JOHANNESBURG CITY COUNCIL

WASTEWATER AND SCIENTIFIC SERVICES DEPARTMENTS

REPORT TO THE
WATER RESEARCH COMMISSION

on

ASPECTS OF SEWAGE SLUDGE HANDLING AND DISPOSAL

by

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NOTICE

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EXECUTIVE SUMMARY

A comprehensive review of literature on the beneficial application of sewage sludge to land confirmed the position that sewage sludge has a wide range of beneficial applications. However the widespread use of sewage sludge has led to increased regulation and the introduction of maximum limits of a number of chemical and microbiological contaminants. The value of maximum limits that have been enforced have led to controversy in most countries where such limits are applied. In the United States in particular the debate remains unresolved.

The apparent conflict between the concept of sewage sludge as a beneficial material and the requirement to limit a variety of its components will require resolution not only in the USA but also in South Africa, where the debate on the hazardous character of sewage sludge has not yet been resolved.

A comprehensive evaluation of currently available disposal options for the handling and disposal of sewage sludge was carried out for the Southern Drainage Basin of the Central Witwatersrand region.

Evaluation of the options in terms of the environmental acceptability, cost effectiveness, operational feasibility (including minimum risk) and political acceptability resulted in four final disposal options being considered for further investigation. These are co-disposal in a landfill; remote farm disposal; composting and incineration. Co-disposal and composting are discussed in this report as alternatives to the current practice of sacrificial land disposal.

Experience at the Goudkoppies landfill site, where co-disposal has been practised for a number of years has demonstrated the potential of this technique. Despite the operational difficulties experienced with the dewatered sludge, in that compaction vehicles are inclined to slip on the material if it is not well mixed with refuse, it has proved to be a successful disposal route for dewatered digested sludge. Monitoring of boreholes in the vicinity of the landfill have not revealed any pollution of the groundwater.

Disposal of sewage sludge to sacrificial land at a rate of $100kg/m^2/a$ over a period of fifteen years has resulted in significant pollution of the groundwater in the vicinity of the lands. Analyses of the soil to which sludge had been applied revealed levels of some metals in excess of Guideline limits. However analysis of a soil to which no sludge had been applied also showed levels of some metals in excess of Guideline limits.

An evaluation of the current maximum limits set by different government departments in respect of the beneficial use of sewage sludge highlighted the necessity for a co-ordinated approach at national level.

Experimental composting of sewage sludge with hay as a bulking agent demonstrated the potential of this technique as a disposal route. Application of the composted sewage sludge to agricultural land resulted in significant increases in crop yields.

Unrestricted beneficial use of this material is dependent on the chemical and microbiological quality of the final product. Analytical techniques were developed to determine the levels of restricted organic compounds in sewage sludge. Application of these techniques to samples of sludge from Johannesburg Works revealed that polychlorinated biphenyls were the only compounds present at levels in excess of the maximum limits. Metal contamination remains a problem.

A survey of metal discharges within the drainage areas of Johannesburg's Wastewater Treatment Plants demonstrated the need for a different approach to controlling this type of industrial discharge. Consideration should be given to a more co-operative arrangement between local authorities and dischargers.

Implementation of fermentation and elutriation facilities at three of Johannesburg's plants clearly demonstrated the positive impact of enriching the reactor feed with respect to volatile fatty acids, on biological phosphorus removal. The improvement in biological phosphorus removal in turn leads to a reduction in chemical costs. Future research in the application of this technology needs to focus on improved automation. The studies described in this report led to the formulation of the recommendations summarized below :

- Opportunities to locate landfill sites and Wastewater Treatment Plants in close proximity to each other should be exploited.
- Sewage Sludge should be promoted as a beneficial material.
- Co-operation between regulatory agencies and sludge producers should be enhanced.
- Proposed regulatory measures for sewage sludge disposal should be discussed with interested parties before finalization.
- Validated analytical methodology must be agreed for all regulated parameters in sludge.
- Consideration should be given to national legislation to control the sources of contaminants, which could cause sludge not to comply with regulatory limits for beneficial use.
- The limits currently set for organic contaminants in sludge should be reviewed.
- Further research is required into the fermentation of sludge to enhance biological phosphorus removal.

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CHAPTER 1

INTRODUCTION

Increasing environmental awareness has forced operators of wastewater treatment plants to review their options for the disposal of wastewater sludges. Environmental impact and cost considerations feature strongly on the list of criteria used to evaluate routes for the disposal of wastewater sludges. Ultimate disposal also depends to a large extent on the characteristics of the processed sludge.

Johannesburg currently treats approximately 600 Mℓ wastewater daily in its four treatment plants. Direct application of sewage sludge to land which is the current disposal route for most of the sludge generated in these plants, is becoming increasingly unacceptable due to environmental considerations. Conversion to a suitable product, i.e. compost has already been successfully carried out at the Johannesburg Northern Works.

During this research project aspects of this route were further investigated, in particular the effect of legislation on the feasibility of this option. International experience was also reviewed in respect of the agricultural uses of sewage sludge.

In addition a wide range of other options were evaluated in a desk study. Minimisation of the amount of sludge produced in the process could make a significant contribution to solving the disposal problem.

1.1 AGRICULTURAL USE OF SEWAGE SLUDGE

<u>International Experience</u>

Use of human wastes as a resource in agriculture has a long history. Nightsoil has been applied to fields since ancient times, and as cities throughout Europe and North America installed water-borne sewerage systems in the nineteenth century, many of them established "sewage farms", adopting crop irrigation as their preferred means of wastewater disposal. Some even argued that an improved food supply could be one of the major benefits of sanitation. The practice became less popular as concern mounted at its potential for disease transmission, and it disappeared in many countries soon after the 1914-18 war, as the development of modern wastewater treatment processes in the early years of the century made it possible to discharge effluent to surface waters without causing appreciable pollution. (Anon, 1990).

In a 1987 survey of the disposal of sewage sludge in the United Kingdom, it was found that utilisation on agricultural land is the most economic option for inland treatment plants and that this route accounts for 40% of the 1,2 x 10^6t DS sludge disposed of annually. (Davis, 1987).

Guidelines for the safe use of the sludge taking into account pathogens and heavy metals are applied. Utilisation of sludge on agricultural land is widely practised in Europe. (See Figure 1.1).

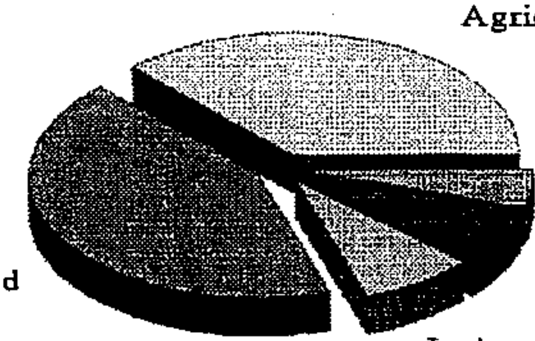


Figure 1.1 : Disposal of sludge in Europe.

Other land uses include landscaping and land reclamation and landfill disposal. Farmers in the UK receive the sludge free on a voluntary basis and only sometimes bear the cost of spreading the material. (Davis, 1987).

Another survey carried out in the European Community in 1987, estimated annual sludge production at 6 million tonnes DS, of which 30% is used in agriculture. (Scheltinga, 1987).

Co-operation in the field of scientific and technical research has been actively promoted by the members of the European Community. Five working parties were set up to consider various aspects of sludge disposal. These were :

- Improvements in the conventional methods of processing (i.e. stabilisation, dewatering, composting) with the objective of reducing costs.
- Methods of odour control and odour evaluation with particular concern for standardisation of olfactometric methods.
- Improvements in anaerobic processes for production of biogas from sludges and manures.
- Development of methods for processing sludges to improve their value, i.e. use as animal feed, as fuels and as chemical feedstock.
- Studies of processes to eliminate heavy metals at their source.
- Improvements in spreading equipment (e.g. injection devices) with the objective of optimising land use.

However, it was not found possible to consider either of the two last topics in the Working Party's activities. Even with just these restricted terms of reference, it was still necessary to narrow down the objectives to a few priority tasks for the period 1984-1985.

More than 706 000 t sludge is sold or given away annually in the United States. Concentrations of 22 pollutants are limited. (Anon, 1989).

In Iowa, sludge is transported to the farmer via injector trucks which inject liquid sludge into the soil. Before a farmer takes part in the programme a careful evaluation of his site is made. Sites with soils with a pH less than 6.5, sandy or sandy loamy soils or sites having a greater than 12 percent slope are ruled out. Locations with a high water table, poor drainage, waterways or areas for runoff are also ruled out. Loading rates are worked out to conform to federal and state requirements. (Haney and Becker, 1987).

In Hong Kong sewage sludge is used for landscaping and topsoil where health risks are minimal. (Wu, 1987).

A review of agricultural application of sewage sludge in the UK concluded the following in 1989 : (Davis, 1989)

1. Agricultural utilisation of sewage sludge is a well-established disposal option in the UK which has developed over the last thirty years.
2. There have been voluntary guidelines to regulate agricultural utilisation for about twenty years, but statutory requirements will be introduced in June 1989 by the implementation of an EC Directive.
3. The water industry uses agriculture to receive 40% of its annual sludge production, but requires only 1-2% of farmland in England and Wales for this purpose.
4. Farmers take sludge on a voluntary basis, therefore sludge producers must offer them a professional service maximizing the benefits of sludge for the farmer and avoiding environmental problems.
5. Research into the effects of contaminants, pathogen destruction and operational aspects has a continuing role in supporting regulations and the professional service and allaying unnecessary public anxiety about sludge utilisation.
6. Apart from agricultural utilisation there is also scope to recycle more sludge to forest land and to land for reclamation.

Experience indicated that two main sources of chemical contamination caused difficulties in the application of sewage sludge to land.

Metal Contamination

Research carried out in France, where metal levels in control plants and plants grown on soils improved with different types of organic waste including sewage sludge, indicated that no significant differences in metal levels occurred. The experiments were carried out over a period of six years and at the end the concentrations of Cadmium and Copper were higher than in the initial values in soils even in the controls. The differences in metal concentration observed with different treatments indicates that the organic wastes themselves play a role in the geochemical metal cycle. (Berthet et al., 1989).

According to EPA guidelines allowable metal concentrations are a function of soil cation exchange capacity. Suggested values are shown in Table 1.1.

Table 1.1 : Suggested limits of metal addition to agricultural crop land (kg ha^{-1}) (U.S. Environmental Protection Agency, 1983).

Metal	Soil cation exchange capacity (meq/100g)		
	5	5-15	15
Pb	560	1 120	2 240
Zn	280	560	1 120
Cu	140	280	560
Ni	140	280	560
Cd	5	10	20

If sludge application ceases after these limits are reached no detrimental effects on plant growth should be observed. (Mininni and Santori, 1987).

In considering the effect of heavy metal contamination of soils, the solubility of the metals is an important consideration. A German study concluded that the solubility of Zinc, Nickel and Cadmium in sludges and soils increases considerably with a decline in pH values. If sludge is to be used as a soil conditioner, Cadmium contents of between 1-1,5 mg/kg should not be exceeded in the interests of longterm soil protection. (Herms, 1987).

Organic Contamination

The polynuclear aromatic hydrocarbon (PAH) levels in soils subjected to 25 separate sludge applications over 23 years were found to be significantly higher than control areas. However these high values were the same as normally observed in urban soils. The sludge application had in fact raised the levels to the same level as in urban soils. This increase resulted from a total application of 44 kg PAH/ha over the 23 years. (Wild et al., 1990).

The presence and behaviour of organic contaminants in the soil depends on substance specific characteristics and a number of soil parameters. The regulation and control mechanisms of the soil are normally sufficient to fix this foreign matter and soil/plant transfer remains relatively low (less than 0,1). Plant animal transfer on the other hand amounts to about 5,0 as a result of the intake of soil or sludge during grazing. (Markard, 1988).

In 1991, a report on a situational analysis of sludge disposal stated that until that date no representative test results on the organo-pollutant load of sewage sludges was available. (Feigner et al., 1991).

However the availability of analytical technology which permits detection of organic contaminants in the parts per million or billion range has allowed the sludge ordinance to stipulate recurrent testing for organically persistent pollutants of sewage sludges used in agriculture. (Bergs, 1991).

In Germany inhibitory measures or restrictions on certain organics have resulted in measurable reduction of the input of these substances to the environment. Even in this technologically advanced country the great number and diversity of substances creates problems in monitoring. (Leschber, 1991).

The pollutant load in sludges in Germany today is considerably lower than limits established or being discussed and the sludge is therefore suitable for use in agriculture.

A long term utilisation concept for sewage sludges in agriculture should be accompanied by strategies which allow swift transition to another option. The use of sludge in agriculture is based on private law agreements and cannot be made mandatory. (Zillich, 1990).

Studies in the USA have shown that the half life of PCB's in the environment is dependent on the structure of the compounds. (Berthouex and Gan, 1991).

As a result of the increased agricultural use of sewage sludge, many countries are in the process of promulgating regulations to manage this practice.

The proposed regulations for disposal of sewage sludge as envisaged by the EPA have released a storm of criticism. One of the main concerns is that the regulations contain maximum application rates for land application of sludge containing certain elements, which make land application on a large scale impractical and therefore appear to be in conflict with the EPA's promotion of beneficial use of sludge. (Anon, 1989).

The limits proposed for the UK compared to those specified by the EEC are given in Tables 1.2 and 1.3. (Ramsay, 1988).

Table 1.2 : Permissible concentrations of heavy metals in sludge amended soils (mg/kg dry matter).

	EEC Values	Probable UK Limits
Zinc	150 - 300	300
Copper	50 - 140	135
Nickel	30 - 75	75
Cadmium	1 - 3	3
Lead	50 - 300	300
Chromium	awaited	600

Table 1.3 : Permissible annual average rate of addition of heavy metals sludge applications (kg/ha/a).

	EEC Values	Probable UK Limits
Zinc	30	15
Copper	12	7,5
Nickel	3	3
Cadmium	0,15	0,15
Lead	15	15
Chromium	awaited	40

This model comprises the following requirements :

- The use of sewage sludges must be organised by a person or organisation which farmers regard as "one of them".
- The control of the sludge quality must always be ensured.
- Considerable financial benefits should arise to all interested parties (farmers, sewage treatment plants, enterprises). (Rudolph et al., 1989).

The European Community has established objectives for waste management which are important in the context of sewage sludge disposal these are : (Truesdale, 1989)

- to reduce the quality of non-recoverable waste and ultimately abolish it;
- to recover, recycle and re-use waste for raw materials and energy;
- to manage non-recoverable waste properly and dispose of it in a harmless manner.

Despite the impending restrictions, a survey in the European Community indicates a saving in mineral fertilizers of 295 million DM, (R 600 million) by the use of sewage sludge. This economic advantage covers the cost of transport over 8 km and that of spreading liquid sludge.

South African Situation

Data obtained from Smith and Vasiloudis (1989) and processed by Ekama in 1992, revealed that approximately 47% of sewage sludge was being disposed of to sacrificial land. (See Figure 1.2).

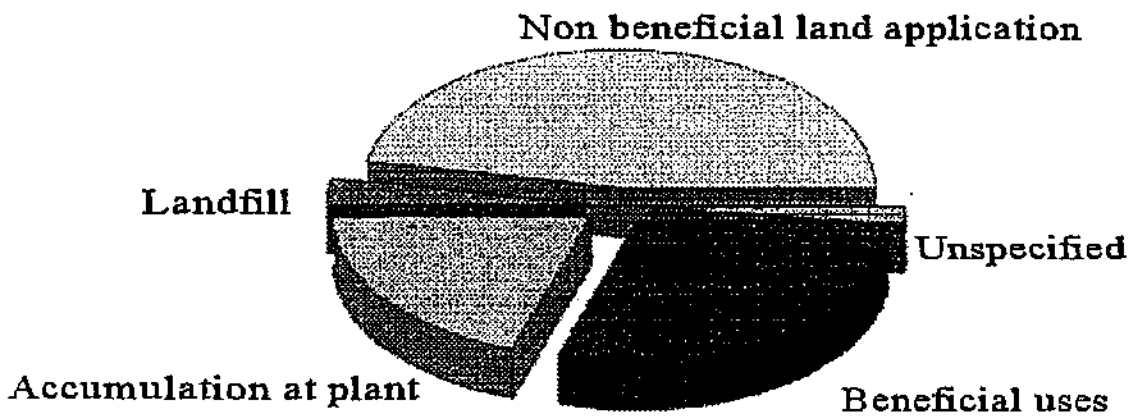


Figure 1.2 : Disposal of sludge in South Africa.

Of the 27% being disposed of in a beneficial manner half was to municipal parks and gardens. (See Figure 1.3).

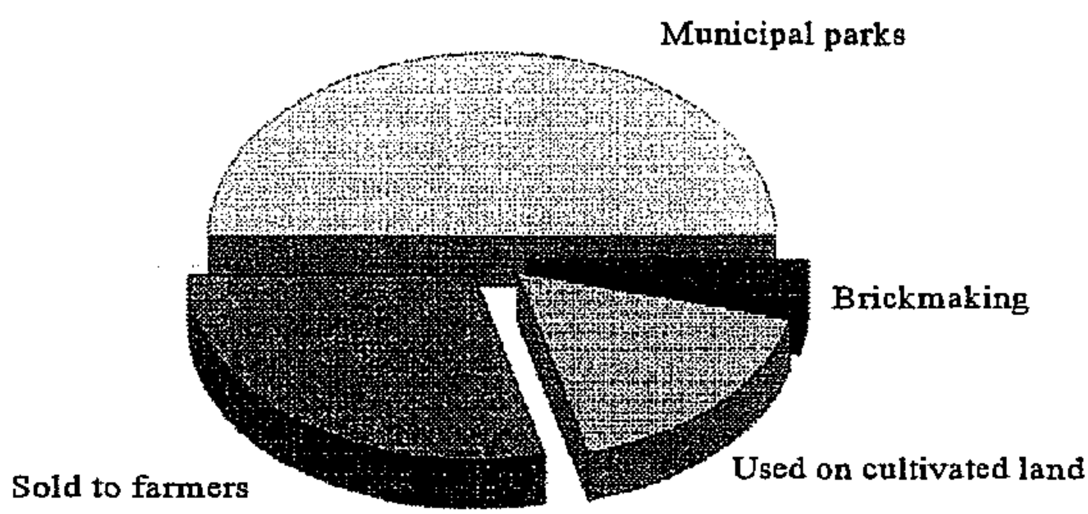


Figure 1.3 : Beneficial use of sludge in South Africa.

1.2 DISPOSAL OPTIONS FOR SEWAGE SLUDGE IN JOHANNESBURG

Composting had already been shown to be a satisfactory option at the Northern Works and was pursued at this plant. It is estimated that 300 t/d of sewage sludge will be generated by wastewater treatment in the Southern Drainage Basin by the year 2014. In order to safely dispose of this amount of sludge a sludge handling strategy had to be developed. The strategy selected had to comply with the following criteria :

- Environmentally acceptable;
- Cost effective;
- Minimum risk;
- Operationally feasible; and
- Politically acceptable.

A project team was formed comprising the two consulting firms who were involved with the extensions to the Olifantsvlei and Bushkoppie plants and Council officials from the Wastewater and Scientific Services Departments. All available options for sludge conditioning and disposal were evaluated. The options considered and the final selection are summarized below.

In view of the sensitivity of sewage sludge disposal in the eyes of the public and the Government authorities it was considered essential to investigate every possible means by which the sludge could be disposed of. Unfortunately there is no single means of sludge disposal that could be acceptably applied, instead there are various steps through which the sludge must proceed in order to be in a suitable condition for the numerous final disposal techniques available. With this in mind, the treatment options were investigated in five categories, namely pre-treatment, conditioning, thickening, dewatering and final disposal.

<u>Pre-treatment</u>

The purpose of pre-treatment is to reduce the volume and mass of sludge and to alter its properties to suit downstream processes, usually in terms of the stability and odour potential of the sludge. Two processes were investigated in this section.

<u>Anaerobic Digestion</u>

The sludge undergoes bacteriological digestion under anaerobic conditions at mesophyllic temperatures (20-40°C). The volatile components of the sludge are reduced in mass and reductions of 30 percent in overall mass were allowed for raw sludge and 15 percent for WAS. Biogas (a mixture of methane and carbon dioxide) is produced as a by-product, at a rate of $1 m^3/kg$ VSS removed.

<u>Dual Digestion</u>

Both aerobic and anaerobic bacteriological digestion take place. This option was not considered in great detail due to the difficulties associated with dewatering the sludge produced by this process, the fact that pure oxygen is required in the aerobic phase, and patent restrictions on the process.

Conditioning

The objectives of conditioning are simply to prepare the sludge for the downstream thickening and dewatering processes so that maximum concentrations of suspended solids can be achieved. Three conditioning systems were investigated.

Aerobic Conditioning

One of the major objectives of aerobic conditioning is to reduce the potential of phosphorus contamination of the liquors that result from downstream thickening and dewatering processes. Sludge liquors contain considerable quantities of phosphorus in solution and in fine colloidal suspension and the aim of aerobic conditioning is to bind the phosphorus in the solid phase and thus prevent problems with the treatment of liquors downstream. Lime is used as the calcium source for binding the phosphorus and the aerobic conditions favour the chemical and bacteriological processes that are required to minimise the dosage of lime.

Chemical Conditioning

The conditioning of sludges by chemical addition modifies the thickening and dewatering characteristics of the sludge by improving the specific resistance to filtration (SRF) and thereby increasing the solids concentration of the thickened and dewatered sludge. The traditional chemicals that are used for conditioning are lime, ferrous sulphate, ferric chloride, aluminium chlorohydrate and a host of synthetic polyelectrolytes.

Thermal Conditioning

Thermal conditioning (Zimpro) is a heat treatment process in which the sludge is subjected to temperatures of between 170°C and 200°C at pressures between 2 200 and 2 500 kPa. The temperature and pressure break down the cell structure of the organic constituents which reduces the overall mass of the sludge and substantially improves its dewatering characteristics. Approximately 20-30 percent of the volatile suspended solids are oxidized or solubilised and the heat treatment results in a pathogen free sludge, which dewaters very well (Smollen, 1986). However between 20 and 30% of the sludge is resolubilized leading to supernatant liquors with a COD of around 10 000 mg/ℓ being returned to the biological treatment process.

Thickening

The sludge conditioning operations are usually carried out at a solids concentration of about 2 percent solids. At this concentration the sludge is too watery to be dewatered efficiently and therefore a thickening step is required to increase the solids concentration of the sludge to around 6 percent. Three techniques for thickening sludge were investigated.

Gravity Thickening

This is the most simple form of sludge thickening and is carried out in a conically shaped vessel using the force of gravity to concentrate the sludge at the bottom of the thickener, from where it is drawn off. Its biggest advantage is that it is a simple system with few moving parts.

Linear Screens

Linear screens also make use of the force of gravity to separate the solid and liquid phases, but in this case the solids are retained on a moving porous cloth onto which the sludge is distributed. The thickened sludge passes off the end of the cloth screen and the liquid is collected in a dish below the screen. The method of thickening is more costly than gravity thickening but does have specific applications with certain dewatering equipment.

Dissolved Air Flotation (DAF)

This process thickens sludge by making use of finely dispersed air bubbles which float to the liquid-air interface carrying with them the sludge solids. The flotation properties of the sludge influence the performance of this system significantly and it tends to work better with WAS as apposed to raw sludge.

Dewatering

Dewatering of sludges is a very important step in an overall sludge disposal system since it reduces the volume of the sludge and improves its handleability by, for example, enabling the sludge to be spadable. There are many dewatering techniques and six processes were investigated.

Filter Belt Presses

Filter belt presses utilise two endless belts of porous polyester material in between which the thickened sludge is compressed. The water from the sludge passes through the belts and the solids are retained between the belts. The performance of belt presses depends very much on the composition of the sludge i.e. whether it is raw sludge, digested sludge or WAS.

Centrifuges

By rotating at high speeds the centrifuge is able to separate liquid from the sludge and achieve a high degree of solid/liquid separation. The composition and dewaterability of the sludge fed to the centrifuge does influence the solids concentration of the final cake.

Rotary Drum Vacuum Filter

The sludge is dewatered by applying a vacuum to the interior of a rotating drum, which is covered with a filtration cloth.

Vacuum Belt Filter

This system operates on a similar principal to the rotary drum vacuum filter. However, instead of the filter cloth rotating on a drum, it moves horizontally across both gravity and vacuum assisted filtration zones.

Filter Presses

This system consists of a number of vertically hung rectangular recessed plates covered with a filter media. The sludge is pumped into the chambers formed by the recessed plates. Filtrate passes through the filter cloth and is directed to drainage ports. As the volume of sludge in the chambers reduces so more sludge is pumped in under pressure. At the end of the press cycle the plates are separated allowing the dewatered sludge to drop off onto a conveyor system below. These units are often operated in a batch mode, but with multiple presses and automation can allow continuous processing of the sludge..

Solar Drying Beds

In this system the sludge is pumped or gravity fed onto open air coarse sand beds which are constructed over a system of collection pipes. Most of the liquid drains through the sand and is discharged, while the sludge remains behind on top of the sand. The heat from the sun dries the sludge over a period of several days (typically 6 - 10 days) after which it is removed manually with a spade or mechanically with specially adapted machinery. A number of sludge drying beds must be available so that sludge can be continuously deposited onto beds which have had the dried sludge removed.

Final Disposal Processes

Twelve final disposal process options were considered, each of which is briefly described below.

High Lime Process

In this process lime $Ca(OH_2)$ is mixed with dewatered sludge to raise the pH of the mixture to pH 12,5. The reaction of the lime with the water in the sludge is exothermic and results in an increase in temperature of the sludge, which is controlled to a minimum of 52°C for at least 12 hours. The resultant product is a pathogen free, low odour potential soil-like product which is easy to apply to land as a reclamation material or a cover mater for landfills.

Direct Agriculture Use

In this process sludge is applied to land for purposes such as sod farming in which the material content of the sludge is used as a growth medium for the instant lawn. Liquid sludge can also be applied to farm land directly when its metals and nitrogen concentrations are not excessive, however, this does require the use of special equipment for the application.

Composting

Composting is an aerobic thermophilic biological process in which the organic matter in the sludge is decomposed and heat is generated as a result. The end product is a relatively stable, pathogen free, humus-like material, low in nutrients which can be applied to domestic gardens and agricultural lands. There are a number of factors which influence the success of a composting installation. An important one is the carbon-nitrogen ratio in the sludge, which is influenced by the composition of sludge being treated and disposed of. Another important consideration is the bulking agent, which has the role of allowing air into the composting pile to maintain aerobic conditions and ensure that suitable temperatures (60°C) are achieved in the mix to kill the pathogenic organisms.

Co-disposal on Landfill

This process involves the mixing of dewatered sewage sludge with municipal solid waste and disposal onto municipal landfill sites. It involves transport (usually by road) of the dewatered sludge to the landfill site, and its overall cost is obviously influenced by the proximity of the landfill site to the sludge dewatering facility. The solids concentration of the sludge after dewatering is also of importance in regard to what the landfill site will accept for disposal.

Mining Disposal

This option covers a number of possible avenues for the disposal of sewage sludge within the mining industry, such as : down disused mine shafts, in the rehabilitation of areas of ground where slimes dams have been removed, for conditioning existing slimes dams to allow vegetation to be grown, and co-disposal with mine tailings.

Incineration

Incineration is a high temperature (900°C) process which burns the sludge and reduces it to a sterile ash of 35-45 percent of the original mass of sludge. Two incineration options were addressed, one utilising totally imported technology, and the other utilising partially imported and partially South African Technology. Modern incineration systems are able to operate in the autothermal mode i.e. utilising the natural calorific value of the sludge as the sole energy source. Air pollution potential has to be considered with this disposal method.

Drying and Pelletization

These systems provide a means of converting a dewatered sludge to a usable end product such as a fuel, in the form of brickettes. The drying option can be either partial (to about 50 percent solids), in which case the system could be used ahead of another disposal method such as composting or incineration, or full drying when the solids concentration is increased to in excess of 90 percent prior to pelletization.

Active Sludge Pasteurization (ASP)

This is a recently developed process in which anhydrous ammonia and phosphoric acid are sequentially added to a dewatered sludge at about 15 percent solids concentration.

The addition of chemicals has a dual effect; firstly increasing the pH to approximately pH 11,5 initially, and then by a series of exothermic reactions increasing the temperature to greater than 65°C to enable pasteurization to take place.

The resultant product in a liquid "fertilizer" with enhanced nutrient concentrations (2,5% N; 4,7% P) reportedly free from pathogens.

Sacrificial Land Disposal

This disposal method involves applying sludge directly to land, allowing liquid to evaporate and seep away, ploughing the land over, and continuing the cycle. The continuous application of sewage sludge at high loading rates to the same area of land over an extended period of time renders it unsuitable for future agricultural use - hence the name sacrificial land disposal. This is the current method of disposal used at Olifantsvlei. Various options were investigated which addressed different sludge loading rates, sludge solids concentrations and the use of underdrains to prevent contamination of underground water resources with, in particular, nitrogen. Metals present in the sludge tend to be chelated into the soil matrix and bound there minimising any potential pollution due to metals.

Brickmaking and Allied Fields

This disposal method addressed a number of recently developed means of disposing and utilising sewage sludge. In the production of bricks various concentrations of sewage sludge are added to the clay to produce the required finish on the brick i.e. stock bricks or face bricks. Dried sludge is also used in this industry as a fuel for firing the brick ovens. Other areas that were identified for using sewage sludge were as a soil supplement for cotton and as a growth medium for mushrooms.

Co-combustion in Coal Fired Power Stations

The City Council owns and operates the 300 MW Orlando Power Station which is in fairly close proximity to the Southern Basin. This option involved dewatering sludge and transferring it to the power station to be mixed and burnt together with the coal used to fire the boilers. It was established that considerable upgrading of the power stations gas emission cleaning equipment would be necessary and that the useful life of the power station itself was not known.

Final Options

Cost comparisons for overall treatment to final disposal showed co-disposal in a landfill as the least expensive, followed by sacrificial land disposal, static pile composting, incineration (SA technology) Composting (Windrows) High lime process and incineration (UK technology).

Four options were identified as worthy of further consideration. These were the following :

- Co-disposal in landfill
- Remote farm disposal
- Composting
- Incineration

Composting and co-disposal in landfills are discussed further in this report.

CHAPTER 2

CO-DISPOSAL OF SEWAGE SLUDGE WITH DOMESTIC REFUSE

2.1 OPERATION OF THE LANDFILL

The Goudkoppies landfill is a modern sanitary landfill designed for minimal adverse environmental impact. This landfill accepts refuse from the southern areas of Johannesburg as well as Soweto, and handles approximately 1 300 t daily.

Digested mixed sludge from the Goudkoppies anaerobic digesters is pre-conditioned via aeration and lime addition and dewatered on beltpresses. Sludge of an average of 17% total solids is obtained by this method.

While the water balance of the landfill is not adversely affected by the disposal of larger quantities of sludge, difficulties with the compaction equipment limit the mixing ratio of sludge to domestic refuse to 1:9. Preliminary experiments with solar drying have indicated that increasing the solids content to above 35% allows this ratio to be increased to 1:3.

The landfill tariff is also based on a rate per ton of wet sludge, thus resulting in reduced costs if the sludge is dryer. Difficulties with the compaction equipment, not being able to operate successfully when ratios higher than 1:9 of dewatered sludge have resulted in less sludge than originally anticipated being disposed of by this route. It is considered essential to study solar drying in greater detail in an attempt to increase this as a disposal route.

2.2 LEACHATE MONITORING

No leachate has been observed in the collecting drains which were constructed under the cells which are used for co-disposal.

Nine boreholes were sunk prior to the opening of the Goudkoppies landfill sites. Two of these boreholes are dry, and the remaining seven continue to be analysed on a two-monthly basis.

The following tests are undertaken on each sample :

Total Dissolved Solids
Chemical Oxygen Demand
Oxygen Absorbed
Ammonia
Nitrate
Nitrite
ortho-Phosphate
pH
Conductivity
Alkalinity
Chloride
Potassium
Sulphate
Total Hardness
Calcium Hardness
Aluminium
Cadmium
Chromium
Copper
Iron
Lead
Manganese
Nickel

2.2

The results are shown in Figures 2.1 to

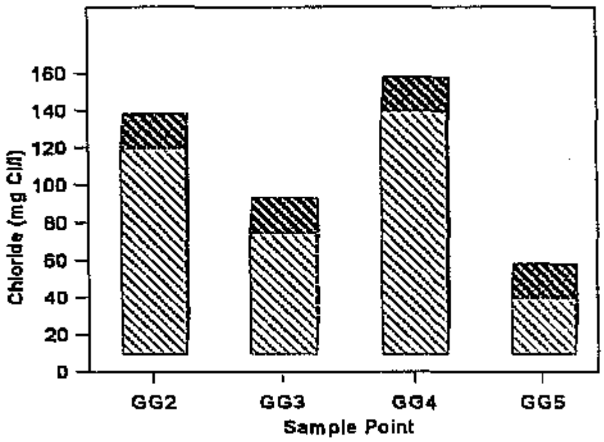


Figure 2.1 : Chloride levels on boreholes in vicinity of Goudkoppies landfill

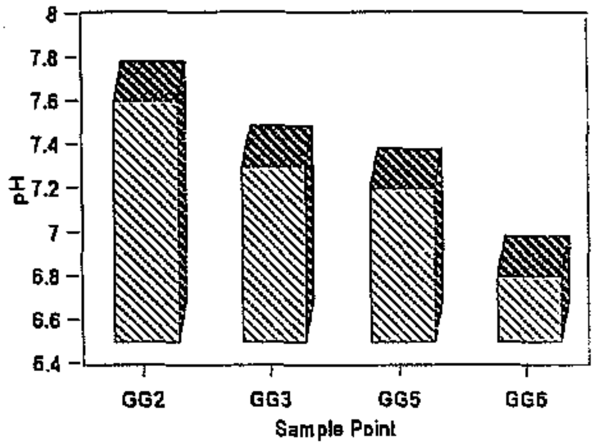


Figure 2.2 pH levels in boreholes in vicinity of Goudkoppies landfill

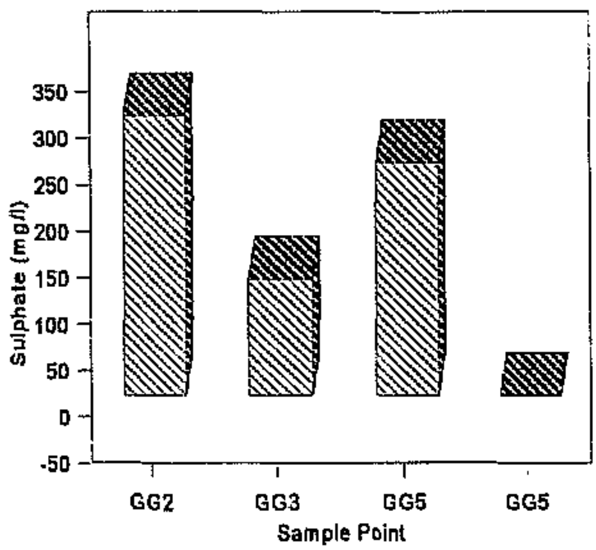


Figure 2.3 Sulphur levels in boreholes in vicinity of Goudkoppies landfill

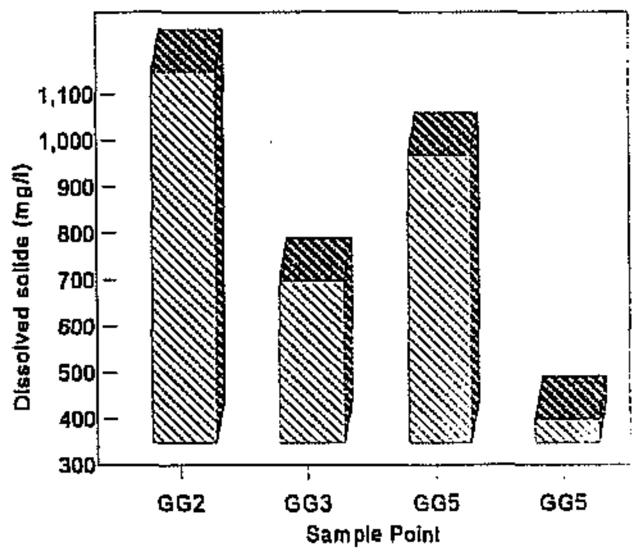
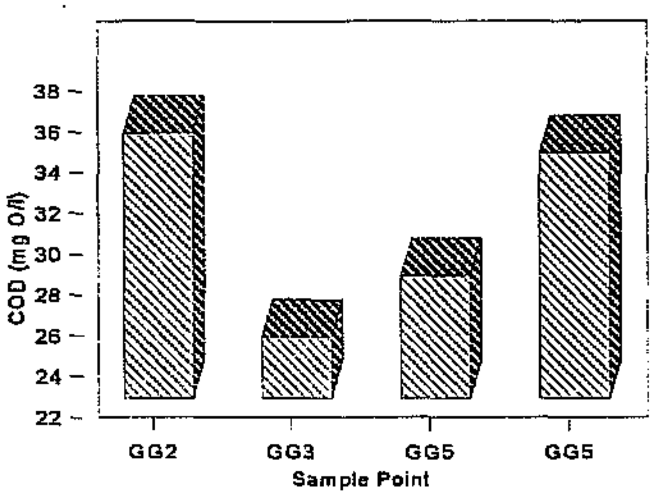


Figure 2.4 Dissolved solids in boreholes in vicinity of landfill



CHAPTER 3

SLUDGE DISPOSAL TO SACRIFICIAL LAND

The Council has been disposing of sewage sludge to sacrificial land at the rate of 100 kg/m^2/a for the last fifteen years, at the Olifantsvlei Wastewater Treatment Plant. Sludge is applied to paddies and ploughed into the soil. Boreholes were sunk in the vicinity of the lands in order to monitor the groundwater quality.

These are 100 mm diameter lined boreholes with depths between 20 and 39 m. The holes are numbered OS0 to OS6 with OS0 being the control. During 1986 when additional land was made available for this activity three additional boreholes were sunk, namely OS7, OS8 and OS9. The most significant indicators of pollution were the COD and nitrate levels. See Tables 3.1 and 3.2.

Table 3.1 : Annual average COD (mgO/ℓ) levels in Olifantsvlei boreholes.

Year	OS0	OS1	OS2	OS3	OS4	OS5	OS6	OS7	OS8	OS9
1981	18	17	50	23	33	22	13	-	-	-
1982	13	13	45	18	25	25	14	-	-	-
1983	23	19	26	22	30	29	22	-	-	-
1984	15	24	33	27	32	22	34	-	-	-
1985	26	25	41	33	40	27	32	-	-	-
1986	15	18	54	20	130	25	-	17	140	20
1987	26	16	62	37	120	94	-	28	158	36
1988	17	32	35	20	-	-	-	27	135	32

Table 3.2 : Annual average nitrate (mgN/ℓ) levels in Olifantsvlei boreholes.

Year	OS0	OS1	OS2	OS3	OS4	OS5	OS6	OS7	OS8	SO9
1981	24	39	20	123	213	190	95	-	-	-
1982	47	46	54	132	241	200	120	-	-	-
1983	64	49	77	136	235	212	112	-	-	-
1984	69	45	75	94	215	180	96	-	-	-
1985	67	50	88	93	340	91	66	-	-	-
1986	59	59	103	115	218	133	-	37	126	2
1987	69	57	103	99	165	-	-	32	44	27
1988	62	50	60	88	-	-	-	82	26	6

The control sample OSO also shown signs of contamination, indicating that the groundwater may not be separated in the vicinity of these boreholes.

In spite of the apparent contamination of the control borehole, which eliminates its use as a control a clear indication of the negative impact of sludge disposal to land is clear from the elevated levels of COD and nitrate in a number of the boreholes. This sampling programme was not intended as a full geohydrological study but rather to serve as an indication of the impact of this disposal practice. This objective has been achieved.

In 1988 sampling was discontinued until 1993 when monitoring recommenced. Results of full analysis for 1992/93 are given in Table 3.3.

Table 3.3 : Average quality of Olifantsvlei boreholes : June 1992 to April 1993.

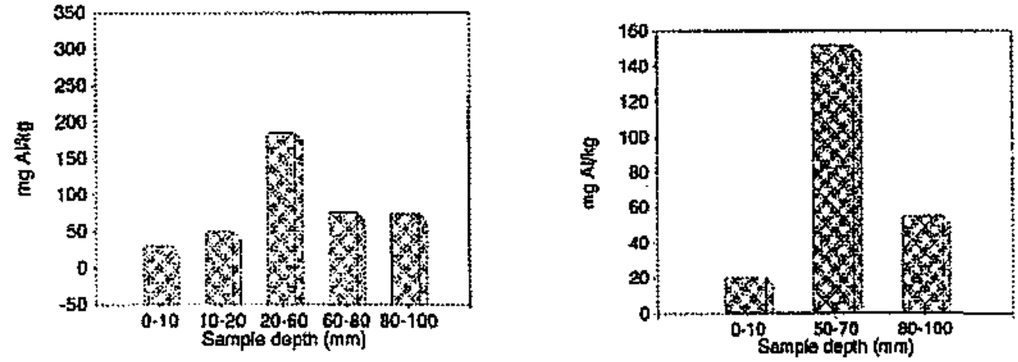
Parameter	OS0	OS2	OS3	OS7	OS8	OS9
COD as O	30	34	27	79	100	52
Nitrate as N	85	110	110	27	81	6,1
Ortho-phosphate as PO_4	0,23	0,10	0,02	0,58	0,49	2,5
pH	5,4	5,8	5,9	6,0	7,0	7,3
Conductivity as mS/m	85	130	120	53	260	92
Chloride as Cl	60	140	63	61	120	97
Alkalinity as $CaCO_3$	9	52	60	36	510	200
Sulphate as SO_4	3,0	11	42	8,7	170	80

Although pollution levels vary considerably over time probably as a result of geohydrological phenomena, the latest results again clearly demonstrate the negative impact of sacrificial land disposal on groundwater quality.

During 1991 samples were taken from this area by the Department of Agriculture and analysed for the presence of metals. At the same time an area to which no sludge had been added was also sampled. See Figure 3.1 to 3.9.

As the sludge is ploughed into the land, a relatively homogenous mixture of sludge and soil is expected throughout the soil profile where the samples were taken. Some metals, like Aluminium appear to move fairly readily through the soil, while others like Zinc, Manganese, Nickel, Cobalt, Copper and Cadmium appear to remain at the surface.

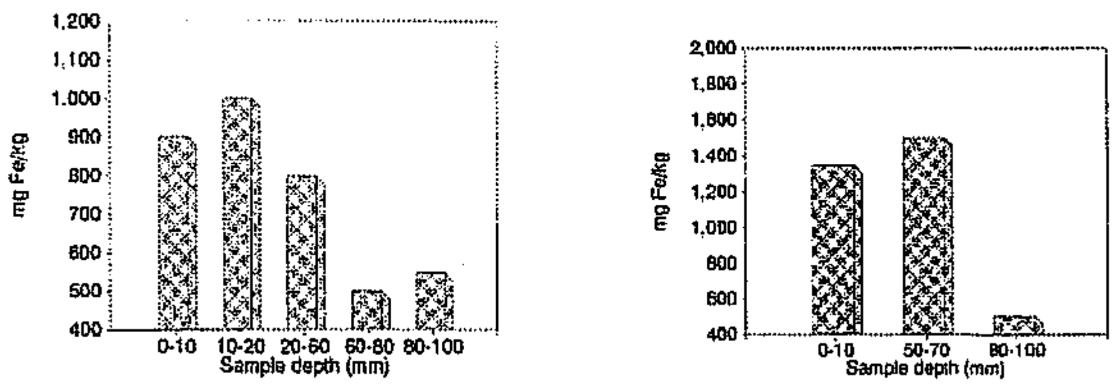
The highest concentrations of each metals are compared with the control (no sludge) and maximum limit set by the Department of National Health and Population Development for soils for agricultural use in Table 3.4.



A: after sludge application.

B : no sludge application

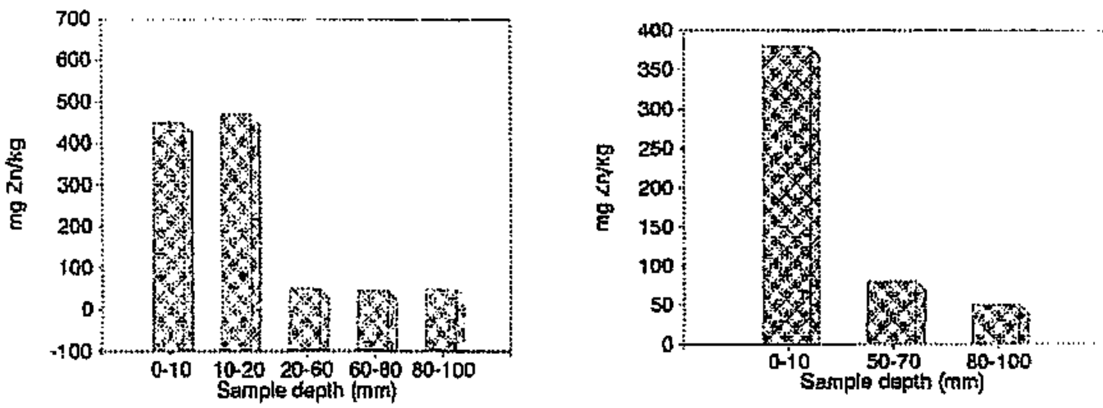
Figure 3.1 Aluminium levels in soils at different depths.



A : after sludge application.

B : no sludge application

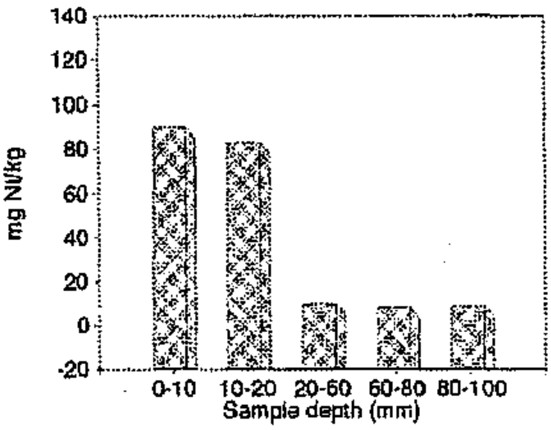
Figure 3.2 : Iron levels in soils at different paths.



A : after sludge application.

B : no sludge application

Figure 3.3 : Zinc level in soils at different depths.



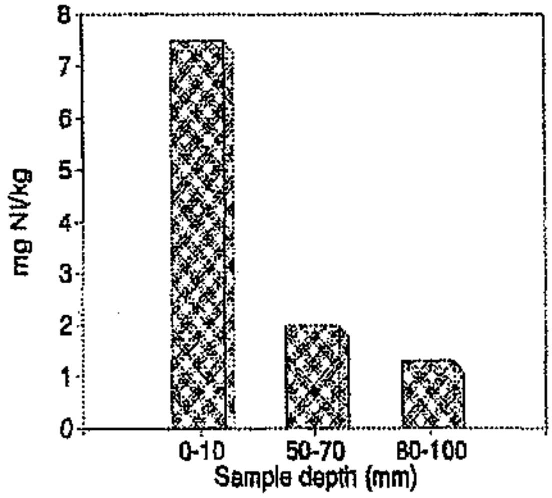
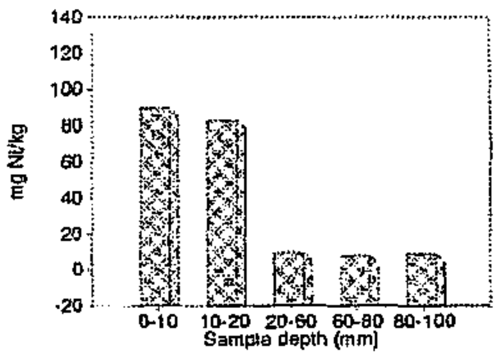


Figure 3.4 : Manganese levels in soils at different depths.
A : after sludge application

B: no sludge application



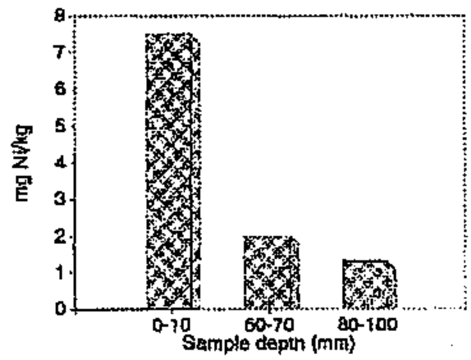
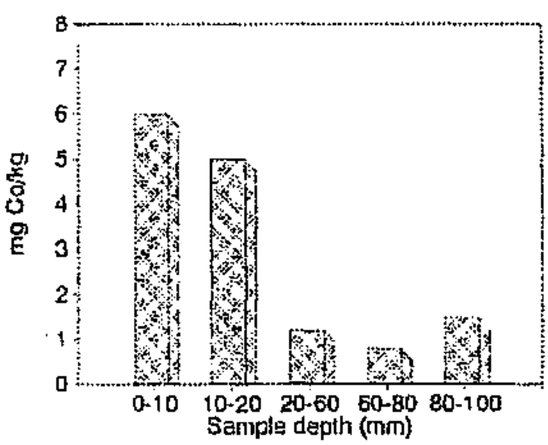


Figure 3.5 : Nickel levels in soils at different depths.
A : after sludge application

B: no sludge application



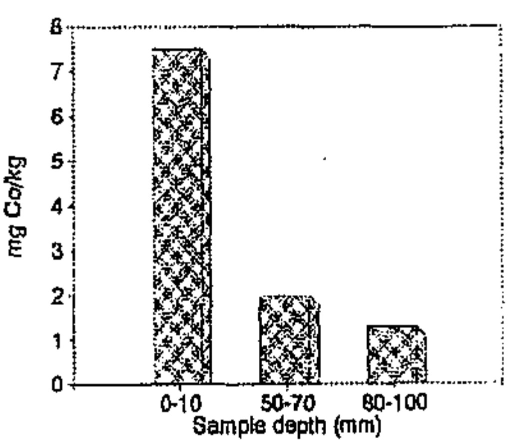
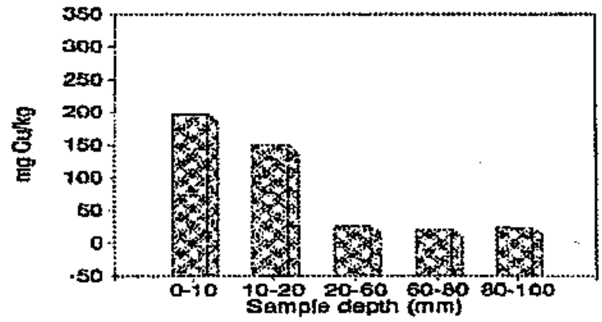
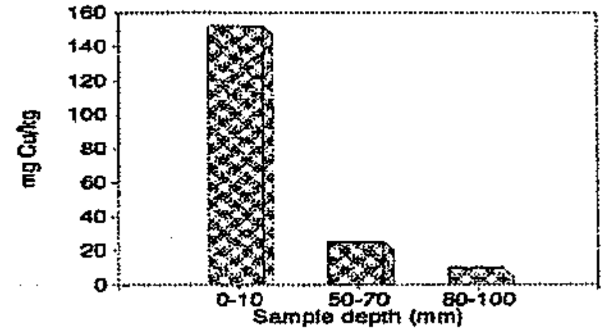


Figure : 3.6 Cobalt levels in soils at different depths.

B : no sludge application

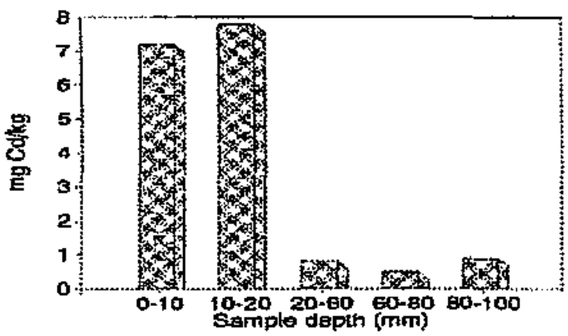


A : after sludge application

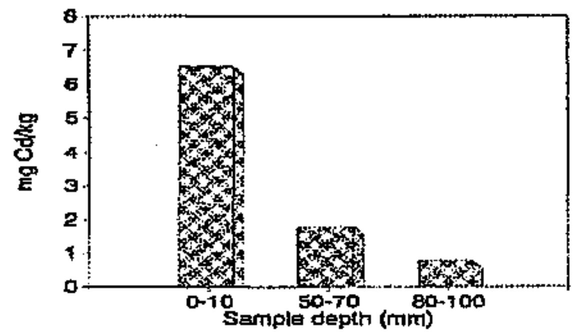


B : no sludge application

Figure 3.7 Copper levels in soils at different depths

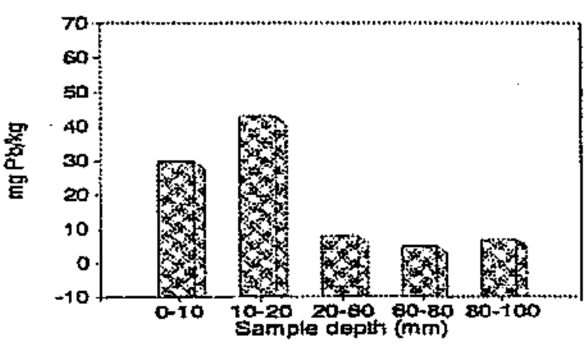


A : after sludge application

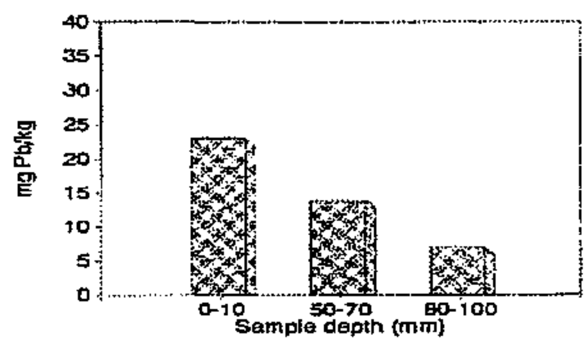


B : no sludge application

Figure 3.8 : Cadnium levels in soils at different depths.



A : after sludge application



B : no sludge application

Figure 3.9 Lead levels in soils at different depths

3.4 : Comparison of soil metal concentrations with and without sludge application. (100kg/m²/a for 15 years)

Metal	No Sludge	With Sludge	Maximum
Cadmium as Cd (mg/kg)	6,5	7,8	2
Copper as Cu (mg/kg)	152	195	100
Lead as Pb (mg/kg)	23	42	56
Nickel as Ni (mg/kg)	80	87	15
Zinc as Zn (mg/kg)	370	450	185
Cobalt as Co (mg/kg)	7,5	6	20

While the metals levels are in most cases way in excess of the maximum limit laid down by the Department of National Health and Population Development, the addition of sludge has in most cases not exacerbated this situation unduly as soils with no sludge addition do not comply with these limits in many cases.

The lack of movement of the metals would facilitate rehabilitation of the soil if this were required.

However the groundwater pollution caused by this activity renders it an unacceptable disposal route. A further disadvantage of this route is the unproductive use of land relatively close to an urban centre where rapid urbanisation is currently taking place, and the negative environmental impact of odours, which may be generated if the digestion process should be impaired for any reason.

CHAPTER 4

REGULATORY ASPECTS

Discussions with the Department of Water Affairs and Forestry have revealed that future effluent discharge permits will require compliance with the "Guide on Permissible Utilisation and Disposal of Sewage Sludge" as well as any requirements which may be set by the Department of Agriculture.

In view of the fact that the statutory enforcement of the requirements will place a heavy burden on wastewater treatment plant operators, it is considered essential to discuss some aspects of the Guide in greater detail.

The quality requirements from the two bodies in respect of soil and sludge are set out below.

Table 4.1 : Comparison of chemical requirements.

	Health Guide		Agricultural Development	
Compound	Soil (mg/kg)	Sludge (mg/kg)	Soil (mg/kg)	Sludge (mg/kg)
Arsenic	2	15	20	80
Cadmium	2	20	3	20
Chromium	80	1 750	100	1 200
Copper	100	750	100	1 200
Lead	56	400	100	1 200
Mercury	0,5	10	2	25
Nickel	15	200	50	200
Selenium	2	15	5	-
Thallium	-	-	1	-
Uranium	-	-	5	-
Zinc	185	2 750	300	3 000
Boron	10	80	25	100
Cobalt	20	100	-	-
Molybdenum	2,3	25	-	-
F^- fluoride	50	400	200	-
CN^- cyanide	-	-	5	-

As can be seen from Table 4.1 the two Departments require significantly different levels for some parameters in soils. Discussions with the two Departments have revealed that negotiations are currently underway to reach agreement on a single limit for each parameter. It is imperative that this agreement be reached before the Guide is enforced via effluent discharge permits. Comparison of these values with international limits in Table 4.2, reveal that many are more stringent than required by those countries.

Table 4.2 : Comparison of South African and International limit values for soil in mg/kg.

Compound	Maximum EEC values	Probable UK values	SA Limits for Soil	
			Health	Agriculture
Zinc	300	300	185	300
Copper	140	135	100	100
Nickel	75	75	15	50
Cadmium	3	3	2	3
Lead	300	300	56	100
Chromium	-	600	80	100

Biological requirements are summarized in Table 4.3.

Table 4.3 : South African Health Department's biological requirements for composted sewage sludge.

Parameter	Maximum/10 g dry sludge
Viable ascaris ova	nil
Salmonella organisms	0
Faecal coliforms	1 000

In order to determine whether Ascaris ova are viable or not, the eggs are incubated under optimum conditions for a period of one month. Not all eggs which have commenced development before incubation actually develop to an infective or worm stage. Generally in a sample of sludge where 95% of the eggs show a degree of development before incubation only 65% of the eggs continue to develop to an infective stage after incubation for one month.

The ova are classified into the following categories :

1. Fully developed worm inside the egg shell
2. Partly developed egg
3. Single cell egg, no apparent damage

4. Degenerated obviously rendered as non viable

All the ova in 3 and 4 are classified as non viable. Those in 1 and 2 were viable at some stage and the proportion of ova falling in these two categories provide the figure for viable ova. However those falling in 2 being able to fully develop to the infective stage under ideal conditions of temperature and moisture can be presumed to have died in a divided state. Thus only those eggs falling in category 1 are classified as potentially infective.

If viable eggs have not progressed to a developed, potentially infective stage after incubation under optimum conditions, it is highly unlikely that they will develop further at a later stage in the product offered for sale. As the aim of this guideline is to protect human health, it is suggested that the quality standard be amended to "no potentially infective Ascaris ova per 10g dry sludge" for type C and D sludge.

In the case of faecal coliforms the standard specifies "immediately after treatment". The Salmonella limit should be treated in the same way as recontamination is just as likely to occur as with faecal coliforms.

The organic contaminants requirements for the two Departments are given in Table 4.5.

Table 4.5 : Comparison of organic chemical requirements.

Compound	Health		Agricultural Development	
	Soil (mg/kg)	Sludge (mg/kg)	Soil (mg/kg)	Sludge (mg/kg)
Pesticides :				
- for each	-	-	0,5	3
- in total	-	-	2	10
Organic Compounds :				
Polycyclic aromatic hydrocarbons (total)	-	-	5	30
Poly chlorinated Biphenyls (total)	-	0,70	0,5	2
Hexachlorobenzene	-	-	0,1	1
Pentachlorophenol	-	-	0,1	0,5
β - BHC (lindane)	-	-	0,1	0,5
Aldrin + Dieldrin	-	2,0	-	-
Benzo-a-Pyrene	-	16,25	-	-

Table 4.5 : contd.

Chlordane	-	150	-	-
DDT + DDE + DDD	-	0,6875	-	-
Dimethyl nitrosamine	-	4,8750	-	-
Heptachlor	-	4,625	-	-
HCB	-	4,875	-	-
Hexachlorobutadiene	-	42,5	-	-
Lindane	-	575,0	-	-
Toxaphene	-	6,0	-	-
Trichloroethylene	-	1,625	-	-

In addition to the specific limits described above, the Guide places specific contractual obligations on the vendor and purchaser.

It is considered totally impractical to enter into contractual agreements in all cases. Particularly in the case of type C or D sludge, the purchaser may well be outside the jurisdiction of the vendor local authority which renders the type of control envisaged impractical if not impossible. As there is no health risk attached in a case of type C and D sludges it is suggested that this requirement only be enforced in respect of type A and B sludge where a direct health risk still exists. In addition the contractual requirements are more stringent in respect of type A, B or C sludge than the quality standards required in Table 1 (of Guide).

It is considered that in view of the impending repeal of the exemption in respect of sale of composted sewage sludge by the Department of Agriculture, which will result in all sludges being sold as fertilizers, requiring registration and therefore compliance with a mandatory quality standard that the contract agreement only be required in respect of Types A and B sludge.

In a review of the agricultural use of sewage sludge in South Africa, Korentajer (1990) concluded that :

"Sewage sludge is a valuable resource material, used as a fertiliser and a soil conditioner by farmers in many countries in the Western world. The main benefits of sludge application to the farmer are : provision of major plant nutrients (in particular N and P), increased supply of some of the essential micronutrients (in particular Zn, Cu, Mn and Mo) improvement in the soil structure, and increased soil water-holding capacity. Sludge can generally be considered as a slow-release fertiliser material which can be used as a maintenance fertiliser on perennial crops, e.g. sugar-cane, fruit trees and grasses. It can be of particular benefit in cases where the availability of nutrients from commercial inorganic fertilisers is low due to factors like high leaching losses (in the case of NO_3-)$_3$ or high soil-P fixing capacity".

In spite of the proven benefits of sewage sludge application, its use in agriculture is limited by factors such as the presence of pathogenic organisms, nitrate contamination of ground water, toxic organics, and heavy metal transmission in the food chain. Of these factors, the transfer of heavy metals and pathogenic organisms from soil to crops, grazing animals and humans, appears to be the greatest potential health threat. Consequently, most of the existing guidelines for sludge application on land limit the amounts of sludge that can be applied on land, according to their heavy metal content (in particular the content of Cd) and the presence of certain pathogenic organisms.

In view of the beneficial effect that composted sewage sludge could have on South African agricultural land, it is considered essential that the Disposal Guidelines be reviewed in the context of a more pragmatic approach.

The potential negative health and environmental impacts of the beneficial use of sewage sludge need to be weighed against the benefits, which may be achieved. The focus of the Guidelines should be on the safeguarding of human health and the availability of Agricultural land. Maximum concentration limits for various parameters should be set realistically after due consideration of prevailing South Africa conditions rather than in competition with developed countries.

Limits such as are proposed for organic compounds place an excessive burden on the country's analytical capacity. For example why analyse every batch of sewage sludge for organic contaminants, which may not even be present in the specific drainage basin. More detailed proposals in this regard are presented in Chapter eight.

CHAPTER 5

COMPOSTING

5.1 METHODOLOGY

5.1.1 Experimental Heaps

Belt pressed waste activated sludge was solar dried on beds to increase the dry solids concentration from 15% to between 30% and 40%. The dried sludge was then mixed with woodchips in the ratio of 1:1 (by volume) by front-end loader. Two 20m^3 trial compost heaps were formed and covered with approximately 80mm of dried crushed digested primary sludge. One trial heap was aerated for 90 seconds per hour by radial vane blower and the other left unaerated. Daily temperatures were taken in various positions in both heaps for a period of 21 days thereafter, the bulking agent was removed by mechanical sieve and the separate piles cured for a further 21 day period. See Figure 5.1 for temperature profiles.

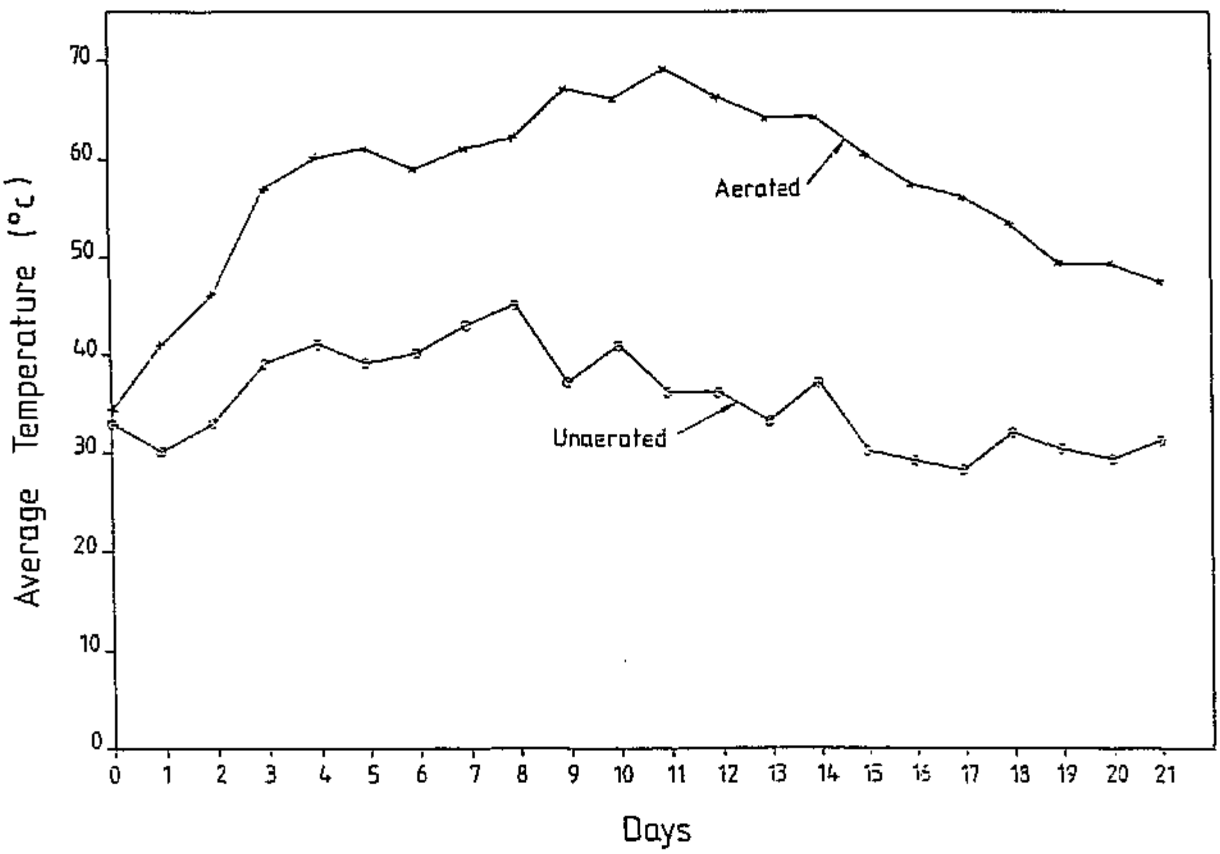


Figure 5.1 : **Comparison of temperature profiles in aerated and unaerated compost piles.**

Pilot scale studies using different mixtures demonstrated that the use of solar dried sludge : hay : kraal manure mixtures in the volume ratio 4:2:4 allowed piles to attain temperatures in excess of 60°C. The use of blowers to aerate the piles was essential.

However the use of kraal manure in the mixture exacerbated the odour problem and this was discontinued. The solar drying of the dewatered sludge continued to be a tedious and costly operation, so it was decided to recycle composted material into the new heaps at a volume ratio of 1:1. When supplemented with grass the moisture content of the mixture was within recommended limits. Temperatures in excess of 70°C were achieved with this mixture. See Figure 5.2.

Composting on a large scale (25 dt/d) was then initiated. In order to save space it was decided to form windrows instead of individual heaps.

A mixture of one part dewatered sludge to one part compost recycle to 0,5 parts thatch grass was used. Each window represented one week's production of compost and was aerated for 5 minutes per hour for 21 days. After the composting period, the aeration period was increased to 10 minutes per hour for the next 7 days.

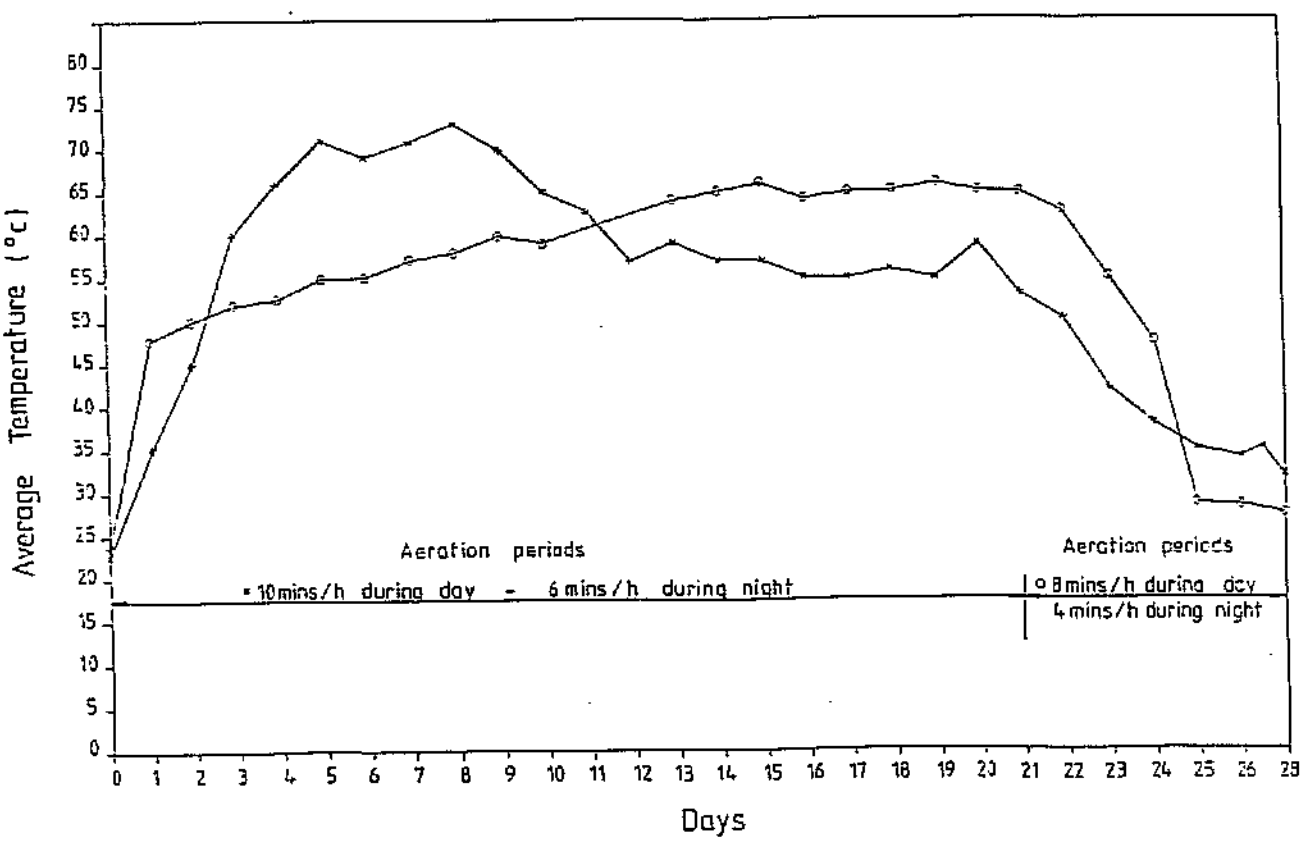


Figure 5.2 : Temperature profiles of successful compost piles.

This stage was introduced to remove as much moisture as possible from the compost heap so that the stability of the new compost heaps were enhanced. The compost not required for recycling was allowed to cure for a period ranging from 20 days to 30 days before being disposed of by land application.

While the results of the initial experimental piles demonstrated that temperatures in excess of 65°C could be achieved with aeration a number of problems arose with the described procedure.

The supply of woodchips to the Works for full scale operation is costly. Approximately 4 500m^3 @ R32/m^3 would be required for initial start-up and be supplemented by approximately 40m^3/d.

The handling costs involved in solar drying dewatered sludge to 40% solids were also high, as were the costs associated with recovery of the woodchips. The latter operation was also difficult to carry out. Mixing of sludge and woodchips by front-end loader was not satisfactory due to its inefficiency.

The high cost of woodchips for use as bulking agent and high handling costs reduced the possibility of achieving a financially viable composting operation. Similar experience in Britain concerning the prohibitive cost of bulking material has resulted in very slow progress in this area for some years; recently the composting of sludge with straw has proved very successful (Border et al., 1988).

It was therefore decided to investigate the use of thatch grass grown on the adjacent Northern Farm. This material had the advantage of being relatively inexpensive to cultivate and harvest (R 1,70/m^3), being partially biodegradable and readily available and could be incorporated in the final product thus obviating the need for recovery.

5.1.2 Sampling and Quality Control

Various potential bulking agents which were available from the adjacent Northern Farm were analysed for their suitability. Twenty samples each of veld hay, Eragrostis hay, kraal manure and silage were taken at random from storage piles and analysed for moisture and carbon content. The results are shown in Table 5.1. For efficient composting the moisture content should be between 500 and 600 g/kg (Nell and Ross, 1987). A sludge/hay mixture was found to be satisfactory. Due to the low moisture content and high absorptive capacity of the hay it was possible to add kraal manure to the mixture as an additional energy source.

Table 5.1 : Moisture and carbon levels of potential bulking agents.

Material	Moisture (g/kg)	Carbon (g/kg)
Veld Hay	79	467
Topping (Kraal manure + hay)	520	215
Eragrostis hay	68	485
Kraal manure	431	80
Silage	786	101
Sludge/Hay	550	136

5.2 QUALITY OF COMPOSTED SEWAGE SLUDGE

Metal Contamination

All compost piles were analysed for metal parameters as required by the guidelines for sewage sludge disposal. (See Figures 5.3 to 5.15).

Cadmium levels remain the most important limiting factor in classifying the sludge from this plant as a Category D sludge. The levels are generally above the 20 mg/kg level. Some of the extremely high levels are probably a result of illegal unmonitored discharges.

Chromium and Cobalt levels are well below the Guide limit, while Copper levels are approaching the limit.

The high iron levels are a result of dosing for phosphate precipitation. While the lead levels are generally within the limit, occasional samples exceed the limit. These random high figures make the testing of each batch essential when considering a Category D classification. Some difficulties have been experienced with the determination of molybdenum. Results to date indicate that the levels are well within the limit.

Nickel levels are approaching the limit and in some instances exceed it. The Potassium levels remain fairly constant between 600 and 1 200 mg/kg with the occasional outlier. This is an important factor in respect of fertilizer value. The same applies to Sodium levels. Zinc levels are approaching the limit. The total nitrogen and phosphorus levels have stabilised due to stricter control of the composting mixture.

The C/N ratio should be below 20 for well composted and matured material. This is not always achieved due to operational problems.

Organic Contamination Methodology

Due to the complex chemical nature of sewage sludge, methods normally used to extract organic compounds from solid samples had to be modified in order to achieve satisfactory recoveries. Four different extraction techniques namely, mechanical shaking with single solvent, mechanical shaking with a series of solvents sequentially, ultrasonication, Soxhlet extraction to produce a base neutral extract, followed by additional solvent extraction to produce the acid fraction. The methods are described in detail below.

Mechanical Shaking

30 grams of compost was weighed into a flask to which was added 50 mℓ dichloromethane:diethylether 7:3.

The suspension was shaken on an orbital shaker for 20 minutes, thereafter it was allowed to stand. The solvent was decanted into a centrifuge tube and retained.

The extraction was repeated and the solvent and compost transferred to the original centrifuge tube for centrifugation at 100 000 rpm for 10 minutes. The supernatant was concentrated to 10 mℓ on a rotary evaporator and made up to 20 mℓ with a dichloromethane : diethylether mixture at 1:1.

The sample was then subjected to gel permeation chromatography using the dichloromethane : diethylether (1:1) mixture as eluent at a flow rate of 4,5 mℓ/min. The programme was as follows :

Dump	32 min
Collect	30 min
Wash	2 min

Sample was injected into two loops and the fractions from both loops combined and concentrated to 500 $\mu\ell$ by gently blowing with nitrogen. This extract was analysed by Gas Chromatography/Mass Spectrometry with the following gas chromatographic conditions :

Column	:	25 metres, 5% phenolmethyl silicone
Initial temperature	:	30°C
Initial time	:	1 minute
Rate 1	:	60°C per minute
Final temperature 1	:	60°C
Rate 2	:	4°C per minute
Final temperature 2	:	270°C
Final time	:	20 minutes

Ultrasonic Extraction

This extraction was carried out in the same way as with mechanical shaking except that the flask was placed in an ultrasonic bath for 10 minutes prior to decantation and centrifugation.

Soxhlet Extraction Method

20 grams of compost was weighed into an extraction thimble and extracted for five hours using 100 mℓ of the dichloromethane : diethylether solvent. The extract was concentrated to 10 mℓ and made up to 20 mℓ with the 1:1 solvent mixture. The extract was further treated the same as for the mechanical shaking method.

Acetonitrile Extraction

The sample was extracted in the same way as for the shaker method using hexane instead of the dichloromethane diethylether solvent as the extraction agent. After filtration, the hexane extract was extracted 3 times with 50 mℓ acetonitrile. The acetonitrile extracts were combined and concentrated to 500 $\mu\ell$ by gently blowing with nitrogen and immediately subjected to Gas Chromatography/Mass Spectrometry analysis in the same way as described above.

The extract obtained after gel permeation chromatography was concentrated to 10 mℓ and transferred into an extraction funnel and extracted with 100 mℓ of 5 Normal sodium hydroxide by shaking for 2 minutes.
The organic fraction was concentrated to 500 $\mu\ell$ by gently blowing with nitrogen. This produces the

base neutral fraction. The pH of the aqueous fraction was adjusted to 2 with a sulphuric acid water mixture in a ratio of 1:2. The acidified aqueous fraction was extracted with 100 mℓ of hexane which was removed and concentrated to 500 $\mu\ell$ to provide the acid fraction. Both fractions were analysed by Gas Chromatography /Mass Spectrometry.

All the extraction techniques were evaluated by extracting spiked compost in duplicate and determining the recoveries of the spiked compost. Compost was ground fine with a pestle and mortar, wet with dichloromethane and then spiked to give the concentrations listed in Table 5.3. Unspiked compost was also extracted as a control.

Table 5.3 : Concentrations of spiking standards in compost.

Compound	Concentration (mg/kg)
Aldrin	2,5
Dieldrin	2,5
Benzo-a-pyrene	2,5
Chlordane	2,5
DDT	2,0
DDE	2,0
DDD	2,0
Heptachlor	2,5
Hexachlorobutadiene	2,5
Hexachlorobenzene	2,5
Lindane	2,5

None of the compounds were present in the acid fraction. Recoveries from duplicate samples using the different extraction methods described above are given in Table 5.4.

Table 5.4 : Recoveries of compounds from compost by various extraction methods.

Compound	Average Percentage Recovery			
	Shaker	Acetonitrile	Ultrasonic	Soxhlet
Aldrin	51	26	28	52
Dieldrin	63	46	36	72
Benzo-s-pyrene	61	23	8.8	31
Chlordane	73	43	42	81
DDT	40	48	47	90
DDE	83	37	40	81
DDD	45	51	38	79
Heptachlor	41	49	37	65
Hexachlorobutadiene	43	10	24	36
Hexachlorobenzene	53	14	34	62
Lindane	38	64	37	64

From Table 5.4 it is clear that the Soxhlet method is overall the most efficient. See Figures 5.16 and 5.17 for Chromatograms of spiking standard and compost.

This method was further evaluated by spiking compost with the remaining compounds required by the Guideline namely, dimethyl nitrosamine, polychlorinated biphenyls, toxaphene and trichloroethylene.

All except trichloroethylene were analysed using the Soxhlet method as described above.

Trichloroethylene was analysed by headspace gas chromatography.

Samples were spiked at levels lower or equal to the Guideline limit (See Table 5.5) and analysed in quadruplicate as described above.

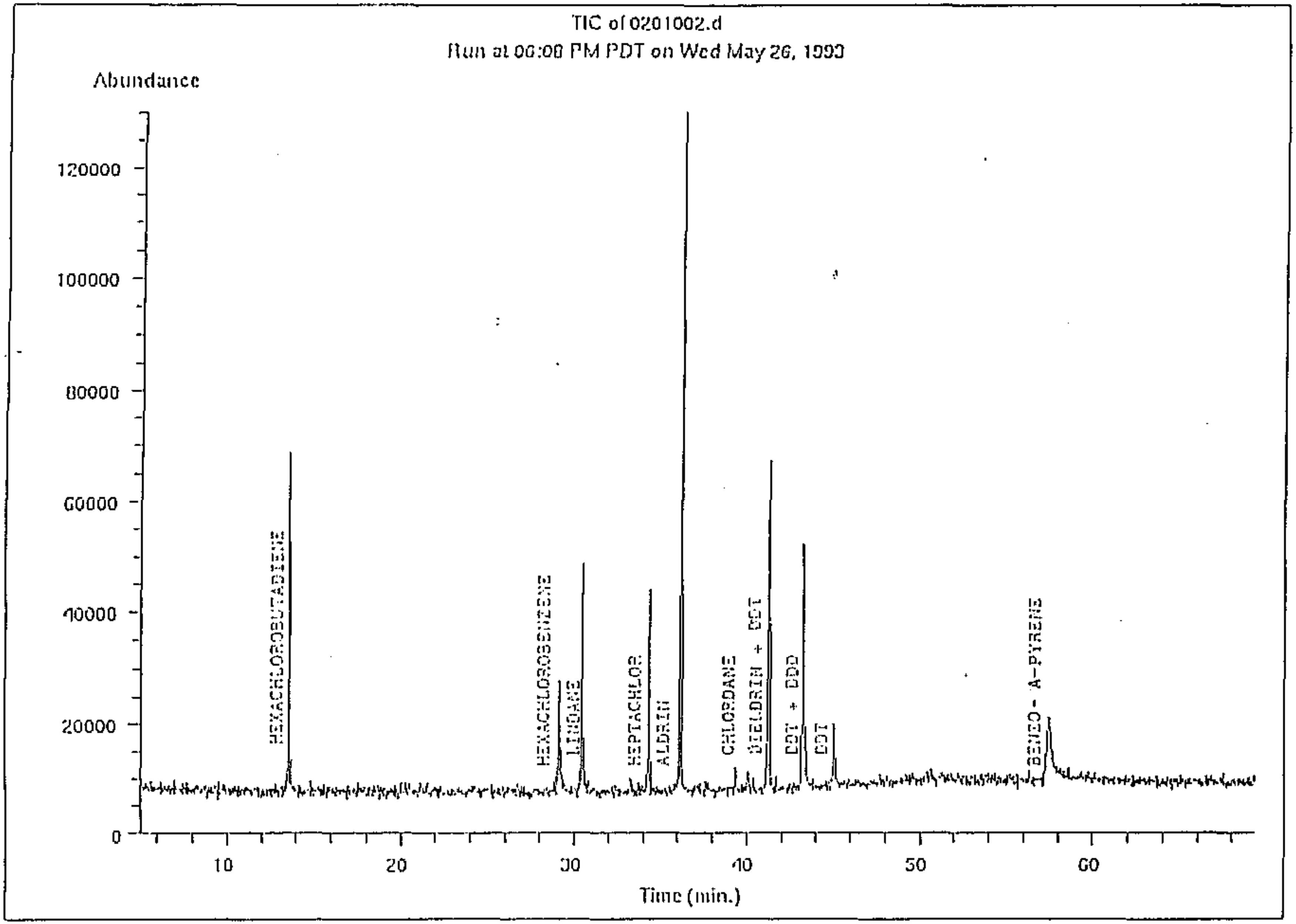


Figure 5.16 : Standards used for spiking compost

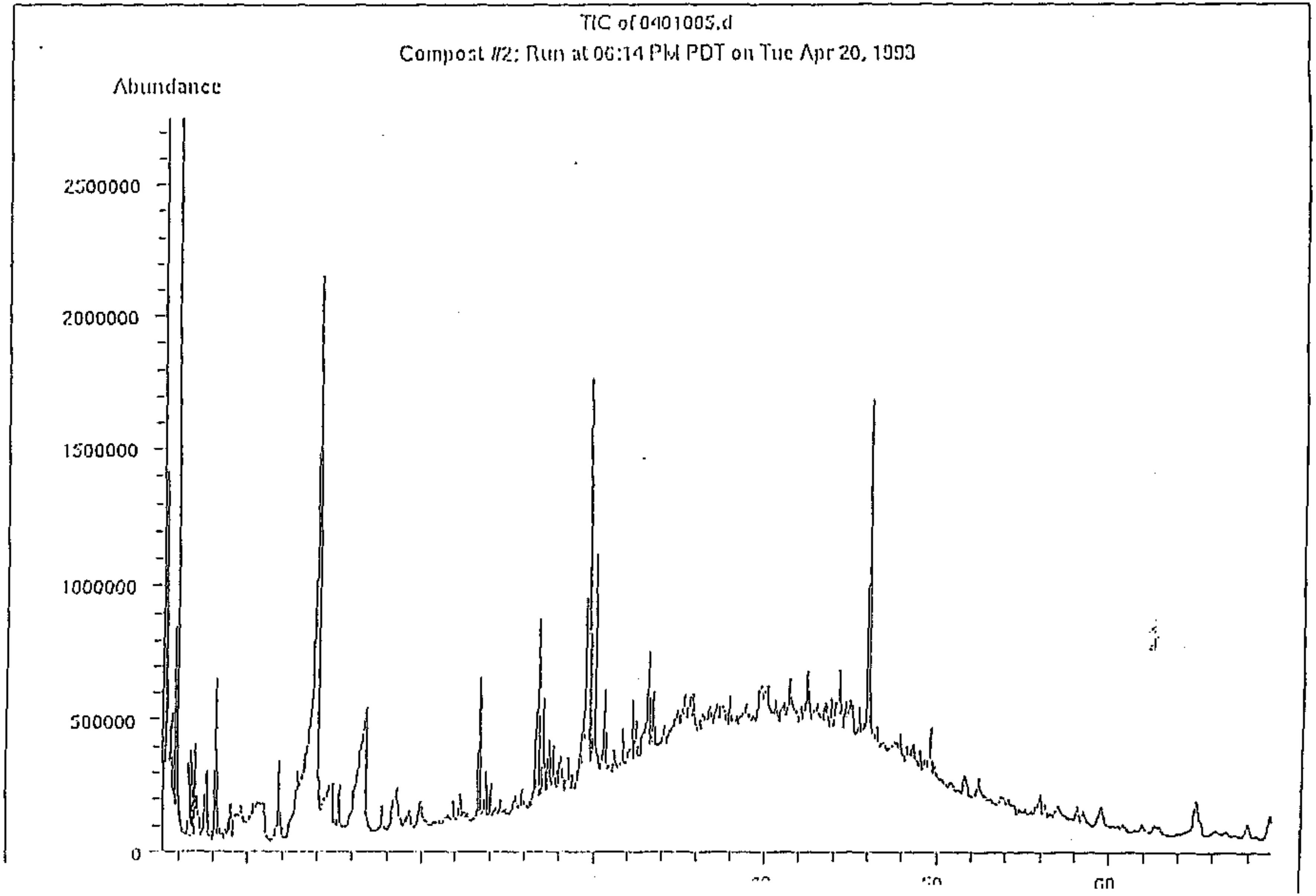

TIC of 0401005.d
Compost #2: Run at 06:14 PM PDT on Tue Apr 20, 1993
Abundance
2500000
2000000
1500000
1000000
500000
0

Table 5.5 : Concentrations of spiking standards in compost.

Compound	Concentration (mg/kg)	Guideline Limit
Ardrin	2,0	2,0
Dieldrin	2,0	2,0
Benzo-a-pyrene	2,5	- 16,25
Chlordane	2,5	150,0
DDT	0,625	0,6875
DDE	0,625	0,6875
DDD	0,625	0,6875
Dimethyl nitrosamine	2,5	4,875
Heptachlor	2,5	4,625
Hexachlorobutadiene	2,5	42,5
Hexachlorobenzene	2,5	4,875
Lindane	2,5	575,0
Polychlorinated biphenyls	0,6	0,70
Toxaphene	2,5	6,0

Average recoveries of greater than 55% were achieved for oil compounds except Hexachlorobutadiene, and the extraction procedure was considered suitable for routine application (See Table 5.6)

Table 5.6 : Recovery of organic contaminants from compost.

Compound	Percentage Recovery				Mean $\bar{x}$	Standard Deviation
	Sample 1	Sample 2	Sample 3	Sample 4		
Aldrin	56	58	64	71	62	6,8
Dieldrin	61	55	53	66	59	5,9
Benzo-a-pyrene	61	59	72	54	62	7,6
Chlordane	82	86	106	97	93	11
DDT	60	56	59	75	63	8,5
DDE	61	58	58	68	61	4,7
DDD	54	49	48	60	53	5,5
Dimethyl nitrosamine	52	66	47	61	57	8,6
Heptachlor	62	61	71	69	66	5,0
Hexachlorobutadiene	29	26	28	29	28	1,4
Hexachlorobenzene	49	49	62	59	55	6,8
Lindane	71	58	88	85	76	14
Polychlorinated biphenyls	76	53	52	71	63	12
Toxaphene	60	64	80	62	67	9,1

Table 5.7 : PCB's in composted and raw sludge.

Sample	Northern Works Composted	Northern Works Raw	Goudkoppies Raw
Concentration (mg/kg)	4,9	2,7	1,7

PCB's have generally been used in soluble oils like cooling or insulating fluids for transformers or in hydraulic fluids.

According to the large oil companies their use has been banned in South Africa for some time. Investigations into potential sources of discharge into the sewer system are currently underway.

Biological Quality

This work has shown that successful composting of sewage sludge, using a relatively inexpensive available bulking agent can be carried out. Control of the process to achieve temperatures in excess of 65°C ensures destruction of pathogens as shown in Table 5.8.

Table 5.8 : Effect of Composting Temperature on Microbiological quality.

Pile No.	Temperature Days		E.coli	Salmonella	Viable Ascaris ova
	65°C	55°C			
3I	3	9	nil	nil	nil
2I	12	17	nil	nil	nil
2E	0	4	positive	nil	nil
8E	0	6	positive	nil	nil
5I	0	18	nil	nil	nil
1/91	15	17	nil	nil	nil
7E	0	2	positive	positive	nil
HI	0	0	positive	positive	nil

In view of the high cost of determining viable ascaris ora and the fact that a consistent correlation between composting temperature and viable ascaris ora counts it is considered feasible to certify composted sewage sludge microbiologically satisfactory if the temperature during composting has remained above 55°C for at least 5 days.

5.3 APPLICATION OF COMPOSTED SEWAGE SLUDGE TO AGRICULTURAL LAND

Compost was applied to a variety of crops on the Northern Farm, at an application rate of 5 t/ha (dry material). A 8m^3 manure spreader was used to apply the compost to lands with a pH value of 6,0 and higher. The improvement in yields observed are given in Table 5.9.

Table 5.9 : Crop yields on composted and non-composted lands at Northern Farm.

Crop	Yield (t/ha)	
	With commercial fertiliser	With compost
Eragrostis curvula	5,14	11
Eragrostis curvula	8,6	16
Digitaria smutsii	2,63	5,1
Kikuyu/Rye grass pasture	grazed	60% better than adjacent controls (grazed)

As can be seen from Table 5.9, yields increased substantially. In addition yields were obtained from lands which were previously uneconomical to harvest. Application to virgin veld stimulated the growth of weeds such as Khaki weed and black jack. However, in competition with the grasses the weeds were suppressed. The reaction cannot be explained solely by application of the macronutrients present in the sludge. It has been suggested that certain micronutrients as well as plant growth factors could be present in municipal wastewater (Kattermaan and May, 1989). The effectiveness of sewage sludge as a fertiliser has been previously reported (Johnson et al., 1987).

Problems were encountered with the manure spreader due to the presence of rocks in the compost. This problem has been overcome by screening the compost prior to spreading. This procedure has proved very successful.

CHAPTER 6

METAL DISCHARGE TO SEWER SYSTEM

Metal contamination remains the greatest obstacle to the classification of composted sewage sludge as Category D. Routine analysis of metal containing industrial effluents, has revealed the distribution of metal loads to Johannesburg's four Wastewater Treatment Plants, shown in Figures 6.1 to 6.6.

Mean results of metal analysis of mixed liquors are given in Table 6.1.

Table 6.1 : Metal levels in reactor mixed liquors (mg/kg).

Metal	Bushkoppie	Goudkoppies	Northern Works	Olifantsvlei
Aluminium as Al	7 475	6 826	5 557	9 008
Cadmium as Cd	3,1	8	31	2,2
Calcium as Ca	15 455	16 965	15 343	15 816
Cobalt as Co	92	145	15	32
Chromium as Cr	1 287	691	264	426
Copper as Cu	274	-	409	181
Iron as Fe	30 800	104 900	59 030	82 120
Lead as Pb	88	382	86	76
Magnesium as Mg	6 744	5 235	7 550	7 116
Manganese as Mn	2 060	1 540	798	1 732
Molybdenum as Mo	7,0	10	10	5,7
Potassium as K	8 380	5 183	8 157	8 628
Nickel as Ni	195	338	112	133
Sodium as Na	3 440	3 726	4 343	3 900
Zinc as Zn	948	2 009	1 593	687

Individual results are graphically depicted below. For Northern Works, Cadmium remains the single greatest problem metal. See Figure 6.6. The wide variation in results indicates the difficulty experienced in obtaining an accurate picture of metal discharge using random grab sampling techniques. Cobalt (Figure 6.7), Copper (Figure 6.8), Lead (Figure 6.9), Molybdenum (Figure 6.10), Nickel (Figure 6.11) and Zinc (Figure 6.12) are still below the limit, although some samples are approaching the limit. In all cases a wide variation in results is observed.

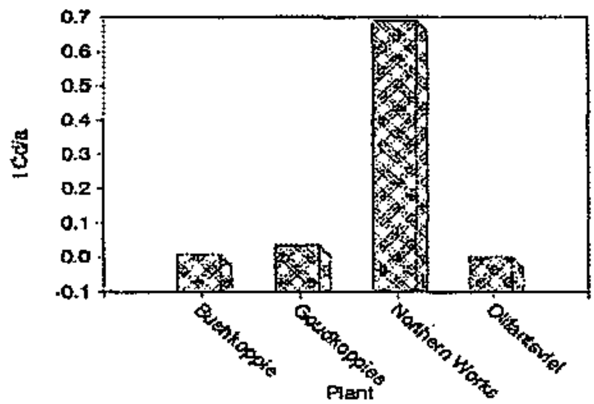


Figure 6.1 : Annual Cadmium load to plants

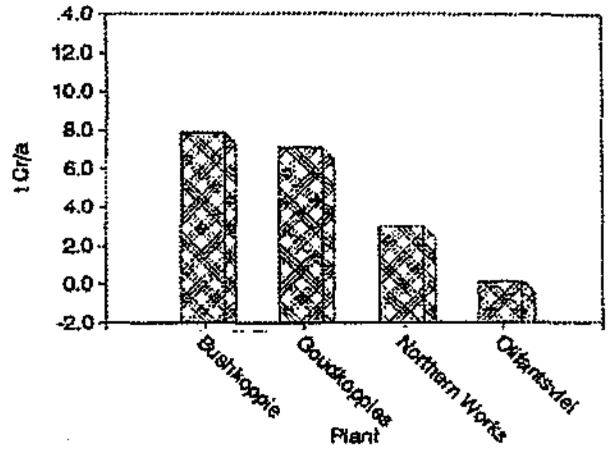


Figure 6.2 : Annual Chromium load to plant

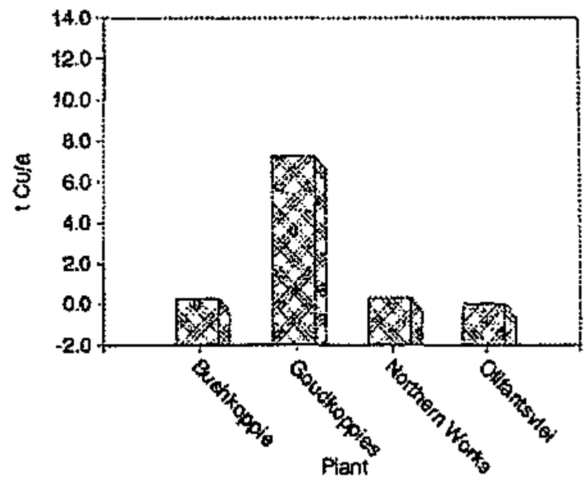


Figure 6.3 : Annual Cooper to plant.

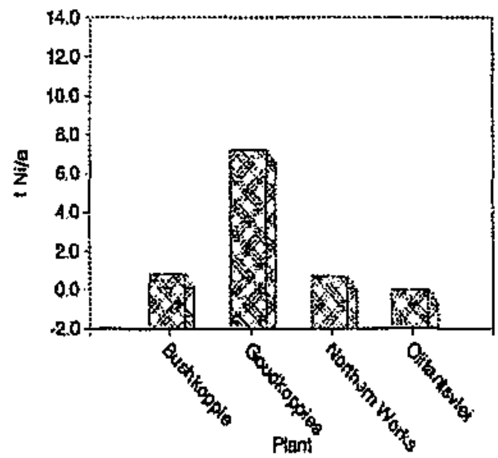


Figure 6.4 : Annual Nickel load to plant.

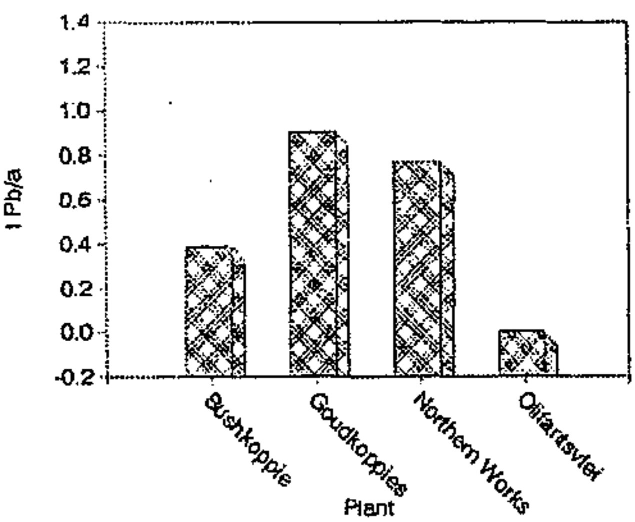


Figure : 6.5 : Annual ZincLead to plant.

Goudkoppies sludge contains a number of metals in excess of the limit. Cadmium (Figure 6.13) is within the limit. Cobalt (Figure 6.14) almost consistently exceeds the limit, as does Copper (Figure 6.15), Lead (Figure 6.16) and Nickel (Figure 6.17).

As in the case of Goudkoppies, Cobalt levels (Figure 6.18) at Bushkoppie exceeds the limit but less frequently. Chromium (Figure 6.19) levels at Bushkoppie also frequently exceed the limit.

At Olifantsvlei all metal concentrations are below the limit, with Nickel the sole element approaching the limit (Figure 6.20).

It is clear from the results shown that control of metal discharge to the sewer is an essential prerequisite to achieving the required composted sewage sludge quality.

Source of Metal Contamination

A survey undertaken by consultants Steffen, Robertson and Kirsten on behalf of the Council revealed the contributions by metal dischargers, shown in Table 6.2.

Table 6.2 : Annual metal load from metal discharges.

Metal	Annual Load (kg)
Copper	11 940
Cadmium	1 668
Chromium	25 226
Nickel	12 966
Lead	2 616
Zinc	61 620

In an attempt to institute control of metal discharge, a punitive tariff for effluent metal concentrations was introduced.

Effluent Tariff

The Council's current tariff for the acceptance of domestic sewage and industrial effluents (wastewater) into the sewer system is based on a number of categories. Those for industrial effluents are calculated using a formula incorporating the organic carbon load of the effluent. Certain minimum charges apply to industries that use small volumes of water or those that discharge effluents having a low organic carbon load. In addition, limits are placed on the concentration of certain chemicals which may be discharged in order to prevent the discharge of substances which could damage Council installations as well as be detrimental to the health of personnel.

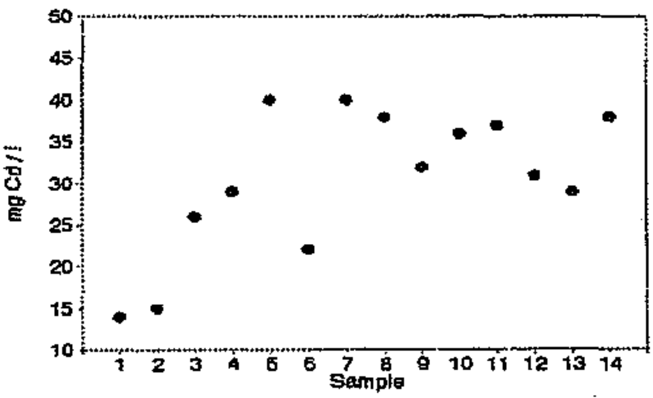


Figure 6.6 : Cadmium levels in Northern Works mixed liquor.

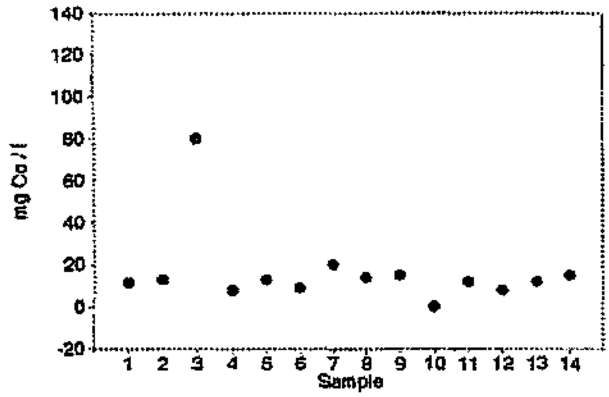


Figure 6.7 : Cobalt levels in Northern Works mixed liquor.

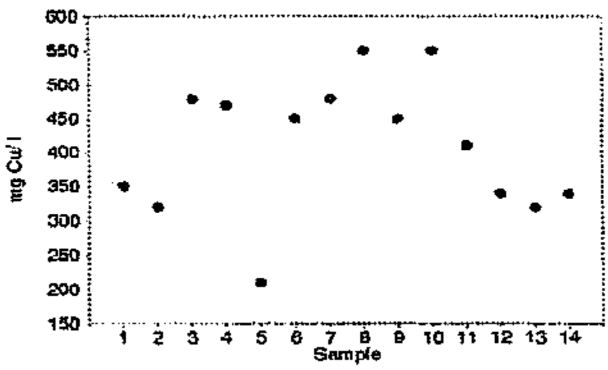


Figure 6.8 : Copper levels in Northern Works mixed liquor.

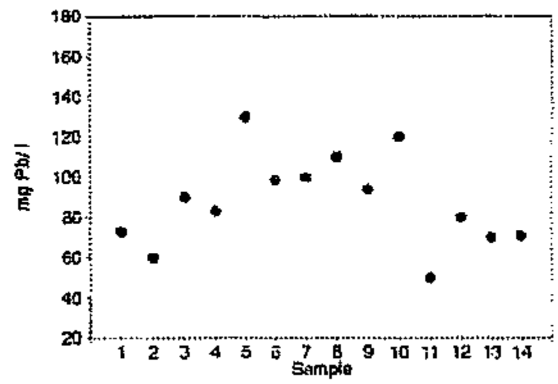


Figure 6.9 : Lead levels in Northern Works mixed liquor.

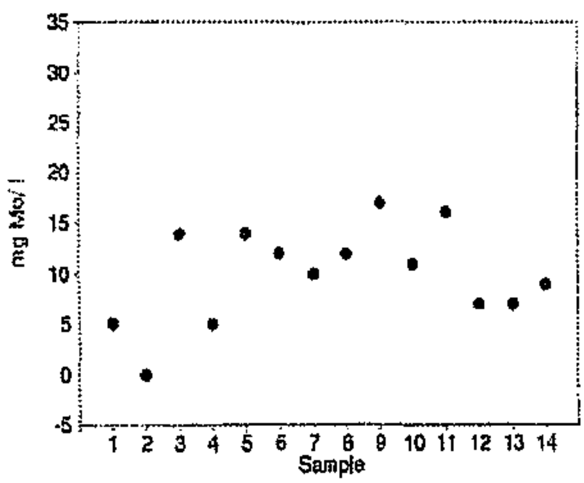


Figure 6.10 : Molybdenum levels in Northern Works mixed liquor.

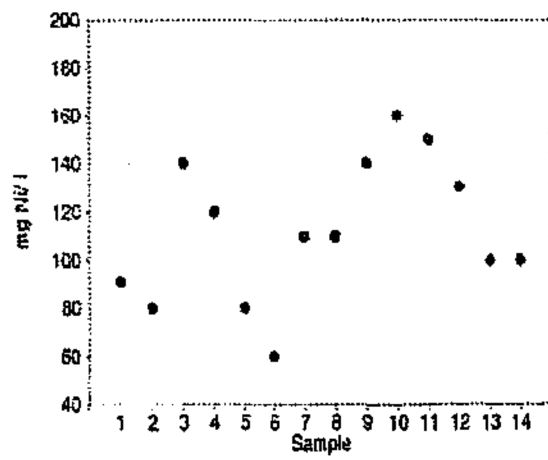


Figure 6.11 Nickel levels in Northern Works mixed liquor

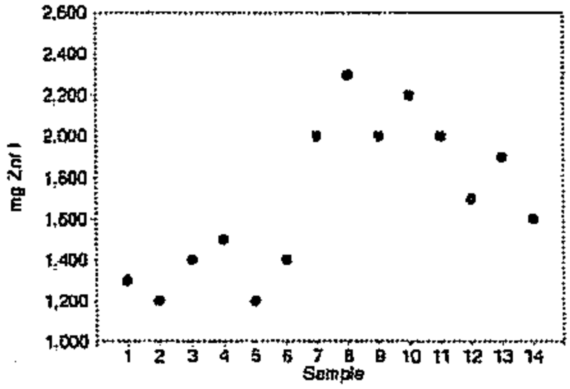


Figure 6.12 : Zinc levels in Northern Works mixed liquor.

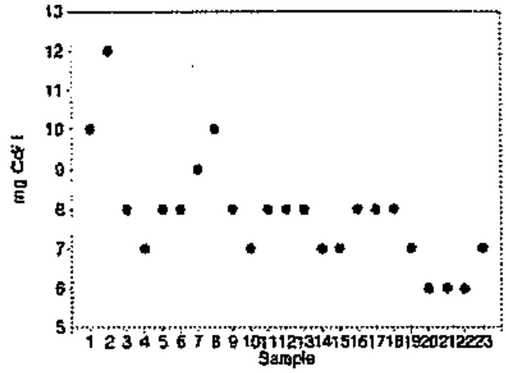


Figure 6.13 : Cadmium levels in Goudkoppies mixed liquor.

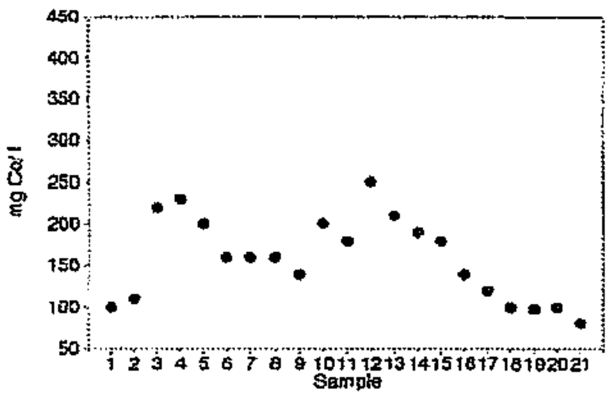


Figure 6.14 : Cobalt levels in Goudkoppies mixed liquor.

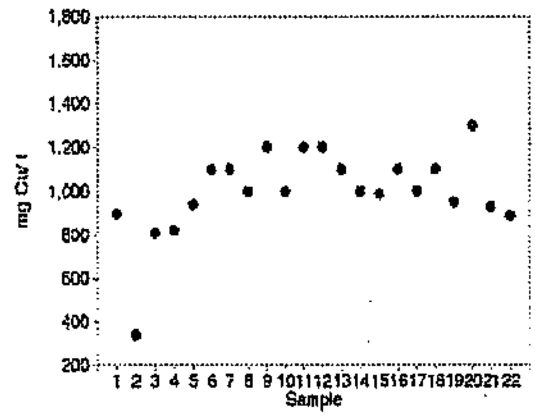


Figure 6.15 : Copper levels in Goudkoppies mixed liquor.

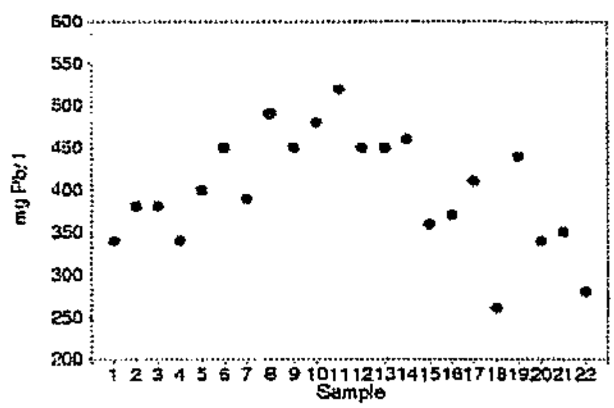


Figure 6.16 : Lead levels in Goudkoppies mixed liquor.

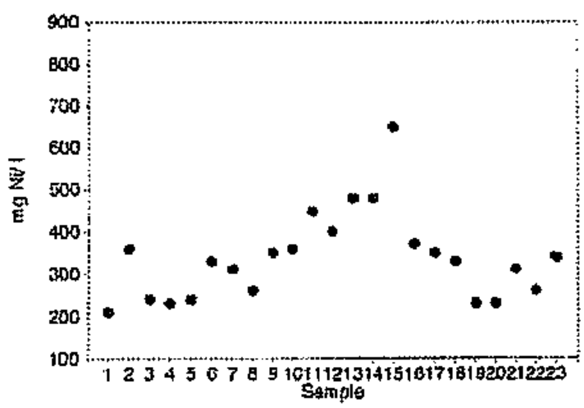


Figure 6.17 : Nickel levels in Goudkoppies mixed liquor

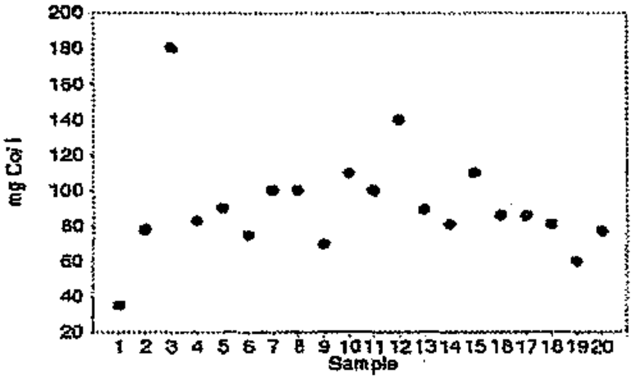


Figure 6.18 : Cobalt levels in Bushkoppie mixed liquor.

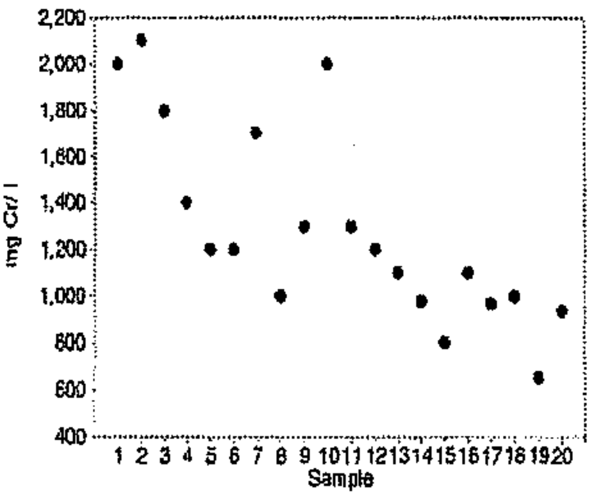


Figure 6.19 : Chromium levels in Bushkoppie mixed liquor.

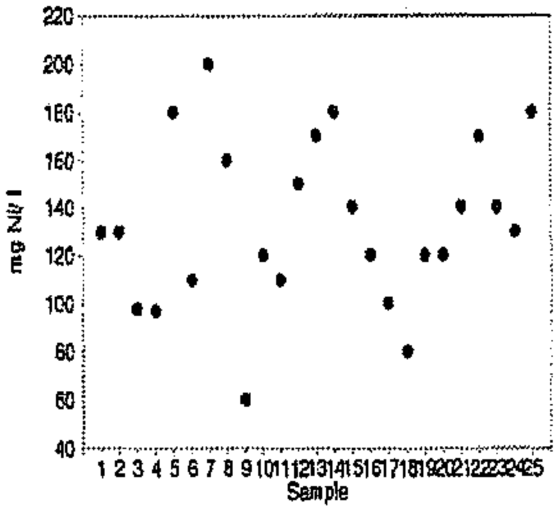


Figure 6.20 : Nickel levels at Olifantsvlei

The present system has been in use since the early 1970's with the charges being increased nearly every year on a percentage basis to recover increases in the total operating costs (i.e. both domestic sewage and industrial effluent portion) of the Wastewater Department.

This procedure has led to the creation of a situation where the current charges do not relate to the actual costs of reticulation and treatment and a certain degree to cross-subsidisation occurs between the different categories of dischargers.

Insufficient control of the discharge of components other than carbon into the sewer system can have a deleterious effect on the final effluent discharged by the Council's wastewater treatment plants and on the sewage sludge produced. The treatment of these wastes adds to the overall treatment cost.

Amendments to the by-laws to incorporate a multi-factor tariff formula for industrial effluents encompassing a variety of components rather than the existing single factor formula incorporating only carbon load were recently promulgated.

A multi factor formula is based on values for conveyance (C) and treatment (T) which are derived from the actual operating costs.

Using the Guideline Limits, the amount of each metal that could be tolerated at each wastewater treatment plant was calculated.

The same calculation was carried out for each works and each metal. Some works have a lower tolerance due to sludge production figures and the lowest value was taken as the limit.

As these levels have been determined only for the volumes discharged by electroplaters and dilution occurs from other effluents a leniency factor can be incorporated. Incorporation of this factor provides a maximum permitted level shown in Table 6.3.

Table 6.3 : Maximum levels for metal discharge.

Metal	Maximum level (mg/ℓ)	Maximum permitted level
Cadmium	0,3	3
Cobalt	1,5	15
Chromium	25	250
Copper	10	100
Mercury	0,2	2
Molybdenum	0,4	4
Nickel	3	30
Lead	6	60
Zinc	40	400
Arsenic	0,2	2
Selenium	0,2	2
Boron	1,0	10
Fluoride	10	100

Full implementation of the tariff would have had a severe impact on the industries concerned as evidenced by the increase in annual industrial effluent charges, which some industries would have incurred. See Table 6.4.

Table 6.4 : Additional tariff to be levied with metal factors (1991R).

Industry	Amount (R)
A	36 301,50
B	38 451,00
C	48 401,54
D	20 070,85
E	31 459,20
F	44 264,89
G	1 579 424,68
H	114 548,80
I	181 509,98
J	151 535,44
K	29 899,25

Early experience with the proposed tariff indicated that lack of skilled manpower and capital resources, made compliance with the new metal limits an onerous task for local industries, resulting in a number resorting to tanker disposal of their effluent.

A survey conducted by Steffen, Robertson and Kirsten in respect of metal plating firms in Edenvale, the sole contributors to the Cadmium load at Northern Works revealed that the implementation of punitive measures without a parallel assistance programme to discharges could well not achieve the primary objective of reducing metal discharges. It was therefore decided to review the current maximum limits and explore strategies to achieve the objective of metal discharge reduction, without destroying the electroplating industry.

<u>Metal Finishing Discharge Standards</u>

It is proposed that Categorical Pretreatment Standards be applied to all Johannesburg Metal Finishers in line with international norms that are technically feasible for the industry whilst achieving an acceptable reduction in metal load received by, and finally discharged from Wastewater Treatment Plants.

The metal content data of the composited Northern Works sewage sludges for 1991/92 indicates that on average the sludge was in compliance with Guideline requirements except for Cadmium, despite exceedances for Zinc, Nickel and Cadmium in the 1990/91 composite sample. Metal analysis of raw and MLSS for Northern Works on a regular basis (± weekly) has only been initiated recently and is indicating that sewage metal loads are highly variable. An annual average compliance, or even being close to compliance, may not be reflected on an individual month by month basis. A significant amount of non compliance can be expected with consequent impact upon sludge disposal options and legal requirements.

Similarly, although sludge disposal is identified as a primary area of concern increasing international and national concerns over our water resources could be a more serious area of concern. The present RSA Special Discharge Standard of the Water Act is not complied with totally and may be expected to further deteriorate as the area develops and metal loads grow whilst the receiving water quality is put under increasing pressure.

Water Quality Guidelines are currently being prepared by Department of Water Affairs and Forestry which are expected to be more stringent than the present Special Standards. However, as these Guidelines are not available as yet, (the RSA Special Discharge Standard) has been adopted as a base case, and the US and Canadian EPA Guidelines as an indication of potential future requirements in assessing how appropriate international Standards are for Johannesburg.

Based upon the Canadian Chronic Criteria for Freshwaters, and assuming that for worst case conditions the discharge from Northern Works provides the bulk of the water in the immediate receiving water, that metal load dilution is not available in the receiving water and that the bulk metal load is discharged over an average of 250 days/annum, the present metal concentrations would all be out of average compliance, with Cadmium, Copper and Lead requiring at least a 20 fold dilution and Zinc greater than 10 fold. The high assimilation of Chromium into sludge, and a relatively high limit assists in reducing the dilution required to achieve compliance.

As with sludge compliance it is to be expected that average compliance will not be acceptable and that compliance will be required continuously, thereby increasing the degree of dilution required, or alternatively the degree of metal load reduction required in the sewage by the dischargers, particularly for shock loads.

Should the Categorical Pretreatment Standards not be sufficient to enable each of the Johannesburg Sewage Works to achieve full compliance it may be necessary to develop tighter Local Pretreatment Limits (LPL) applicable to each sewerage zone.

A range of pretreatment technologies are available for handling metal containing effluents, for example : Many of these options have been shown to be generally uneconomical for individual discharges. Reclamation by a metal recovery specialist may be a more appropriate option.

Strategies to reduce metal discharge to the sewer were investigated.

Strategies to reduce metal discharges

In order to comply with the required effluent standards, metal discharges must be reduced. Although waste minimization offers some measure of achieving this objective it is unlikely to result in the achievement of the required levels. Waste minimization programmes have the advantage of reducing operating cost and could be seen as a measure to offset the cost of treating the remaining waste.

A survey amongst metal discharges has revealed a reluctance to becoming involved in what is to them an unknown technology. Instances where pretreatment facilities have been installed and are not achieving the required levels are common in the industry. It became clear that successful strategies would include those, which would promote waste minimization, while at the same time providing metal discharges with a service in respect of their remaining waste. Two basic options are available either individual on-site pretreatment or tanker haulage of the waste to a central treatment facility.

CWT offers advantages in being operated by treatment professionals, increases potential for recovery of metals, and allows industries to share waste handling facilities. Localized collection points would allow the transportation of the "hazardous" wastes to be co-ordinated with the capacity and treatment regime of the Treatment Plant Operator and minimises costs of individual generators.

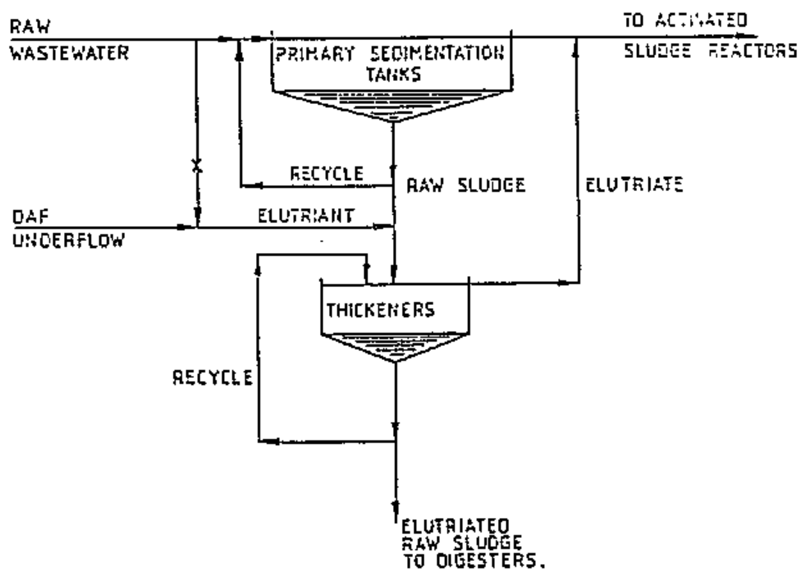
This option is currently being investigated in greater detail for possible implementation.

CHAPTER 7

FERMENTATION AND ELUTRIATION OF SLUDGE

7.1 BUSHKOPPIE WORKS

The Bushkoppie Plant comprises four identical 3-stage modules each designed to treat 50 Ml/d. Four additional 35m diameter primary sedimentation tanks (PST's) were retrofitted and the original two primary settling tanks converted to gravity thickeners. Sludge can be recycled from the underflow to the inlet of the thickeners. DAF underflow or raw sewage is added to the sludge stream entering the thickeners, as an elutriant. (See Figure 7.1). In addition PST underflow sludge can be recycled to the inlet of individual or all the PST's.



BUSHKOPPIES FERMENTATION AND ELUTRIATION PLANT

Table 7.1 : **Mean monthly volatile fatty acid levels at various stages in the fermentation process.**

Sample	Total Volatile Fatty Acids as Acetic Acid kg/d		
	February	March	April
Raw sewage	11 786	11 454	14 016
Settled sewage	8 030	9 024	15 099
Thickened sludge	576	576	650
Thickener overflow	11 470	3 988	3 970
Feed to reactor		12 890	17 687

The results are reported in kg/d rather than concentration as the different flows do not allow direct comparison.

However due to the high volatile fatty acid content of the influent to this plant, large scale generation of these compounds is not always necessary.

The Bushkoppie facility is designed to operate in three different modes. The conventional or batch mode comprises sequential desludging of all four primary sedimentation tanks one at a time with no recycling onto the PST's. In the continuous mode with recycling, each of the four tanks go through accumulation, recycling and wasting of sludge independently, cycling on a time basis. In the batch recycle and wasting mode, the sludge, undergoes accumulation and recycling for a period of, for example, 4 days and is then wasted on the fifth day. The thickeners can operate in a similar fashion.

The results described in this paper were obtained using the conventional mode on the thickeners; with the thickener overflow being fed back downstream of the PST's.

7.1.1 Plant Performance

Samples were taken from all points in the fermentation elutriation process which could result in a change in the chemical quality. Samples were analysed for ammonia, phosphate, COD and solids by methods described in Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1981) and volatile fatty acids were determined by headspace gas chromatography. Samples for volatile fatty acids were preserved by the addition of sodium carbonate to pH 12,9. Prior to headspace analysis samples were acidified by the addition of sulphuric acid.

The generation of VFA's through the gravity thickeners is shown in Table 7.1. The plant was operated in the conventional mode, with a low solids retention period in the PST's.

The retention of raw sludge in the primary sedimentation tanks to allow fermentation, results in degradation of organic nitrogen and phosphorus compounds resulting in the release of ammonia and phosphate to the supernatant. Further release to the liquid phase occurs during elutriation. An increase in phosphate is usually observed, as is a lower increase in ammonia. The suspended solids entering the plant are also normally higher that is the case with settled sewage alone. An increase in COD as a result of the fermentation and elutriation is also observed. A summary of the results obtained since the commissioning of the plant is given in Table 7.2.

Table 7.2 : Summary of results obtained from fermentation and elutriation plant for the period 1 December 1990 to 30 April 1991.

Parameter	Mean	Minimum value	Maximum value
Raw sewage			
COD as O	600	260	1 200
Ammonia as N	21	15	28
Phosphate as p	4,6	1,4	8,1
Suspended solids	220	90	350
Settled sewage			
COD as O	490	190	1 100
Ammonia as N	20	4,7	37
Phosphate as P	4,7	1,1	8,2
Suspended Solids	110	37	200
Feed to reactor			
COD as O	550	180	980
Ammonia as N	21	9,9	38
Phosphate as P	5,8	2,9	9,1
Suspended Solids	170	75	370

All results expressed as mg/l

The performance of the plant is shown in Tables 7.3 and 7.4.

Table 7.3 : Summary of effluent quality for the period 1 January 1989 to 31 December 1990 : Bushkoppie before commissioning of fermentation facilities.

Parameter	Mean	Minimum value	Maximum value
COD as O	72	12	130
Suspended solids	6	0	31
Ammonia as N	1,8	0	15
Phosphate as P	0.4	0	5,4
Nitrate as N	4.7	1.3	13

All results are expressed in mg/l.

Table 7.4 : Summary of effluent quality for the period 1 March 1991 to 31 May 1991 : Bushkoppie after commissioning of fermentation facilities.

Parameter	Mean	Minimum value	Maximum value
COD as O	74	34	140
Suspended solids	8	0	22
Ammonia as N	1,6	0	9,3
Phosphate as P	0,7	0,1	3,5
Nitrate as N	3,4	0,9	8,2

All results are expressed in mg/l.

The plant continued to perform well with only a few occasions where compliance with the standard was not achieved.

Subsequent to the above studies severe problems occurred with the DAF units of Bushkoppie. This necessitated the decommissioning of part of these units for refurbishment. In order to handle the thickening of waste activated sludge (WAS) one of the primary sludge thickeners was converted to WAS gravity thickener with the second remaining as a thickener for all of the raw sludge. The plant was operated with no accumulation or recycle of primary sludge in the PST's. The single raw sludge thickener was operated with accumulation (thickening) of sludge but no recycle. Overflows from both thickeners were recycled to the inlet of the PST's because of a excessive solids content of these flows.

This operating mode necessitated the occasional addition of supplementary iron salts in order to ensure compliance with the phosphate standard. These additions usually took place between Sunday and Wednesday as a result of the low strength weekend sewage flows to Bushkoppie. The iron dosing rate varied between 0,2 and 0,7 Fe/P over this period. With the repair of the DAF units it was decided to convert the gravity thickeners back to primary sludge thickeners. The plant was operated with some accumulation of sludge in the PST's but no recycle on these units. The gravity thickeners were operated to achieve the maximum degree thickening (accumulation) but no recycle of thickened sludge occurred back onto the thickeners. Either raw sewage or DAF unit underflow was fed to these thickeners to assist the washing out of VFA's. All thickener overflow was pumped back to the inlet of the PST's. This period was the most successful so far with minimal supplementary iron salt addition being necessary. For example the plant could be operated for over a month without any iron addition.

7.2 NORTHERN WORKS

The Northern Works activated sludge Plant comprises two units namely Unit 3 and 4. Unit 3 consists of two 3 stage modules and one 4 stage module each designed to treat 50Mℓ/d.

In contrast to Bushkoppie, the feed to Northern Works is low in volatile fatty acids and requires enrichment by fermentation of the raw sludge. On Unit 3 two 24m diameter sludge thickener/fermenters were added to the existing primary sludge treatment facilities.

Raw sludge from the primary sedimentation tanks is fed to two mixing chambers to which settled sewage is added as an elutriant. The sludge is then pumped to the thickeners. Large accumulations of raw sludge in the PST's are avoided as they are prone to methane fermentation.

The units can be operated in two different modes, namely the batch mode, where one unit continuously handles the whole elutriation-recycle duty for a selected sludge age period, while the other unit is desludge, or in continuous mode where each unit handles half the elutriation recycle duty with intermittent recycling and desludging from alternate units to maintain the desired sludge age. (See figure 7.2.)

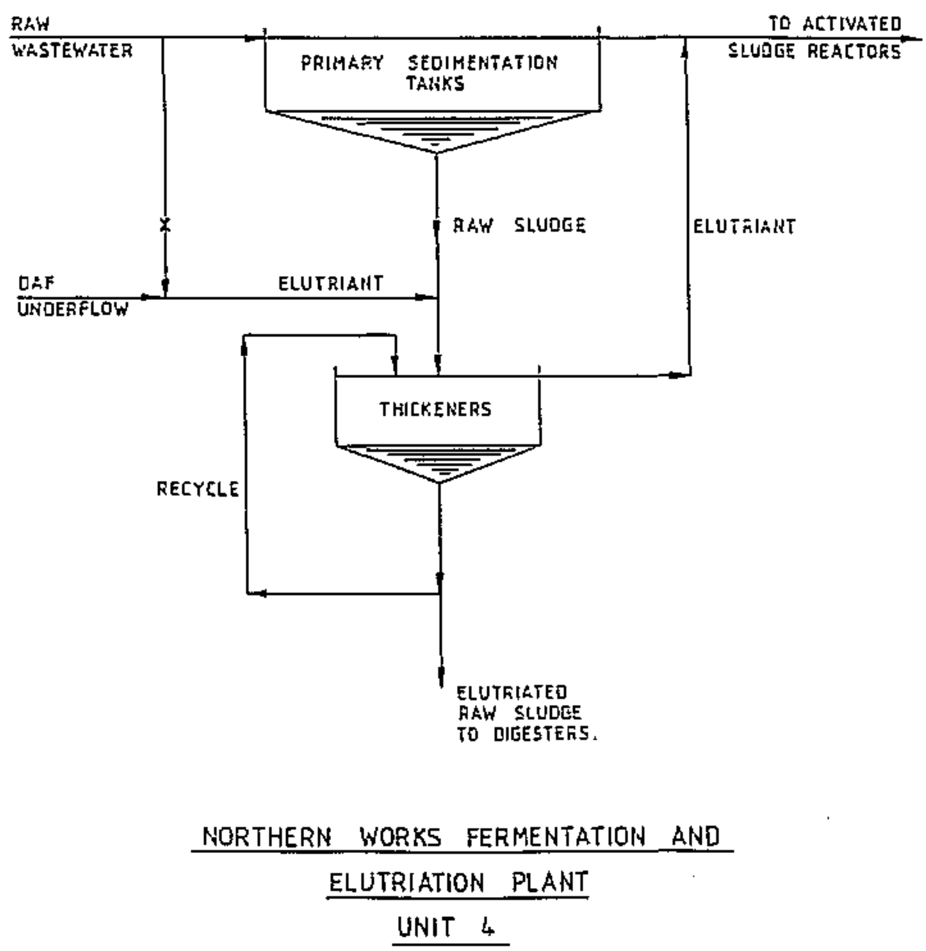


Figure 7.2 : Fermentation and elutriation of sludge : Northern Works Unit 4.

The results described in this paper were obtained using the continuous mode. During this test period the thickener overflow was fed back downstream of the PST's.

Fermentation and elutriation facilities were commissioned on Unit 3 in March 1991. The Unit 4 fermentation/elutriation facilities are similar to Unit 3 with the exception of an upgraded automatic control system.

At the time of writing, the new Unit 4 at Northern Works had operated for 5 months during which period its performance had been very good.

7.2.1 Plant Performance : Unit 3

As in the case of Bushkoppie samples were taken at all points in the fermentation elutriation process where quality changes were expected. Volatile fatty acids were successfully generated using the continuous mode (see figure 7.3) with a retention time in the PST's and thickeners of 3 days. The results are shown in Table 7.5.

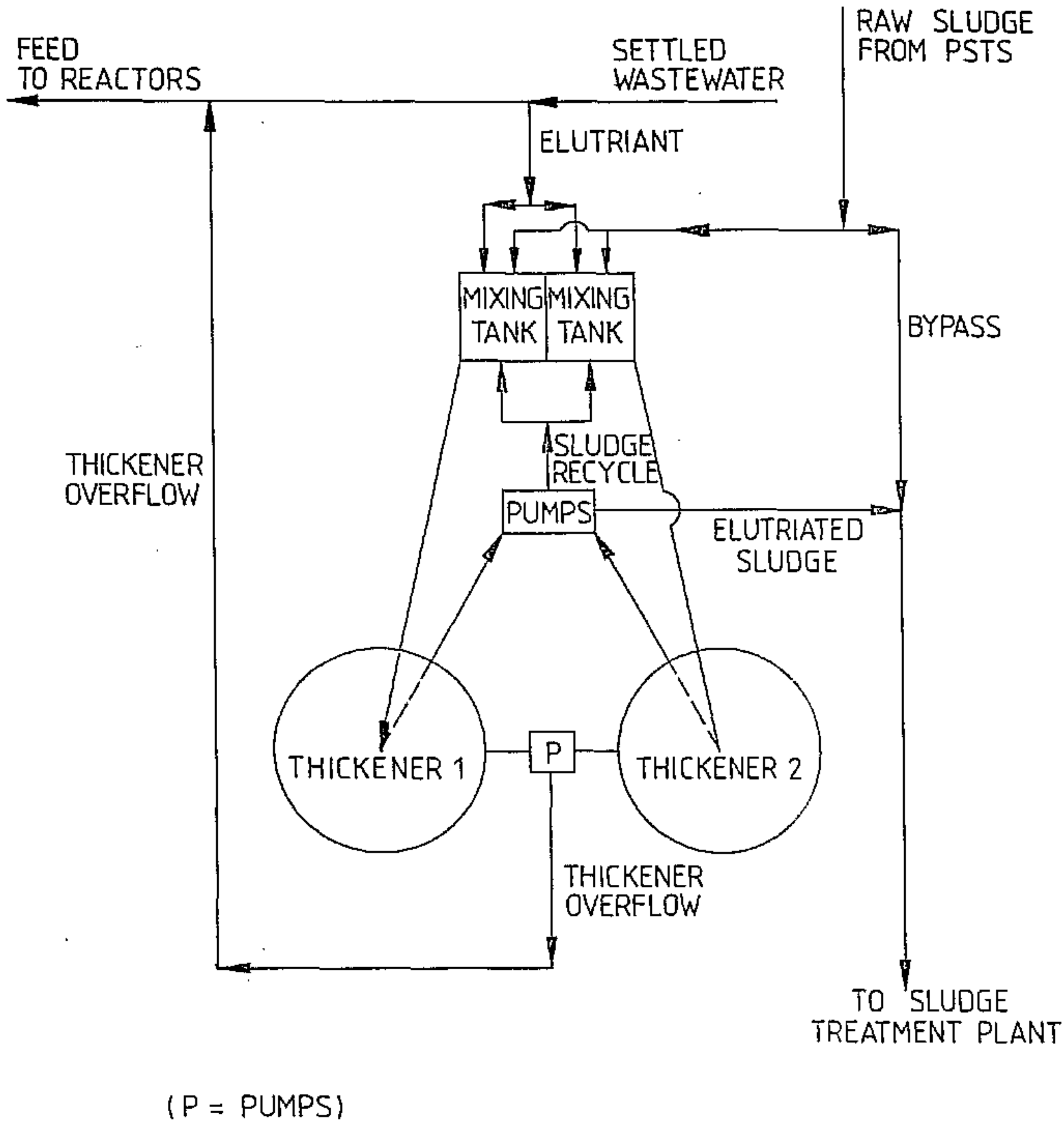


FIG. 4 - FERMENTATION / ELUTRIATION AT NORTHERN WORKS - UNIT 4

Table 7.5 : Mean monthly volatile fatty acid levels at various stages in the fermentation process.

Sample	Total Volatile Fatty Acids as Acetic Acid (kg/d)	
	March	April
Raw sewage	1 540	810
Settled sewage	690	777
Raw sludge	880	3 099
Thickener overflow	1 060	3 096
Feed to reactor	8 530	6 042

The VFA load to the plant is enhanced significantly by this process. Before commissioning of the fermentation and elutriation plant, biological removal was supplemented with chemical addition, as can be seen in Table 7.6

Table 7.6 : Summary of effluent quality data for the period 1 January 1990 to 31 December 1990 : Northern Works before commissioning of fermentation facilities.

Parameter	Mean	Minimum value	Maximum value
COD as O	43	17	120
Suspended solids	13	0	150
Ammonia as N	1,3	0	8,0
Phosphate as P	0,8	0	3,7
Nitrate as N	2,6	0	9,5

All results are expressed in mg/l.

Compliance with the standard was achieved most of the time, but high doses of iron salts were required to achieve the phosphate standard. In an attempt to quantify biological removal in the presence of chemical removal the Fe/P ratio is used. Experience with plants exhibiting very little biological removal has revealed that this ratio normally ranges between 2,0 and 2,5. (The stoichiometric ratio is 1.8) Ratios below this would give and indication of the level of biological removal.

The addition of VFA enriched feed to the reactor significantly reduced the chemical dose required to achieve the phosphate standard as the biological removal increased. After the commissioning of the primary sludge fermentation and elutriation facilities in March 1991 and Fe/P ratio dropped from levels above 2,0 to well below 1,0. The superior performance of module 2 in respect of biological removal is attributed to the longer anaerobic retention time (double modules 1 and 3).

Similar to the experience at Bushkoppie the introduction of the liquor from the gravity thickeners into the settled sewage stream also results in an increase in the ammonia, phosphate and solids to the plant, as shown in Table 7.7.

Previous research has shown that the introduction of these additional solids has a beneficial effect on enhanced biological phosphorus removal (Osborn et al., 1986).

Table 7.7 : Summary of results obtained from fermentation and elutriation plant for the period 1 March 1991 to 30 April 1991.

Parameter	Mean	Minimum value	Maximum value
Raw sewage			
COD as O	490	320	660
Ammonia as N	18	12	20
Phosphate as P	4,1	2,0	5,9
Suspended solids	220	160	280
Settled sewage			
COD as O	250	110	400
Ammonia as N	23	10	33
Phosphate as P	5,8	1,8	12
Suspended Solids	95	20	200
Feed to reactor			
COD as O	410	170	630
Ammonia as N	26	11	41
Phosphate as P	7,2	2,6	13
Suspended Solids	180	60	40

All results are expressed in mg/l.

The performance of the plant since commissioning of fermentation facilities is shown in Table 7.8.

Table 7.8 : Plant performance after commissioning of fermentation facilities.

Parameter	Mean	Minimum value	Maximum value
Suspended solids	10	4	20
Chemical oxygen demand as O	41	9	22
Ammonia as N	1,2	0,2	4,4
Phosphate as P	0,3	0,1	0,9
Nitrate as N	4,1	0,1	7,6

All results are expressed in mg/l.

Plant performance in respect of phosphate removal was improved and compliance with the standard was achieved more consistently and the chemical dose was reduced. In 1991, Dr Lötter reported on the apparent deleterious effect of iron addition on polyphosphate storage. The results of phosphorus fractionation of the mixed liquor solids before and after commissioning of fermentation facilities is given in Table 7.9.

Table 7.9 : Ratio of chemically bound phosphate to intracellular polyphosphate.

Date (1991)	Monthly average ratio of chemically bound phosphate to intracellular polyphosphate
Before fermentation	
February	
March	2,07
April	1.80
	1,26
After fermentation	
May	0.37
June	0.43

After the iron dose had been reduced to below the stoichiometric precipitation dose, biological phosphorus removal improved and polyphosphate storage became the principal phosphorus storage mechanism within the sludge as evidenced by the low ratios of chemically bound phosphorus to polyphosphate observed for May and June. Subsequent to the above studies the Unit 3 fermentation and elutriation plant was taken off line in order to eliminate certain flow restrictions in the raw sludge feed pipes. During this period iron salt addition to the Unit 3 reactors had to be increased dramatically to comply with the phosphate standard. Dosage rates varied between 3,0 and 5,0 kgFe per kg/P removed. This situation was exacerbated by the downloading of Unit 3 in order to supply wastewater flow to the new Unit 4 at Northern Works. After the above repairs the Unit 3 fermentation plant was recommissioned with typical results achieved shown in Table 7.10.

Table 7.10 : Typical results of the modified Unit 3 fermentation/elutriation plant.

Sample	Total Volatile fatty acids as acetic acids mg/ℓ		
	Mean	Minimum value	Maximum value
Outfall Sewer	0	5	12
Settled Wastewater	0	8	49
Thickener overflow	91	211	344
Feed to reactors	0	49	168

With this performance it was possible to reduce iron salt addition back with the range of 1,5 to 2,5 Fe/P.

7.2.2 Plant Performance : Unit 4

After the commissioning of two of the bio-reactors the plant was operated for a preliminary period without the full commissioning of the fermentation elutriation plant. The results showed that biological phosphate removal was incomplete with an effluent total P in the range 2 - 3 mgP/l.

With the subsequent commissioning and optimisation of the fermentation/elutriation plant effluent phosphorus levels could be reduced to below 1 mgP/l. Table 7.11 shows the last monthly average results for the Unit 4 fermentation/elutriation plant.

Table 7.11 : Performance of the Unit 4 fermentation/elutriation plant.

Sample	Total Volatile fatty acids as acetic acid		
	Mean	Minimum value	Maximum value
Outfall Sewer	5	0	12
Settled Sewage	15	0	62
Thickener overflow	242	34	659
Feed to Balancing tank	61	19	111
Feed to reactors	25	2	50

As can be seen the results indicate a significant generation of VFA in the plant. However there is a disturbing apparent loss of VFA through the load balancing tanks. This will be investigated further. Table 7.12 shows the typical performance of Unit 4 after the optimisation of the fermentation/elutriation plant.

	COD as O	Suspended Solids	Phosphate as P	Ammonia as N	Nitrate as N
Raw Wastewater	700	300	12	26	-
Settled wastewater	200	40	10	26	-
Balancing tank feed	360	80	11	30	-
Feed to reactor	350	100	10	27	-
Pre-anoxic zone	-	-	13	8,8	3,1
Anaerobic zone	-	-	27	14	0,4
Anoxic zone	-	-	17	8,8	2,3
Aerobic zone	-	3 400	0,5	0,1	11
Effluent	37	2	0,3	0,2	11
Return sludge	-	7 000	2,0	0,1	10

(All results in mg/l)

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Disposal options for sewage sludge

The evaluation of various options for the final disposal of sewage sludge was carried out within the context of a large wastewater treatment operation. Strategies which may be suitable for smaller amounts of sludge may well not be appropriate in the case of the 300t DS/d being considered here. It is essential that this be kept in mind by readers of this report as evaluation of options for smaller amounts could well result in the adoption of different strategies.

Historical successful application of some technologies like co-disposal in a domestic landfill and proximity to a landfill clearly have an impact on the selection of this alternative. Where the opportunity exists to place landfills and wastewater treatment plants in close proximity to each other, this should be exploited.

Generation of waste without a care as to its eventual impact on the environment is a problem that faces every country in the world today. It is anticipated that world trends towards waste minimization and waste recycling will take hold in South Africa.

Examples of the potential of waste recycling for job creation are already evident. In the light of this trend the conceptual approach to sewage sludge as a potentially useful material should be promoted in contrast to the more negative waste material approach. Composting sewage sludge to produce a useful soil conditioner is considered to be integral to the more positive conceptual approach. Successful implementation of this approach will require a co-operative approach between regulatory agencies and sludge producers.

8.2 Co-disposal of sewage sludge with domestic refuse

Experience at the Goudkoppies site has highlighted the advantages of siting a landfill in close proximity to a wastewater treatment plant thus allowing co-disposal of sewage sludge to be facilitated. Operational problems can be experienced with compaction equipment but can be overcome with the proper attention to mixing ratios.

The higher the solids content of the sludge the higher the loading rate which can be achieved. Provision for facilities for solar drying of dewatered sludge prior to landfill disposal should be considered.

At the Goudkoppies site no contamination of groundwater in the vicinity of the landfill has been observed. Co-disposal of sewage sludge has had no dieterious effect on this situation.

8.3 Sludge disposal to sacrificial land

Fifteen years experience during which approximately 100kg/m^2/a has been disposed of to paddies and ploughed into the soil has clearly demonstrated the negative environmental impact of this practice. Groundwater in the vicinity of the boreholes has been severely contaminated.

While this disposal route may be attractive from a cost point of view, implementation at a large scale is not recommended without adequate drainage and subsequent disposal of the leachate to protect groundwater sources.

Contamination of the soil should be viewed in the appropriate context. In many cases the natural metal levels in the soil approach or even exceed Guideline limits.

8.4 Regulatory aspects

Regulation of sewage sludge disposal falls within the ambit of a number of government departments, all of who have different approaches to the problem. The adoption of different approaches is understandable as each department has a different primary objective.

Quality parameters for the regulation of sewage sludge can be divided into three categories, namely metal, organic and microbiological. In respect of metal and organic compound levels, it is essential that all regulatory agencies agree on specific limits for each compound. In deciding on the limits, factors like potential risk to both human health and agriculture should be considered in conjunction with factors like ease of enforcement, analytical constraints, potential for source control and applicability to local conditions.

The proposed organic compound limits need particularly stringent review in this regard. It is proposed that the relevant government departments facilitate a workshop with all stakeholders before finalizing legislative measures.

Microbiological quality standards need to be reviewed in the context of human health and the realities of local conditions.

8.5 Analytical methodology

When expressing maximum limits for metals in soils and sludge, it is assumed that unless otherwise specified, reference is being made to the total content of each metal rather than the available as the total metal content of soil is generally a rather meaningless value in terms of interpreting the impact of that soil on plant growth for example, it may be reasonable to assume that in this instance reference is being made to the "available" metal content.

In order to facilitate comparison of results obtained by different organisations, it is essential that validated analytical methods are agreed upon for all parameters. The choice of techniques for the determination of organic compounds is even wider than is the case with metals. The choice of extraction technique has a significant impact on the results obtained and must be specified in any Guideline document. Attempts to analyse trace amounts of these compounds without the benefit of mass spectrometry is practically impossible.

Attention also needs to be given to the method of expressing Ascaris ora. From a health point of view only "potentially infective" ora are relevant. Counts should therefore be expressed in these terms.

8.6 Quality of composted sewage sludge

The chemical quality of composted sewage sludge is directly related to the chemical quality of the sewage sludge. While some dilution of contaminant levels may occur as a result of the addition of bulking agent, it is considered appropriate to evaluate the potential for a composted sewage sludge to comply with a maximum limit by evaluating the raw and waste sludge in respect of chemical contamination.

Routine monitoring of the sludge in activated sludge plants can provide plant operators with information on metal discharge trends. Metal contamination in particular is expected to be a problem where industrial wastewater is treated. For this reason control at source is an essential prerequisite to the production of a high quality composted sewage sludge.

Routine monitoring of the mixed liquor of a activated sludge plant for metal contamination should be considered as sufficient to ensure compliance of the composted material with a maximum limit. This would obviate the necessity for analysing all compost batches, which would result in a very high analytical cost.

The high cost of testing for Ascaris ova, makes the routine application of this test very difficult. It is therefore proposed that quality certification of microbiological quality should be permitted in terms of process monitoring, i.e. if the required temperature has been achieved for a specified time it can be assumed that the microbiological quality is satisfactory.

8.7 Agricultural potential of composted sewage sludge

The use of composted sewage sludge should be promoted as a soil conditioner, particularly in the light of the large amounts of top soil lost annually by erosion.

8.8 Control of metal discharge sewer systems

Strategies to achieve the production of a high quality composted sewage sludge must indicate control of metal discharge at source. This is very difficult to achieve at local level without the support of the central government. Consideration must therefore be given to national legislation in this regard.

8.9 Control of organic compound discharge to sewer systems

The discharge of organic compounds to the sewer is an even more complex affair as the source is not easily identified. The compounds in question particularly compounds like polychlorinated biphenyls, are only present as components of other products and without regulation of their use, control of discharge to the sewer is not possible. In the case of these compounds a review of the limits may be the most appropriate way to deal with the problem.

8.10 Strategies for pretreatment of metal containing effluents

The most effective strategies for the pretreatment of metal containing effluents appears to be for the Council to assist metal dischargers to treat their waste prior to discharge to the sewer.

8.11 Fermentation and elutriation of sludge

Although results achieved to date have demonstrated the usefulness of fermentation and elutriation of sewage sludge to enrich the reactor feed with respect to volatile fatty acids thus promoting biological phosphorus removal. the processes involved have not been explored to their limits. Longer retention times may allow high concentrations of acids to be fed to the reactors thus further enhancing biological phosphorus removal.

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