.2	251	108
Lanthanum	La	1	384.2	11.83	3.2
Tungsten	W	3	534.2	5	0.8
Platinum	Pt	3	534.2	0.225	0.045
Mercury	Hg	3	534.2	4.7	1.8
Thallium	Tl	1	459.3	0.144	0.026
Lead	Pb	3	534.2	300	106
Bismuth	Bi	3	534.2	8.1	3.2
Uranium	U	3	534.2	7.2	1

DEFINITIONS AND DESCRIPTION OF KEY TERMS

Agricultural land:	Land on which a food crop, a feed crop, or a fibre crop is grown. This includes grazing land and forestry.
Agronomic rate:	The sludge application rate (dry-weight basis) designed (i) to provide the amount of nitrogen needed by the food crop, feed crop, fibre crop, cover crop, or vegetation grown on the land and (ii) to minimise the amount of nitrogen in the sewage sludge that passes below the root zone of the crop or vegetation grown on the land to the groundwater.
Agricultural use:	The use of sludge to produce agricultural products. It excludes the use of sludge for aquaculture and as an animal feed.
Annual pollutant loading rate:	The maximum amount of a pollutant that can be applied to an area of land during a 365-day period.
Assimilative capacity:	This represents the ability of the receiving environment to accept a substance without risk.
Beneficial uses	Use of sludge with a defined benefit, such as a soil amendment. Disposal, such as landfilling, is not beneficial use.
Bioavailability:	Availability of a substance for uptake by biological system.
Wastewater sludge:	Stabilised Sludge. Organic solids derived from biological wastewater treatment processes that are in a state that they can be managed to sustainably utilise the nutrient, soil conditioning, energy, or other value.
BPEO:	Best Practicable Environmental Option. BPEO is the outcome of a systematic consultative and decision-making procedure that emphasises the protection of the environment across land, air and water. It establishes, for a given set of objectives, the option that provides the most benefit or least damage to the environment as a whole at acceptable cost in the long term and as well as the short term.
Co-disposal (liquid with dry waste):	The mixing of high moisture content or liquid waste with dry waste. This affects the water balance and is an acceptable practice on a site equipped with leachate management measures.
Co-disposal (dewatered sludge with dry waste):	The mixing of dewatered sludge with dry waste in a general landfill site or hazardous landfill site without affecting the water balance of the site.
Composting:	The biological decomposition of the organic constituents of sludge and other organic products under controlled conditions.
Contaminate:	The addition of foreign matter to a natural system. This does not necessarily result in pollution, unless the attenuation capacity of the natural system is exceeded.
Controlled access:	Where public or livestock access to sludge application areas is restricted or controlled, such as via fences or signage, for a period of time stipulated by this guideline.

Cumulative pollutant loading rate:	The maximum amount of an inorganic pollutant that can be applied to a unit area of land.
Dedicated land disposal:	Sites that receive repeated applications of sludge for the sole purpose of final disposal.
Delisting:	DWAF Minimum Requirements. If the EEC (Estimated Environmental Concentration) is less than the Acceptable Risk Level ($0.1 \times LC_{50}$), the waste can be delisted, i.e., be moved to a lower Hazard Rating or even disposed of at a General Waste landfill with a leachate collection system (G:B+landfill).
Dewatering:	Dewatering processes reduce the water content of sludge to minimise the volumes for transport and improve handling characteristics. Typically, dewatered sludge can be handled as a solid rather than as liquid matter.
Disinfection:	A process that destroys, inactivates or reduces pathogenic microorganisms.
Domestic septage:	Liquid or solid material removed from a septic tank, cesspool, portable toilet, marine sanitation device, or similar treatment works that receives only domestic sewage. Domestic septage does not include liquid or solid material removed from a septic tank, cesspool, or similar treatment works that receives either commercial or industrial wastewater and does not include grease removed from a grease trap at a restaurant.
Domestic sewage:	Waste and wastewater from humans or household operations that is discharged to or otherwise enters a treatment works.
Drying:	A process to reduce the water content further than a dewatering process. The solids content after a drying process is typically > 75%.
Dry-weight (DW) basis:	The method of measuring weight where, prior to be weighed, the material is dried at 105°C until reaching a constant mass (i.e., essentially 100 % solids content).
E. coli:	A subset of coliforms found in the intestinal tract of humans and other warm-blooded animals. They can produce acid and gas from lactose at 44 to 44.5°C; hence the test for them is more specific than for total coliforms and selects a narrower range of organisms. They are a more specific indicator of faecal contamination than total coliforms.
Effluent:	A stream flowing from a larger stream, lake, sewerage tank, industrial process.
Estimated Environmental Concentration (EEC):	The Estimated Environmental Concentration represents the concentration of a substance to the aquatic environment when introduced under worst-case scenario conditions, i.e., directly into a body of water. It is used to indicate possible risk, by comparison with the minimum concentration estimated to adversely affect aquatic organisms or to produce unacceptable concentrations in biota, water or sediment.
Faecal coliform:	Faecal coliforms are the most commonly used bacterial indicator of faecal pollution. Faecal coliforms are bacteria that inhabit the digestive system of all warm-blooded animals, including humans.
General Waste:	Waste that does not pose an immediate threat to man or to the environment, i.e., household waste, builders' rubble, garden waste, dry industrial and commercial waste. It may, however, with decomposition, infiltration and percolation, produce leachate with an unacceptable pollution potential. (See Waste.)
Hazardous Waste:	Waste, other than radioactive waste, which is legally defined as Hazardous in the state in which it is generated, transported or disposed of. The definition is based on the chemical reactivity or toxic, explosive, corrosive or other characteristics which cause, or are likely to cause, danger to health or to the environment, whether alone or when in contact with other waste. After UNEP definition. (See Waste.)
Helminth ova:	The egg of a parasitic intestinal worm.
Immobilisation:	Immobilisation (or chemical stabilisation) is a process in which the waste is converted

	to a more chemically stable or more insoluble or more immobile form.
Incineration:	Incineration is both a form of treatment and a form of disposal. It is simply the controlled combustion of waste materials to a non-combustible residue or ash and exhaust gases, such as carbon dioxide and water.
Industrial wastewater:	Wastewater generated in a commercial, industrial, or manufacturing process.
Land application:	The spraying or spreading of sewage sludge onto the land surface; the injection of sewage sludge below the land surface; or the incorporation of sewage sludge into the soil so that the sewage sludge can either condition the soil or fertilise crops or vegetation grown in the soil.
Land disposal	Application of sludge where beneficial use is not an objective. Disposal will normally result in application rates that exceed agronomic nutrient requirements or cause significant contaminant accumulation in the soil.
Landfill:	To dispose of waste on land, whether by use of waste to fill in excavation or by creation of a landform above grade, where the term "fill" is used in the engineering sense.
LC₅₀:	The median lethal dose is a statistical estimate of the amount of chemical, which will kill 50% of a given population of aquatic organisms under standard control conditions. The LC ₅₀ is expressed in mg/l. There are many source documents available for determining the LC ₅₀ . A recent and reliable source is "The Dictionary of Substances and their Effects" (see list of references). In cases where toxicological data are not available or doubtful, models should be used to derive a defensible hazardousness, in which case a qualified toxicologist should be approached.
LD₅₀:	The median lethal dose is a statistical estimate of the amount of chemical which will kill 50% of a given population of animals (e.g., rats) under standard control conditions.
MAT	Maximum available threshold. The maximum available (NH ₄ NO ₃ extractable) metal concentration allowed for soils receiving sludge
Metals	Generally refers to elements that occur in natural and perturbed environments in small amounts and that, when present in sufficient bio-available concentrations, are toxic to living organisms.
Monthly average:	The arithmetic mean of all measurements taken during a given month.
Most probable number (MPN):	A unit that expresses the amount of bacteria per gram of total dry solids in sewage sludge.
Pathogenic organisms:	Disease-causing organisms. This includes, but is not limited to, certain bacteria, protozoa, viruses, and viable helminth ova.
pH:	The logarithm of the reciprocal of the hydrogen ion concentration. The pH measures acidity/alkalinity and ranges from 0 to 14. A pH of 7 indicates the material is neutral. Moving a pH of 7 to 0, the pH indicates progressively more acid conditions. Moving from a pH of 7 to 14, the pH indicates progressively more alkaline conditions.
Precautionary Principle:	Where a risk is unknown; the assumption of the worst-case situation and the making of provision for such a situation.
Recycle:	The use, re-use, or reclamation of a material so that it re-enters the industrial process rather than becoming a waste.
Residue:	A substance that is left over after a waste has been treated or destroyed.
Sludge-amended soil:	Soil to which sludge has been added.
Sludge:	Solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Sewage sludge includes, but is not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and material derived from sewage sludge in a sewage sludge incinerator. It

	does not include the grit and screenings generated during preliminary treatment of domestic sewage in a treatment works.
Soil organisms:	A broad range of organisms, including microorganisms and various invertebrates living in or on the soil.
Specific oxygen uptake rate (SOUR):	The mass of oxygen consumed per unit time per unit mass of total solids (dry-weight basis).
Stabilisation:	The processing of sludge to reduce volatile organic matter, vector attraction, and the potential for putrefaction and offensive odours.
Stabilised Sludge	Wastewater sludge. Organic solids derived from biological wastewater treatment processes that are in a state that they can be managed to sustainably utilise the nutrient, soil conditioning, energy, or other value.
Sterilise:	Make free from micro organisms.
Supplier:	A person or organisation that produces and supplies sludge for use. This includes a water business producing and treating sludge and reprocessor's involved in further treatment.
Sustainable use:	The use of nutrients in sludge at or below the agronomic loading rate and/or use of the soil conditioning properties of sludge. Sustainable use involves protection of human health, the environment and soil functionality.
TIL	Total investigative level. The total metal concentration in soils where further investigation is necessary before sludge application can commence
TMT	Total maximum threshold. The maximum total metal concentration allowed in soils receiving sludge.
Toxic:	Poisonous.
Toxicity Characteristic Leaching Procedure (TCLP):	A test developed by the USA Environmental Protection Agency to measure the ability of a substance to leach from the waste into the environment. It thus measures the risk posed by a substance to groundwater.
VAR:	Vector Attraction Reduction.
Vector attraction:	The characteristic of sewage sludge that attracts rodents, flies, mosquitoes, or other organisms capable of transporting infectious agents.
Vectors:	Any living organisms that are capable of transmitting pathogens from one organism to another, either: (i) mechanically (by transporting the pathogen) or (ii) biologically by playing a role in the lifecycle of the pathogen. Vectors include flies, mosquitoes or other insects, birds, rats and other vermin (source USEPA 1999).
Waste disposal site:	Any place at which more than 100 kg of a Hazardous Waste is stored for more than 90 days or a place at which a dedicated incinerator is located is termed a Waste Disposal Site. It must be registered as such in terms of the Environment Conservation Act (Act 73 of 1989).
Waste:	An undesirable or superfluous by-product, emission, or residue of any process or activity, which has been discarded, accumulated or stored for the purpose of discarding or processing. It may be gaseous, liquid or solid or any combination thereof and may originate from a residential, commercial or industrial area. This definition excludes industrial wastewater, sewage, radioactive substances, mining, metallurgical and power generation waste. After definition in Government Gazette No. 12703, August 1990. (See General Waste and Hazardous Waste.)
Wastewater sludge	The material recovered from predominantly domestic wastewater treatment plants
Wastewater Treatment Plant (WWTP):	Any device or system owned by a municipality or state entity used to treat (including recycling and reclamation) either domestic sewage or a combination of domestic sewage and industrial waste of a liquid nature.

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