Permissible Utilisation and Disposal of

Sewage Sludge

Edition 1

Department of Agriculture

Department of Health

Department of Water Affairs and Forestry

Water Institute of Southern Africa

Water Research Commission

TT 85/97

August 1997

Published by:

WATER RESEARCH COMMISSION
P O BOX 824
PRETORIA
0001

The "SLADS" software referred to in this document, emanates from a project entitled: "Research on Municipal Sewage Sludge Disposal: Development of Guidelines and Expert System" and was developed by the CSIR and funded by the Water Research Commission (WRC Project No. K5/605/0/1). "SLADS" software and installation instructions are included with this document.

ISBN 1 86845 281 6

Printed in the Republic of South Africa

Beria

FOREWORD

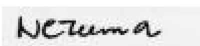
The recycling of sewage sludge for certain agricultural and other beneficial uses is one alternative to incineration, landfilling and ocean disposal practices that is receiving increasing attention. The potential benefits from recycling the soil-building and nutrient resources in sewage sludge by land application have been well demonstrated and have led to the utilisation of sludge in agriculture in many areas. Sludge management projects that recycle sewage sludge for agricultural use can, in many cases, be designed and operated to be both cost-effective and environmentally acceptable. This is especially true for small communities which have high quality sludge in terms of the lower concentrations of chemical pollutants, and are located in areas where adequate farmland is readily available.

However, public doubts and officials' concerns about adding potentially toxic substances and pathogens found in the sludge to productive farmlands must always be carefully considered. Therefore, land application of sewage sludge.to agricultural lands must still be examined closely and controlled effectively for the protection of human and animal health, crop quality and future land productivity.

The Sewage Sludge Discussion Forum was formed to address and study this multidisciplinary field of waste-water treatment in relation to beneficial uses of sludge that originates from sewage treatment plants. The Forum which evolved out of the Sludge Management Division (SMD) of the Water Institute of Southern Africa (WISA), consisted of thirteen concerned groups, including four government departments, research institutions, university academics, local authorities and consultants. The objective of this Forum was to produce a practical and workable document based on current national and international research data and regulatory strategies, ensuring that it will be acceptable to all parties involved. The Departments of Water Affairs and Forestry, Agriculture and of Health will formally refer and implement this document via several permitting procedures under current and new regulations.

This first edition of the guide "Permissible Utilisation and Disposal of Sewage Sludge" is indeed an example of co-operative government and collaboration with the private sector. The Water Research Commission and the CSIR developed a complementary and unique Sludge Land Application Decision Support software, "SLADS", based on the guide, which will further enhance the responsible utilisation of sewage sludge. We would like to take this opportunity to express the hope and expectation that this guide will be widely used by treatment plant operators, water practitioners, engineers, farmers and health workers alike, to the benefit of all people in South Africa.

The guide is also a consultative publication, seeking comments from all concerned parties on the current criteria and approaches adopted, thereby ensuring the updating and improvement of the guide. Comments should be addressed to The Director Environmental Health, Department of Health, Private Bag X828, Pretoria 0001.




Dr N C Dlamini Zuma, MP
MINISTER OF HEALTH

Mr D AHanekom, MP
MINISTER OF AGRICULTURE AND LAND AFFAIRS

Prof Kader Asmal, MP
MINISTER OF WATER AFFAIRS AND FORESTRY

ACKNOWLEDGEMENTS

Many individuals and organisations contributed towards the development of this guide. The following individuals, representing a variety of institutions, actively participated through the Sewage Sludge Discussion Forum, which was convened by the Sludge Management Division of the Water Institute of Southern Africa (WISA), to ensure the final composition of this guide:

- **Department of Agriculture, The Registrar of Act 36 of 1947**
  Mr G Steenkamp
- **Department of Agriculture, Directorate Resource Conservation**
  Mr K P Taylor
  Mr D J van Nieuwenhuizen
- **Department of Environmental Affairs and Tourism**
  Mr W E Scott and other representatives as observers
- **Department of Health, Directorate Environmental Health**
  Mr W van der Merwe (Technical editor/compiler)
  Mr F S Vivier
- **Department of Water Affairs and Forestry, Directorate Water Quality Management**
  Mr J L J van der Westhuizen
  Mr L Bredenhann
  Mr G Hefer
  Mr C S Crawford
- **Sludge Management Division (SMD) of WISA**
  Most of the mentioned persons are members of the SMD of WISA
- **Water Research Commission**
  Dr S A Mitchell (Convener/facilitator of the Forum) Mr
  H C Chapman
  Mr J Bhagwan
- **University of Cape Town, Department of Civil Engineering**
  Prof G Ekama (Chairman/facilitator of the Forum and chairman of the Sludge Management Division of WISA)
- **Agriculture Research Council, Institute for Soil, Climate and Water**
  Mr H J C Smith
  Mr C E Steyn
- **Umgeni Water**
  Mr Neil McNab
- **Environmentek, CSIR**
  Mr K O'H Murphy
- **Ockie Fourie Toxicologists CC**
  Dr H O Fourie
- **Local authorities**
  Dr L H Lötter (Johannesburg)
  Mr P B King (Cape Metro)
  Mr A R Pitman (Johannesburg)

TABLE OF CONTENTS

LIST OF TABLES

1. INTRODUCTION

In view of its organic and plant nutrient content, sewage sludge is regarded as a soil conditioner and fertiliser for agricultural and horticultural purposes. Since sewage sludge is produced during the treatment of sewage and waste water, originating from residential areas as well as from trade and industrial premises, it contains pathogenic organisms, various metals as well as inorganic and organic chemicals. Therefore, in utilising sewage sludge, careful consideration must be given to its potentially dangerous and hazardous properties in order to protect human and animal health and the environment in general.

2. AIM AND OBJECTIVES OF GUIDE

The aim of this guide is to assist and give direction to all responsible organisations for and concerned with sewage treatment and to promote safe handling, disposal and utilisation of sewage sludge.

Sludge Land Application Decision Support software, named SLADS, was developed by the Water Research Commission and the CSIR and is based entirely on the current guide. SLADS can, *inter alia*, be used in the determination of application rates and the classification of sewage sludge. SLADS is also a valuable source of additional information ranging from permit requirements to recommendations regarding agricultural activities. The printed document, *Permissible Utilisation and Disposal of Sewage Sludge* will be complementary to SLADS and both can be obtained from the Water Research Commission.

3. TO WHOM IS THIS GUIDE ADDRESSED?

3.1 To all 'local authorities", as defined in terms of the Health Act, 1977 (Act 63 of 1977)

- In terms of Section 20 of the Health Act 1977 (Act 63 of 1977), every local authority shall take all lawful, necessary and reasonable and practical measures to maintain its district in a hygienic condition and to prevent the occurrence of nuisances, unhygienic or offensive conditions or any other condition which will or could be harmful or dangerous to the health of any person within its own district or the district of any other local authority and where such conditions have occurred, to abate or to remedy such conditions. In general these duties and related powers also pertain to sewage purification and sewage sludge treatment, storage, processing, utilisation and disposal. This function and powers were assigned to the Provinces (Provincial Health Departments) in a Government Notice No. R. 152, 1994.

3.2 To the Department of Water Affairs and Forestry

- Recommendations made by the Department of Health to the Department of Water Affairs and Forestry, regarding sewage sludge aspects of Exemption Permits in terms of Section 21 of the Water Act, 1956 (Act 54 of 1956), will be based on the principles described in this guide.

- Waste disposal sites are permitted by the Department of Water Affairs and Forestry in terms of the Environmental Protection Act (Act 73 of 1989). Disposal and co-disposal of sewage sludge to waste disposal sites are therefore also regulated by this Act. Only sludge that complies with the TYPE D SLUDGE specifications will be accepted for such disposal (See classification of sludge in Table 1), but need not to be registered as a soil conditioner or fertiliser by the Department of Agriculture. The repeated use of a specific area for sewage sludge disposal (more than permitted application rate) will change that area into a disposal site.

3.3 To the Department of Agriculture

- Recommendations made by the Department of Health to the Department of Agriculture, regarding the registration of TYPE D SLUDGE products in terms of the Fertiliser, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947), will be based on this guide.

- The Department of Agriculture will in terms of the Conservation of, Agricultural Resources Act (Act 43 of 1983), apply these guidelines to prevent any pollution that may occur by the application of sewage sludge to agricultural soil.

3.4 Others

- To all bodies, parties and individuals in control of sewage sludge treatment, processing, storage, disposal and beneficial utilisation thereof in agricultural and other activities.

4. GUIDELINES

4.1 Classification of sewage sludge (Table 1)

Referring to Table 1, it will be noted that sewage sludge is **basically classified as three TYPES; A, B and C** in a decreasing order of **potential to cause odour nuisances and flybreeding as well as to transmit pathogenic organisms to man and his environment.** Although examples are presented for the origin or treatment of sludge, the principles on which these three sludge types should be differentiated, are the following:

- **TYPE A SLUDGE:** Unstable with a high odour and fly nuisance potential; high content of pathogenic organisms.
- **TYPE B SLUDGE:** Stable with low odour and fly nuisance potential; reduced content of pathogenic organisms.
- **TYPE C SLUDGE:** Stable with insignificant odour and fly nuisance potential; containing insignificant numbers of pathogenic organisms.

- **(TYPE D SLUDGE):** Sewage sludge included in this classification is of **similar hygienic quality as TYPE C** but since it is produced for unrestricted use on land at a maximum application rate of 8 dry t/ha.yr, **the metal and inorganic content are limited to acceptable low levels**. TYPE D SLUDGE products must be registered at the Registrar of Act 36 of 1947. (Detailed information is available from the Department of Agriculture).

As it is impossible to analyse for all pathogenic organisms and too costly to determine the presence of a wide range of these organisms, only the numbers of Ascaris ova, Salmonella organisms and Faecal coli are included as indicators of hygienic quality requirements of TYPE C and TYPE D SLUDGE.

4.2 Beneficial uses and disposal of sewage sludge as well as general requirements and precautionary measures according to type of sludge (Tables 2 and 3)

Referring to Table 2, the intention is to list the most common horticultural and agricultural uses of sewage sludge and methods of disposal as well as the conditions under which the various types of sludge may be applied.

The permissibility to utilise the various types of sludge, the basic general requirements and precautionary measures presented (Table 2) and the degree of restrictive measures (Table 3), were designed to minimise nuisances and transmittance of pathogenic organisms directly to man or indirectly through his food chain as well as to protect water sources and the environment from being polluted to an unacceptable level. For example the permissibility to utilise sewage sludge ranges from extremely restrictive on growing vegetables and for private garden use to highly restrictive in public parks and on grazing for food-producing animals to less restrictive for fertilising trees.

TABLE 1
CLASSIFICATION OF SEWAGE SLUDGE TO BE USED OR DISPOSED OF ON LAND

TYPE OF SEWAGE SLUDGE	ORIGIN/TREATMENT (EXAMPLES)	CHARACTERISTICS-QUALITY OF SEWAGE SLUDGE
TYPE A SLUDGE	Raw sludge Cold digested sludge Septic tank sludge Oxidation pond sludge	•Usually unstable and can cause odour nuisances and fly-breeding •Contains pathogenic organisms •Variable metal and inorganic content
TYPE B SLUDGE	Anaerobic digested sludge (heated digester) Surplus activated sludge Humus tank sludge	•Fully or partially stabilised – should not cause significant odour nuisance or fly-breeding •Contains pathogenic organisms •Variable metal and inorganic content
TYPE C SLUDGE	Pasteurised sludge Heat-treated sludge Lime-stabilised sludge Composted sludge Irradiated sludge	•Certified to comply with the following quality requirement: (If not certified this sludge is considered a TYPE B SLUDGE) - Stabilised - should not cause odour nuisances or fly-breeding - Contains no viable Ascaris ova per 10g dry sludge -Maximum 0 Salmonella organisms per 10g dry sludge - Maximum 1000 Faecal coliform per 10g dry sludge, immediately after treatment (disinfection/sterilisation)
TYPE D SLUDGE A sludge product produced for unrestricted use on land with or without addition of plant nutrients or other materials **This product must be registered in terns of Act 36 of 1947 if used for agricultura/horticultural activities**	Pasteurised sludge Heat-treated sludge Lime-stabilised sludge Composted sludge Irradiated sludge	Certified to comply with the following quality requirements - Stabilised - should not cause odour nuisances or fly-breeding - Contains no viable Ascarls ova per 10g dry sludge -Maximum 0 Salmonella organisms per 10g dry sludge -Maximum 1000 Faecal coliform per 10g dry sludge,immediately after treatment (disinfection/sterilisation) •Maximum metal and inorganic content in mg/kg dry sludge Cadmium 15,7 Cobalt 100 Chromium (Cr^{3+}) 1750 Copper 50,5 Mercury 10 Molybdenum 25 Nickel 200 Lead 50,5 Zinc 353,5 Arsenic 15 Selenium 15 Boron 80 Fluoride 400 • User must be informed about the moisture and N P K content • User must be warned that not more than 8t/ha (or 10 kg sq.m)(dry sludge may be applied to soil and the pH of the soil should preferably higher than 6.5.

TABLE 2

CROP TYPES THAT MAY BE FERTILISED WITH SEWAGE SLUDGE AND OTHER METHODS OF UTILISATION OR DISPOSAL

CROP TYPES/OTHER OPTIONS	TYPE A SLUDGE	TYPE B SLUDGE	TYPE C SLUDGE	TYPE D SLUDGE
1. Selling or alienation	Permissible - Restriction 1	Permissible - Restriction 1	Permissible - Restriction 1	Permissible - No restriction
2. Household vegetables consumed raw or cooked and tobacco	Not permissible	Not permissible	Not permissible	Permissible - Recommendation 2,6
3. Vineyards and fruit trees (Excluding private gardens	Not permissible	Permissible - Restriction 3,6	Permissible - Restriction 6	Permissible - Recommendation 6
4. Cereal culture and sugar-cane	Not permissible	Permissible - Restriction 3,6	Permissible - Restriction 6	Permissible - Recommendation 6
5. Public gardens and traffic islands only for beautifying with minimum human contact	Not permissible	Permissible - Restriction 6	Permissible - Restriction 6	Permissible - Recommendation 6
6. Public parks, recreation areas, lawns at schools, swimming pools, sorts fields	Not permissible	Permissible - Restriction 2,6	Permissible - Restriction 2,6	Permissible - Recommendation 6
7. Private gardens: Lawns, shrubs, trees, vegetables	Not permissible	Not permissible	Not permissible	Permissible - Recommendation 6
8. Nurseries: shrubs, trees and other plants	Not permissible	Permissible - Restriction 3,5	Permissible - Restriction 5	Permissible
9. Instant lawn cultivation	Not permissible	Permissible - Restriction 3,5	Permissible - Restriction 3,5	Permissible
10. Grazing for milk-, meat- and egg- producing animals	Not permissible	Permissible - Restriction 2,6	Permissible - Restriction 6	Permissible - Recommendation 6
11. Crops not for grazing, but utilised as dry fodder	Not permissible	Permissible - Restriction 3,4,6	Permissible - Restriction 6	Permissible - Recommendation 6
12. Stabilising of mine dumps - grass or other plants	Not permissible	Permissible - Restriction 6,7	Permissible - Restriction 6, 7	Permissible - Recommendation 6,7
13. Composting with other organic material	Permissible see e C sludge)	Permissible (see type C sludge)	Permissible	Permissible
14. Natural veld and tree plantations	Permissible - Restriction 4,5,6,8	Permissible - Restriction 3,4,6	Permissible - Restriction 6	Permissible
15. Land application - ploughed in repeatedly, disposal and co-disposal on disposal site	Not permissible	Not permissible	Not permissible	Permissible Restriction 9
GENERAL REQUIREMENTS AND PRECAUTIONARY MEASURES ACCORDING TO TYPE OF SLUDGE	MAXIMUM SLOPE OF SITE: 1:25 (4 %) Depth of aquifer: >5m >500 m from dwelling >200 m from river, dam, borehole Soil pH >6,5	MAXIMUM SLOPE OF SITE: 1:17 (6 %) Depth of aquifer: >2m >200 m from dwelling >200 m from river, dam, borehole Soil pH >6,5	>100 m from river Soil pH >6,5	Soil pH preferably >6,5

See Table 3 for restriction/recommendation 1 to 9

TABLE 3
RESTRICTIONS/RECOMMENDATIONS REFERRED TO IN TABLE 2

1. Only as per contract see Table 8.
2. Application only during planting.
3. Application only with planting and during the period subsequent to harvesting and prior to the next growing season in order to minimise sewage sludge coming into contact with crops to be harvested.
4. Application permissible, only if the area is effectively fenced to keep out unauthorised persons as well as milk-, meat- and egg-producing animals.
5. No subsequent selling or alienating of sludge or any mixture containing such sludge is allowed by the user.
6. All sludge must be mixed or covered with soil whenever possible.
7. Soil pH and slope requirements could be relaxed on condition that no contaminated runoff and seepage water will pollute any surface or underground water.
8. Application of excessive quantities of sewage sludge to land causes that site to be unfit for any other purpose during such operation and for a minimum period of two years after termination thereof. (Waste disposal site, see 9.)
   No nuisance or any other condition posing a potential health hazard or which may cause pollution of any water source will be tolerated on such site.

   Utilisation of this site for any other purpose will only be permitted after the necessary investigation has proved this to be safe.
9. Disposal of sludge and the co-disposal of sludge with domestic waste and other waste, on disposal sites, must comply with the following:

   - Permit requirements in terms of the Environmental Conservation Act, Act 73 of 1989.
   - "Minimum Requirements for Waste Disposal by Landfill", a Department of Water Affairs and Forestry document.

4.3 Restriction on the utilisation of sewage sludge related to the metal and inorganic content thereof (Tables 4 and 5).

In areas where waste water from metal-related and other industries is accepted to be discharged into sewers, the production of sewage sludge containing high levels of metals and other chemicals can be expected. Various metals and inorganic contaminants at varying concentrations may be toxic, either to plants, animals or man. Due to the numerous variables such as stability properties, rate of absorption and accumulation in different plant species, it is virtually impossible to define detailed requirements in this regard. In view of available international data and local research results, the maximum permissible metal and inorganic contaminants in the soil, as well as the total maximum permitted application rate (Total Load) thereof in soil, are tabled in Table 4. The maximum application rate of sewage sludge must therefore be limited according to the metal and inorganic contaminants concentrations in the sludge and the maximum application rate thereof allowed. Examples of the maximum application rate of sewage sludge versus the corresponding total maximum metal and inorganic content are tabled in Table 5. It is recommended that the frequent user of sewage sludge for agricultural purposes should also consider the plant-available concentration of metals and inorganic content of the soil in collaboration with professional agricultural consultants to ensure optimum plant growth and sufficient soil protection.

TABLE 4
MAXIMUM METAL AND INORGANIC CONTENT IN SOIL AND PERMISSIBLE APPLICATION RATE OF METAL AND INORGANIC CONTENT TO SOIL (TOTAL LOAD)

METAL	MAXIMUM PERMISSIBLE METAL AND INORGANIC CONTENT IN SOIL mg/kg	TOTAL LOAD g/h.25 year	MAIN REASON WHY METALS AND INORGANIC CONTAMINANTS ARE LIMITED	
			PHYTOTOXICITY	ZOO-TOXICITY
Cadmium Cd	2	3140		x
Cobalt Co	20	20 000		x
Chromium Cr	80	350 000	x	
Copper Cu	6,6	10100	x	
Mercury Hg	0,5	2 000		x
Molybdenum Mo	2,3	5 000		x
Nickel Ni	50	40 000	x	
Lead Pb	6,6	10100		x
Zinc Zn	46,5	70 700	x	
Arsenic As	2	3 000	x	
Selenium Se	2	3 000		x
Boron B	10	16 000	x	
Fluoride F	200	80 000		x

TABLE 5
PERMISSIBLE SLUDGE APPLICATION RATE IN RELATION TO THE METALS AND INORGANIC CONTAMINANTS PRESENT

APPLICATION RATE FOR SLUDGE - t/ha.yr (or kg/10 sq m) (DRY MASS)	MAXIMUM METAL AND INORGANIC CONTAMINANT CONCENTRATIONS IN SLUDGE (DRY MASS) kg (or 9R) PERMITTED FOR THE CORRESPONDING SLUDGE APPLICATION RATE												
	Cd	Co	Cr	Cu	Hg	Mo	Ni	Pb	Zn	As	Se	B	F
0,5	251	1 600	28 000	808	160	400	3 200	808	5 656	240	240	1 280	6 400
1,0	126	800	14 000	404	80	200	1 600	404	2 828	120	120	640	3 200
5	84	533	9 333	269	53	133	1 067	269	1 885	80	80	427	2 133
2,0	63	400	7 000	202	40	100	800	202	1 414	60	60	320	1 600
2,5	50	320	5 600	162	32	80	640	162	1 131	48	48	256	1 280
3,0	42	267	4 667	135	27	67	533	135	943	40	40	213	1 067
3,5	36	229	4 000	115	23	57	457	115	808	34	34	183	914
4,0	31	200	3 500	101	20	50	400	101	707	30	30	160	800
4,5	28	178	3 111	90	18	44	356	90	628	27	27	142	711
5,0	25	160	2 800	81	16	40	320	81	566	24	24	128	640
6,0	21	133	2 333	67	13	33	267	67	471	20	20	107	533
7,0	18	114	2 000	58	11	29	229	58	404	17	17	91	457
8,0	15,7	100	1750	50,5	10	25	200	50,5	353,5	15	15	80	400

4.4 Restrictions related to nitrogen application rate (Table 6)

The application rate of sewage sludge should ideally be based on the P-content rather than N-content of sewage sludge. The reason is attributed to the relatively low N-content of sewage sludge. The amount of total N in sewage sludge which can become available for plants, is approximately 30% in the first year after application, 15% in the second year and 5% in the third year. When it is known how much N is needed for optimum plant growth, the amount of available N from the sludge must be subtracted from the N demand and the balance N added with another sources such as fertiliser (artificial) nitrogen. However, excess application of fertiliser nitrogen must be avoided to prevent potential pollution of groundwater. Table 6 may be used as a general guide for the nitrogen demand of crop types. It is recommended that the frequent user of sewage sludge for agricultural purposes should also consider the nitrogen demand of crops in collaboration with professional agricultural consultants to ensure optimum plant growth and sufficient soil- and groundwater protection.

4.5 Restrictions related to the presence of organic chemicals in sewage sludge (Table 7)

The presence of many pesticides and organic chemicals in sewage sludge may present environmental and health hazards. Producers of sludge for utilisation should be prepared to undertake the necessary measures when waste water from a chemical industry is accepted to be discharged into their sewers, especially when a TYPE D SLUDGE for unrestricted use is to be produced. After consultation with toxicologists the following maximum annual loading limits for some organic chemicals are presented in Table 7 as preliminary guidance and information.

TABLE 6
GENERAL INDICATION OF SEASONAL NITROGEN DEMAND

NITROGEN DEMAND kg/ha	CROP OF USE
30 – 50	Maize
10 – 30	Wheat (Summer rainfall area)
30 – 50	Wheat (Winter rainfall area)
30 – 50	Sunflower
12 – 40	Dry and soya bean
40 – 70	Cotton
15 – 40	Potatoes
40 – 50	Tomatoes
150	Onions
180	Sweet peppers
160	Cabbages
45 – 75	Asparagus
80 – 120	Other vegetables
80-100	Lawns
30 – 80	Tobacco
30 – 40	Pastures and fodder crops

TABLE 7
MAXIMUM LIMITS FOR ORGANIC AND OTHER POLLUTANTS IN SEWAGE SLUDGE

POLLUTANTS	CONCENTRATION DRY SLUDGE mg/kg
Aldrin	0,202
Benzo(a)pyrene	2,53
Chlordane	3,5
DDT	0,35
Dieldrin	0,303
Dimethyl nitrosamine	2,9
Heptachlor	0,35
HCB	16,2
Lindane	1,36
PCB	1,0
Trichloroethylene	2020,0

4.6 The importance of the pH of soil

The mobility and availability of heavy metals are greatly increased at soil pH (water) values of 6,5 and below, with the exception of As, Mo, Se and V as well as some valence states of Cr. Therefore most heavy metals are more available for plant uptake at low soil pH values. This is an important factor for South African soils as many soils, especially in the higher rainfall areas, are acidic or can easily be acidified because of poor buffer capacity. Soils, where sludge containing metals are administered should therefore be monitored and treated with lime to keep the pH (water) above a level of 6,5.

4.7 Disposal of sewage sludge to landfill sites: Co-disposal of sewage sludge with domestic waste and repeated land application

The repeated use of a specific area for sewage sludge disposal (more than permitted application rate) will change that area into a disposal site. This area must be permitted in terms of the Environmental Conservation Act (Act 73 of 1989). The permit system is administered by the Department of Water Affairs and Forestry and they may be contacted for more information. Considering the possible accumulation of heavy metals, especially in groundwater, sewage sludge disposed or co-disposed on landfill sites should comply with TYPE D SLUDGE specifications. However, the Department of Agriculture need not register sewage sludge destined for disposal sites as a fertiliser in terms of Act 36 of 1947.

5. CONTROL MEASURES

5.1 Contractual agreement (Table 8)

Although the local authority of the district in which the sewage sludge originates, will be primarily responsible to ensure compliance with these guidelines, all other parties within or outside this district concerned with treating, handling, transporting, processing, selling, alienating, utilising or disposing of this sewage sludge, would also be jointly and severally responsible to comply with these guidelines. In many cases this will necessitate a joint effort and mutual understanding between all authorities and individuals responsible for handling a specific sewage sludge from the place where it is produced to the area where it is utilised or disposed of. In view of this mutual responsibility and the fact that the alienation of TYPE A, B and C SLUDGE is regarded as a beneficial disposal method, the guide makes provision for the necessary contractual agreement between the producer and receiver. In Table 8 those aspects which should be made known and on which the two parties concerned should agree, are proposed.

5.2 Sludge quality control, sampling frequency and laboratory analyses

No sampling frequency and methods for analyses are specified. The producer of the sewage sludge for utilisation should decide on such a sampling frequency and reputable laboratory which will enable them to certify the required sludge quality with reasonable accuracy and reliability.

TABLE 8
ESSENTIAL ITEMS TO BE INCLUDED IN CONTRACTUAL AGREEMENT (TYPE A, B OR C SLUDGE)

SUPPLIER/PRODUCER

1. Name and address
2. Type of sewage sludge - A, B or C
3. Quality: Hygienic - stability and micro-organisms
   Moisture content, nitrogen, phosphate and potassium content
   Maximum metal and inorganic content
   (Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Zn, As, Se, B, F)
4. Limiting metal and maximum application rate in dry tlha.yr
5. Recommended maximum application rate in t/ha.yr in terms of nitrogen demand of crop
6. Notification of local authorities involved

RECEIVER/USER

1. Name and address
2. Name of transporter of sludge
3. Name of farm or site where sludge will be stored and used
4. Date of application as well as size and the exact location of sludge application area
5. Crops to be fertilised or alternative use
6. Previous sewage sludge application - annual rate and frequency
7. Metal and inorganic content in soil (Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Zn, As, Se, B, F)
8. Details of sewage sludge processing, addition of other materials or chemicals and quality of final product, if produced for selling

AGREEMENT

1. Sewage sludge to be used in terms of current guide
2. Inspection of user's activities by local authority
3. Breach of contract - Termination of sewage sludge supply and punitive measures

6. CONCLUSION

The guidelines presented are based on a wide spectrum of international and local research results and experience and contain the minimum restrictions and requirements, provide for sufficient flexibility and should contribute to the satisfactory protection of human health and the environment. These guidelines should rather be seen as a comprehensive effort to put sewage sludge treatment, processing, beneficial utilisation and disposal on a uniformly sound basis country-wide. The Departments of Water Affairs and Forestry, Agriculture and of Health will formally refer and implement this document via several permitting procedures under current and new regulations and therefore will have legal status. Complementary to the guide the Sludge Land Application Decision Support software, named SLADS is a source of additional information ranging from permit requirements to recommendations regarding agricultural activities. Background information pertaining to the guide and South African sewage sludge, benefits of sewage sludge, application to agricultural land and extracts from the relevant Acts can be found in Sewage Sludge Utilisation and Disposal Information Document prepared by the Water Institute of Southern Africa (WISA).

The successful implementation of this guide will, however, depend on the goodwill of authorities, private sector and the public to co-operate within present legislation.

ENQUIRIES

All enquiries regarding the implementation of the guide should be addressed to the Department of Health, Directorate Environmental Health, Private Bag X828, Pretoria, 0001 or the nearest Provincial Health Department. Copies of this document can be obtained from the Water Research Commission (WRC), P O Box 824, Pretoria, 0001. The Sludge Land Application Decision Support software, SLADS can also be obtained from the Water Research Commission (WRC). The document prepared by the Water Institute of Southern Africa (WISA), namely Sewage Sludge Utilisation and Disposal Information Document can be obtained from W ISA at P 0 Box 6011, Halfway House, 1685.

MUNICIPAL SEWAGE SLUDGE DISPOSAL: DEVELOPMENT OF GUIDLINES AND EXPERT SYSTEMS

SLADS USER MANUAL

Report to the
WATER RESEARCH COMMISSION

K. O'H. MURPHY
CAPE WATER PROGRAMME
DIVISION OF WATER, FORESTRY & ENVIRONMENTAL TECHNOLOGY
CSIR, STELLENBOSCH

WRC Report No. K5/605a/1/97
CSIR Report No. ENV/S – C9711b

CURRENT STATUS AND FURTHER CHANGES
Please note that the current version of SLADS addresses contaminant pathway information in some detail for cadmium and lead only. Future versions may address contaminant pathway information in detail for other contaminants should funds be made available for this.

DISCLAIMER
This document and accompanying software has been reviewed by the Water Research Commission. The Commission's approval does not signify that the contents of the document nor the software reflect the views and policies of the Water Research Commission, nor does it constitute their recommendation for use.

CONTENTS

LIST OF FIGURES, TABLES AND TERMS

Term	Description applicable to SLADS and/or this document
I & AP :	Interested and Affected Parties
Screening :	Process of determining whether overriding conditions are applicable (e.g. "go" or "no-go")
Scoping :	Framework for defining the extent and depth of study
DWA&F :	Department of Water Affairs & Forestry
DNH&PD :	Department of National Health & Population Development (Now the Department of Health)

1 INTRODUCTION

In the scientific environmental professions, there is a need for people to have convenient access to relevant information, whether it be descriptive or functional information and whether it be static (unchanging) or dynamic (change according to the requirements at the time). Computers are being used more and more to supply such information. A requirement which is being addressed more and more is that of providing routine expertise on a computer. "Expert systems" are computer programs which incorporate expertise ("clever" programs).

Modern expert systems are now often designed to perform some of the functions of database systems, conventional programs and hypertext systems, but are driven by sets of rules, logic, and a "reasoning system". An analogy to this can be made with an expert at a site who uses a field manual to obtain design criteria from a table, or who takes out a calculator in order to quantify a solution to a problem. Expert systems development usually involves trapping routine expertise and then making it readily accessible to users in a form suitable for decision-support, guidance and educational purposes. Routine expertise is defined here as being expertise required to address a problem for which there are well-formulated, repetitive decision processes. Examples of the latter occur in weather forecasting, disease diagnosis, mechanical and electrical fault-finding, permitting procedures, site identification, irrigation management and tax advice.

An expert system may be used to do the following (amongst others):

* provide routine expertise;
* give direction in determining types and depths of studies required;
* access and display relevant electronic text in guideline documents according to identified needs;
* carry out required numeric calculations;
* access relevant information from a database;
* draw up reports;
* obtain the required information from a user in order to select and run an external program;
* interpret results supplied by an external program.

A decision-support system, which consists of a suite of expert-systems-based computer programs, and which attempts to carry out some of the tasks mentioned above, is described in this document. The overall system is called **SLADS**: **S**ludge **L**and-**A**pplication **D**ecision-Support **S**oftware. Installation instructions and an outline of SLADS, the latter showing what each component does, are addressed in the next chapter.

2 INSTALLATION INSTRUCTIONS

The file "slads.exe" should be copied from the `stiffy' disk to the C root directory. This file should then be run. Its purpose is to install the software in a subdirectory called "slads".

The file "sludge.exe" in the root directory (C:\) may then be deleted and the batch file "slads.bat" may be copied from the "slads" subdirectory to the root directory. The file "slads.bat" may be run from the root directory or from the "slads" subdirectory.

To run the software, the following should be typed:

slads
<Enter>

NOTE(1): There should be more than about 512 Kb of DOS memory available for the software to run. For faster processing time, about 540 Kb is adequate.

NOTE(2): If at any time the <F2> function key is used to exit **SLADS**, options are presented to the user to re-run the current program or to return to the Leonardo" operating system (or "shell"). If the latter is chosen, a list of expert-system names will be presented for further selection: SLCOORD, SLEVAP, S LSITE, SLUDGE and SL W&R. Except for SLCOORD, these are the same programs as the ones presented in the initial menu system in **SLADS**. Their functions are as follows:

SLCOORD - **The coordinating expert system.**
This presents some preliminary information and calls up the other expert systems when they are required.

SLUDGE - **Sludge permitting assistant.**
This addresses sludge-to-land permit requirements.

SLSITE - **Site/area identification aid.**
This is designed to help identify suitable areas for sludge application.

SL W&R - **A site-suitability ranking tool.**
This is designed for use as a site/area relative-evaluation aid.

SL EVAP - **Surface water-balance and run-off storage estimation aid.**
This is designed to help determine the capacity of an area of land to accept liquid sludge on a monthly basis taking into account monthly precipitation-evaporation, disposal-area and liquid sludge-volume data.

These expert systems are discussed in further detail in the following chapter.

3 COMPONENTS OF SLADS

3.1 The Coordinating Expert System

The coordinating expert system is a simple program designed to present preliminary information and to call up other programs. Its functionality is perhaps best shown in a table as follows:

Table 1 Description summary of expert systems in SLADS

The **coordinating expert system.** This presents some preliminary information and calls up the other expert systems, below, when they are required.			
Sludge permitting assistant	**Site/area identification aid**	**A site-suitability ranking tool**	**Water balance and run-off storage estimation aid**
Addresses sludge-to-land permit requirements. (See Section 3.2)	Designed to help identify suitable areas/sites, planning constraints and other mitigatory measures. (See Section 3.3)	Designed for use as a relative site evaluation tool: Uses weighting and rating formulae. (See Section 3.4)	Estimates monthly "water-balance" values, given precipitation-evaporation, disposal-area and liquid-sludge data. (See Section 3.5)
Select this if you want to obtain or process a permit for the following: * application of sludge to land, * disposal of sludge, * transfer of sludge ownership.	Select this if you want to identify suitable areas for sludge application to land, taking into account existing regulations (or guidelines) in the guide: Permissible Utilization and Disposal of Sewage Sludge (DNH&PD) as well as other recommendations.	Select this if you want to compare areas or sites using a weighting-and-rating technique for site-comparative impact assessment purposes.	Select this if you want to determine the capacity of an area of land to accept liquid sludge on a monthly basis taking into account: * sludge volume, * storage of contaminated runoff, * size of extra available land.

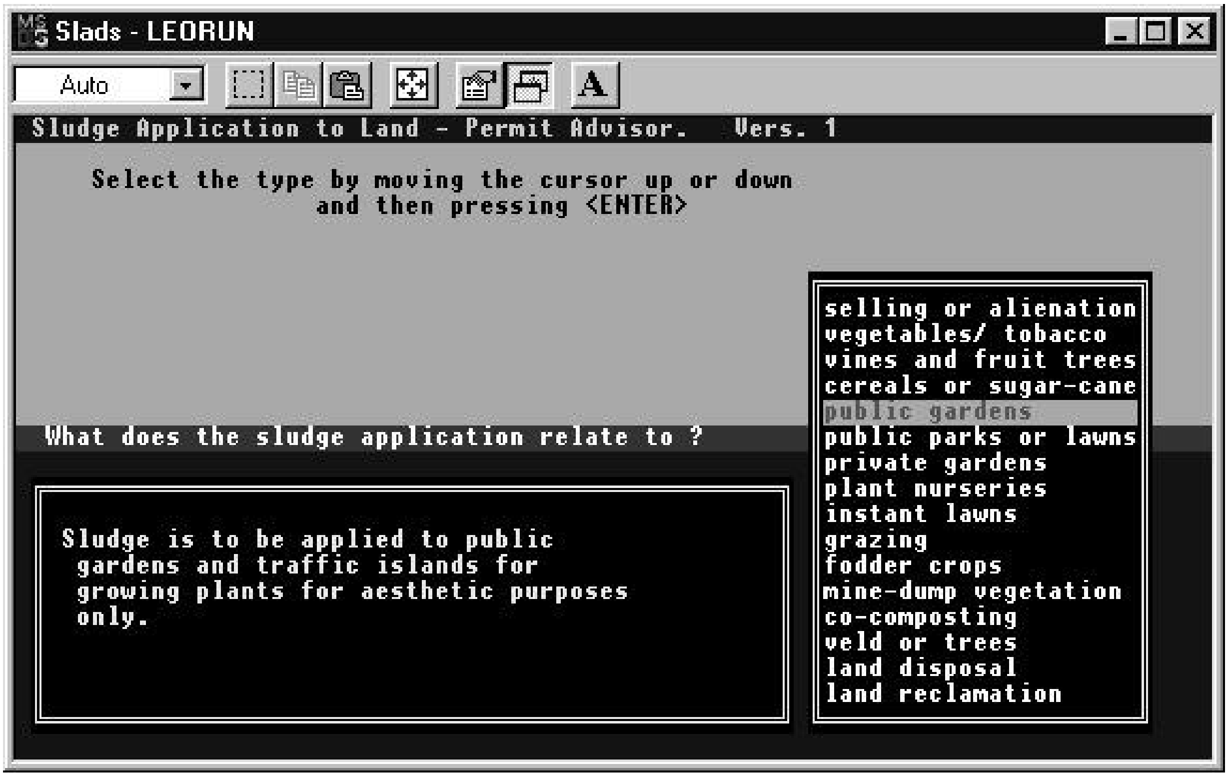


Figure 1: Land-use question screen (The item “public gardens” is highlighted)

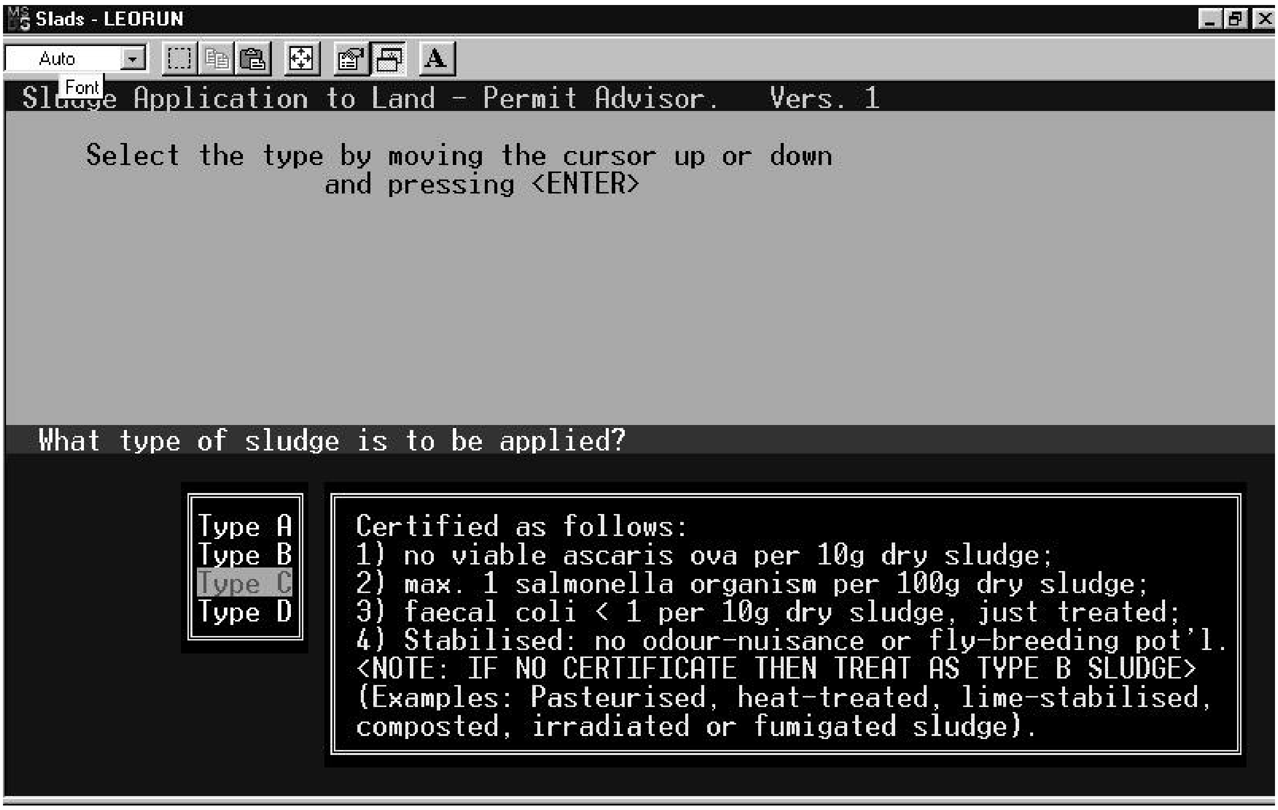


Figure 2: The sludge-type screen (Item “Type C” is highlighted)

3.2 Sludge permitting assistant

The sludge permitting assistant helps to evaluate the following:

* Determine whether application of the sludge for a certain crop or land use/crop use/other use is permissible or not, given sludge and land-use types (See **Figure 1** and **Figure 2**).
* Determine whether certain site-specific factors such as soil pH, site slope and distance to water cause the site to be unsuitable for application of a certain type of sludge.
* Determine to what extent trace-element/contaminant concentrations in soil fall within the prescribed concentration limits. If one is exceeded, the site is not considered suitable for sludge application. A display of tabulated results is presented (See **Figure 3**).
* Given a required sludge application- rate to land and given trace-element/contaminant concentrations in the sludge, determine to what extent the application rate of each is within its prescribed limits. If any is at or above its prescribed limit, the application rate is considered to be too high. The user is able to revise the application rate and compare application rates as percentages of the prescribed limits (See **Figure 5** and **Figure 6**).

Decision-support within the sludge-permitting assistant includes:

* An expert system whose purpose is to help determine the application rate of sludge based on crop nitrogen requirements. Included in this is an electronic form which is used to calculate the nitrogen (N) application rate, depth of applied liquid for liquid sludges given % solids content, the land area required for a given mass of sludge and the mass of sludge needed for a given land area (See **Figure 4**).
* Display of supporting textual and calculated numeric information in the upper part of the screen while a question is presented. The latter is updated dependent on the results of the previous trial run. Display of textual data on crop nitrogen requirements is read from a file on the computer's hard disk (See **Figure 7**).

If the user is satisfied with the interim results, a screen showing a summary of the results is presented (See **Figure 8**), and detailed information is then presented on screens which follow (See **Figure 9**, **Figure 10** and **Figure 11** as examples). After this, an option is presented for a report and a log file to be printed to a text file on the computer's hard drive (See Figure 12). These files may then be imported into any word processor for final editing and printing.

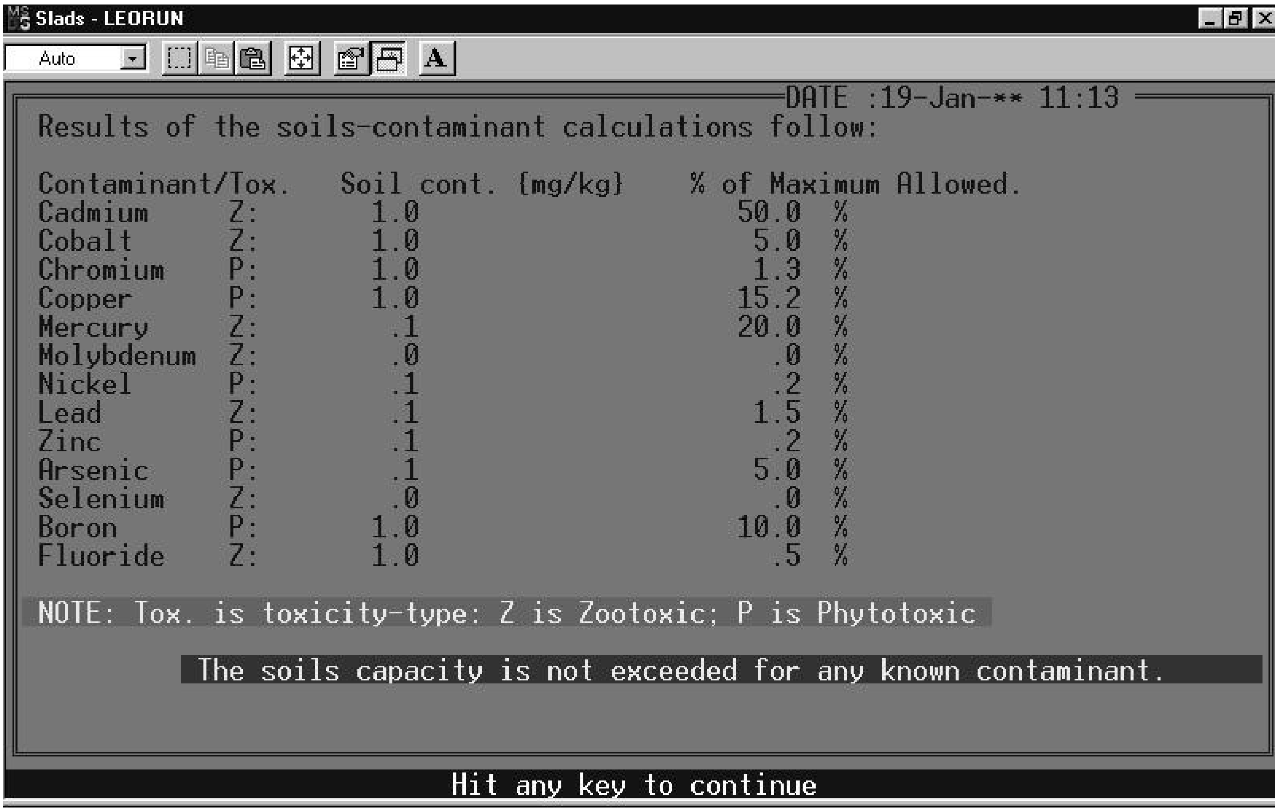


Figure 3: Display of soil contaminant concentrations versus % of prescribed limits.

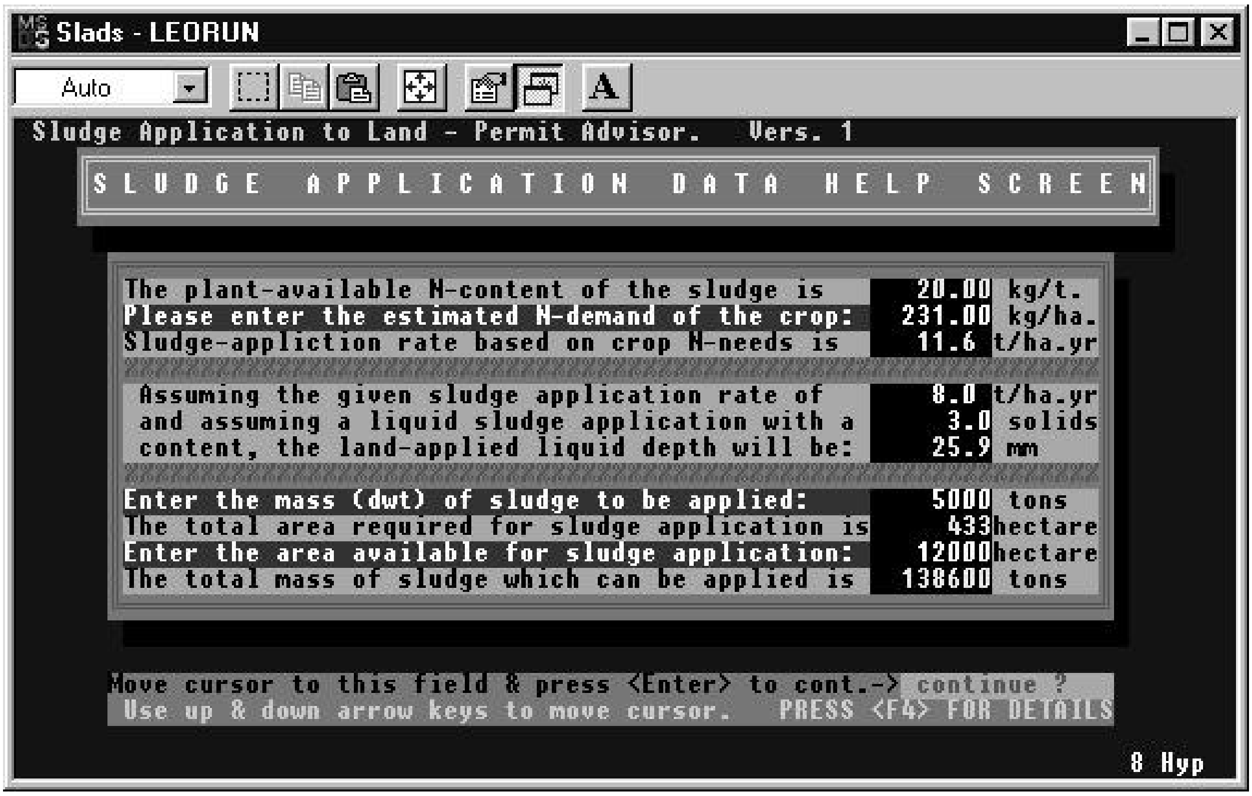


Figure 4: Screen showing a data entry and display form.

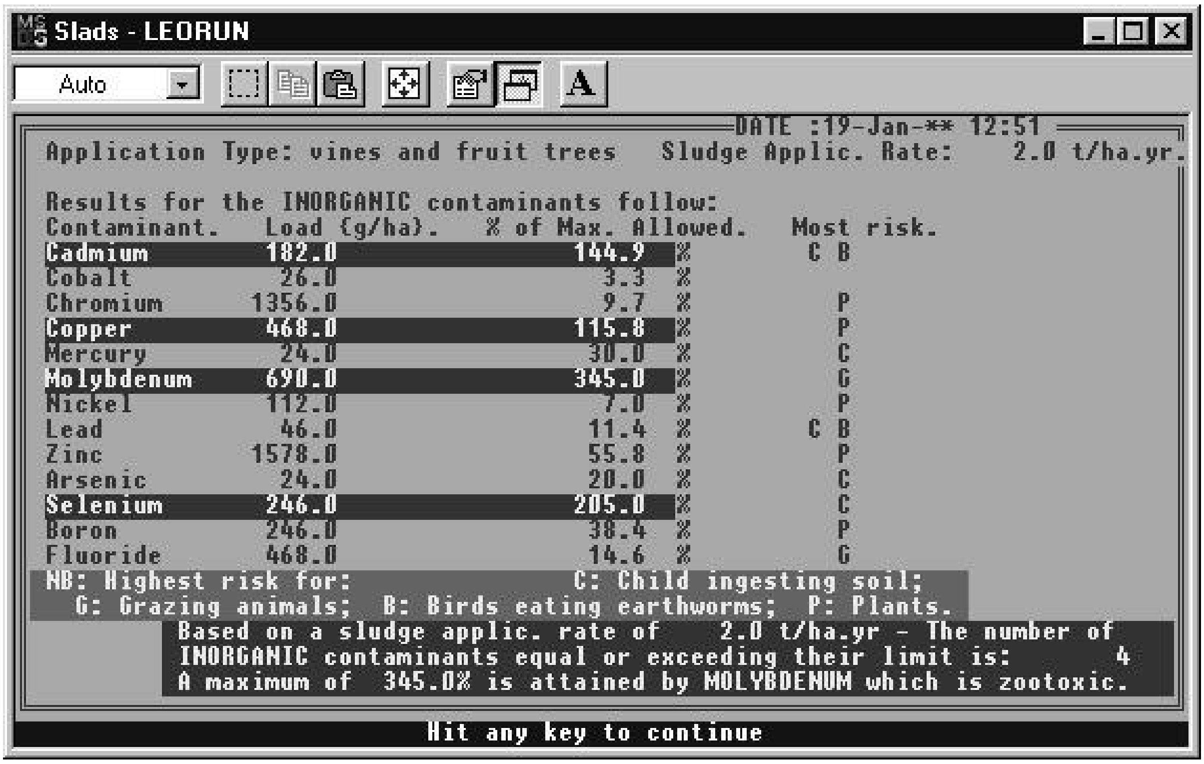


Figure 5: Display: Inorganic contaminant concentrations in sludge and % of allowed limits.

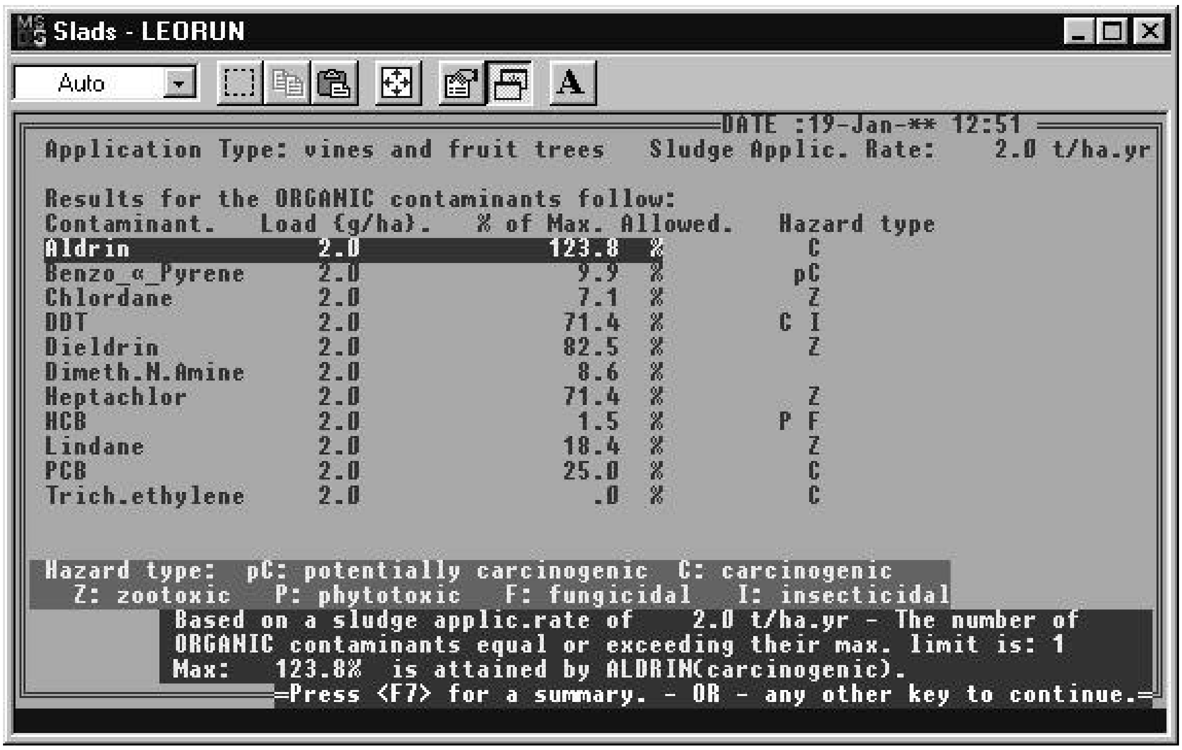


Figure 6: Display of organic contaminant concentrations in sludge and % of allowed limits.

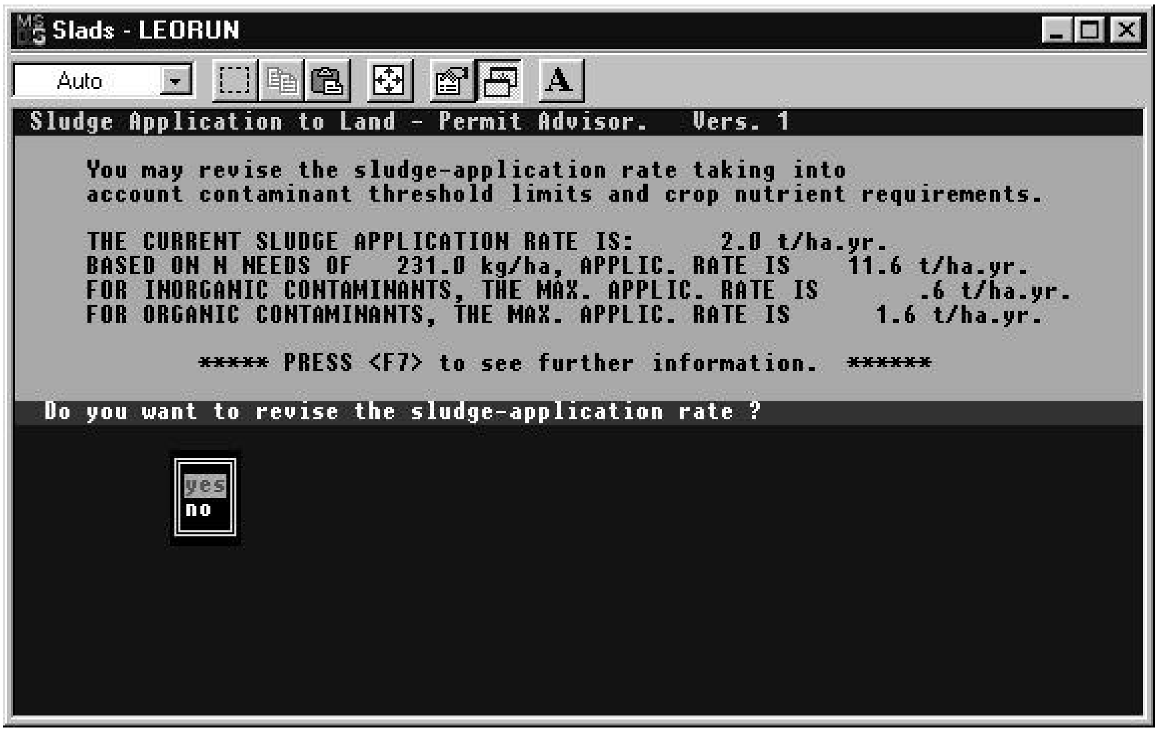


Figure 7: Question screen with display of limits on sludge application rates at top.
(The item "yes" is highlighted)

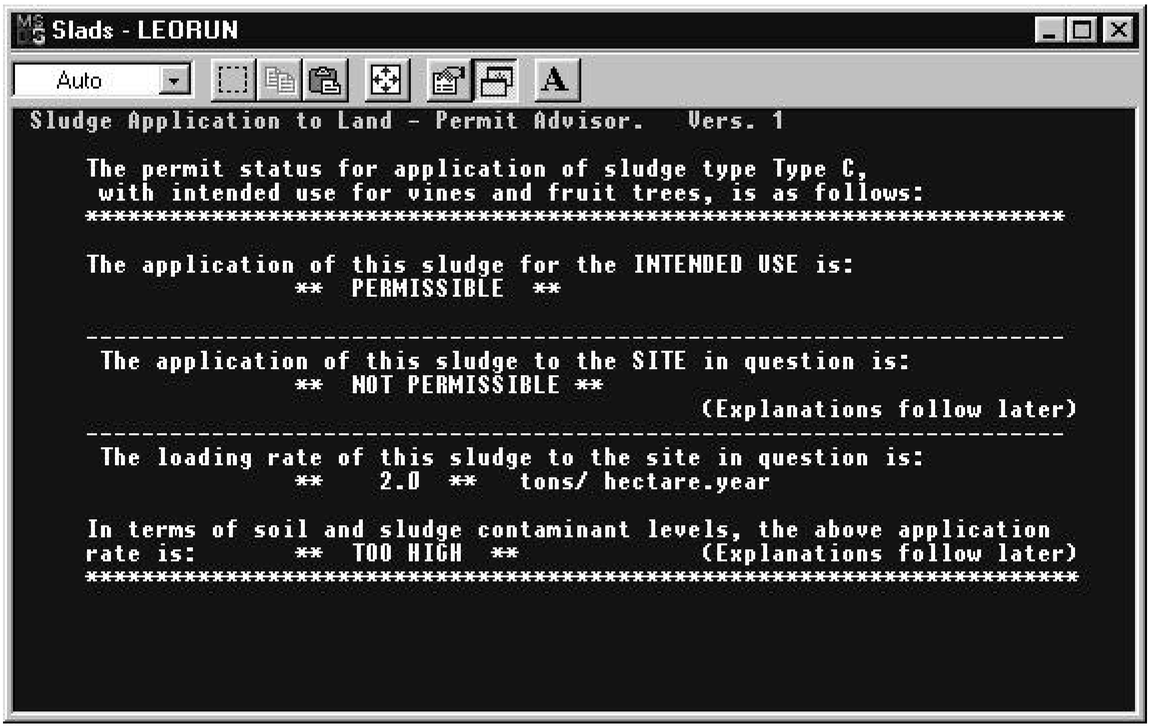


Figure 8: Display of summarised results

Figure 9: Requirements for applying Type C sludge to vines and fruit trees.

Figure 10: Issues which make the site unsuitable for sludge application.

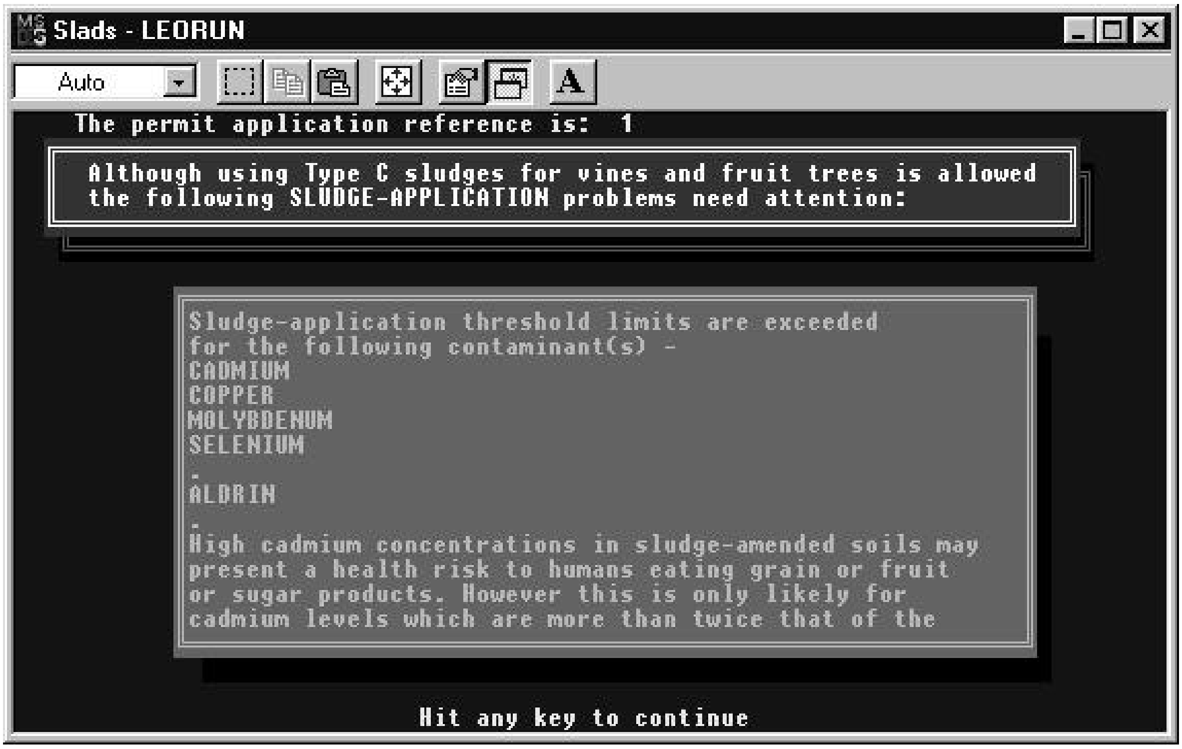


Figure 11: Problems relating to the proposed sludge application rate.

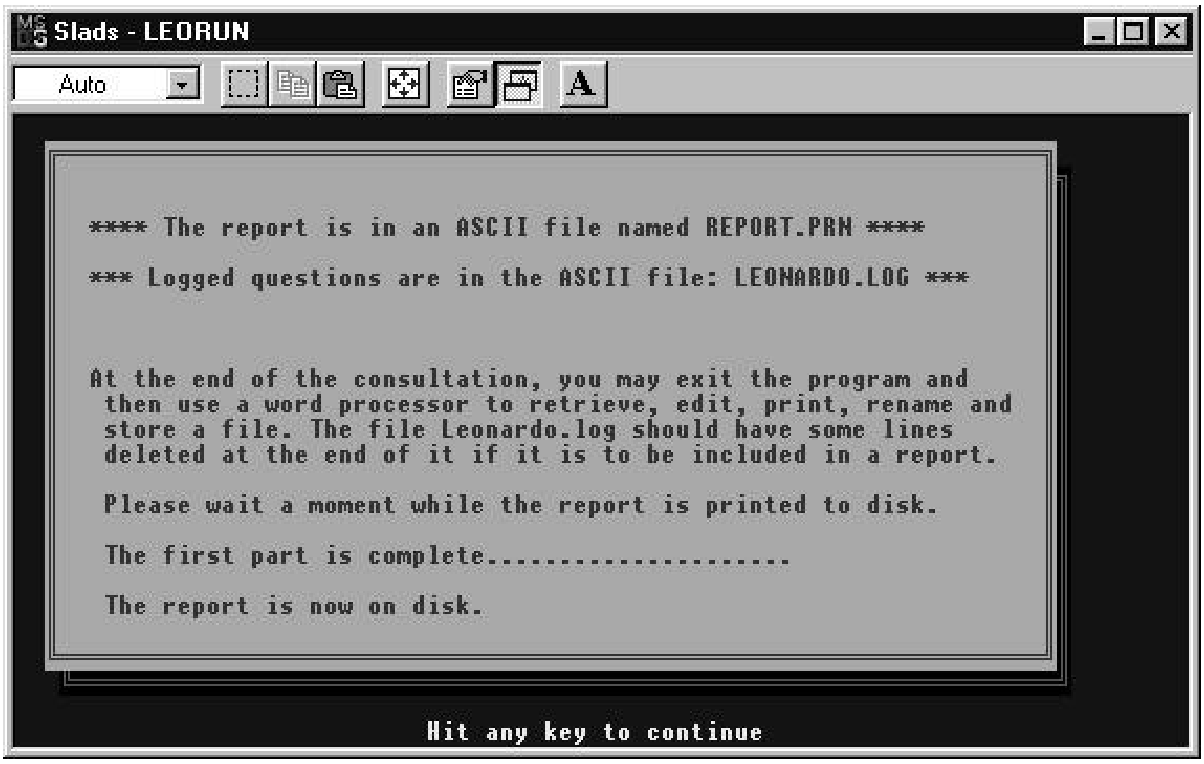


Figure 12: Final screen of the permitting assistant.

3.3 The site/area identification aid

This expert system is designed to help determine suitable areas/sites, to identify applicable site planning constraints and other mitigatory measures. The expert system uses a checklist approach and is designed to identify:

* issues which are covered by existing regulations
* other potentially important issues which may affect the suitability of the area for sludge application.

The software may also be used to help identify "pros" and "cons" of selected areas/sites for preliminary comparison purposes.

The first two questions asked relate to the area/site reference and type of sludge. The rest address sitespecific issues as follows:

* slope
* host environment
* aquifer type
* depth to groundwater
* 1-in-50 year flood level
* top soil type
* geology type
* zoning
* aesthetic/odour impact
* concave topography
* third party aspects
* site availability
* site access

Questions are also asked on the presence of seepage areas, flood plains, wetlands and rare and endangered plant species. Set-back distances are also considered: distances to nearest borehole, water bodies, nature reserves and residential areas.

In places in the program, when regulatory issues become relevant, an option is presented to exit the consultation and go to the end. When this option is presented, currently applicable issues may be displayed before an answer is required. After this, one can stop the consultation and proceed immediately to the screens containing the results, or else continue the consultation.

The expert system then presents the issues of concern, as well as relevant regulatory requirements, mitigatory measures and recommendations for further investigations, and asks if a printed report is required. (Examples: See Figure 13 for a display of some regulatory requirements, and Figure 14 for a display of some recommendations not directly addressed by the health guidelines.)

If a printed report is required, the following will be printed out:

Answers to the questions (user input).

List of issues.

List of regulatory requirements.

List of possible mitigatory measures/recommendations.

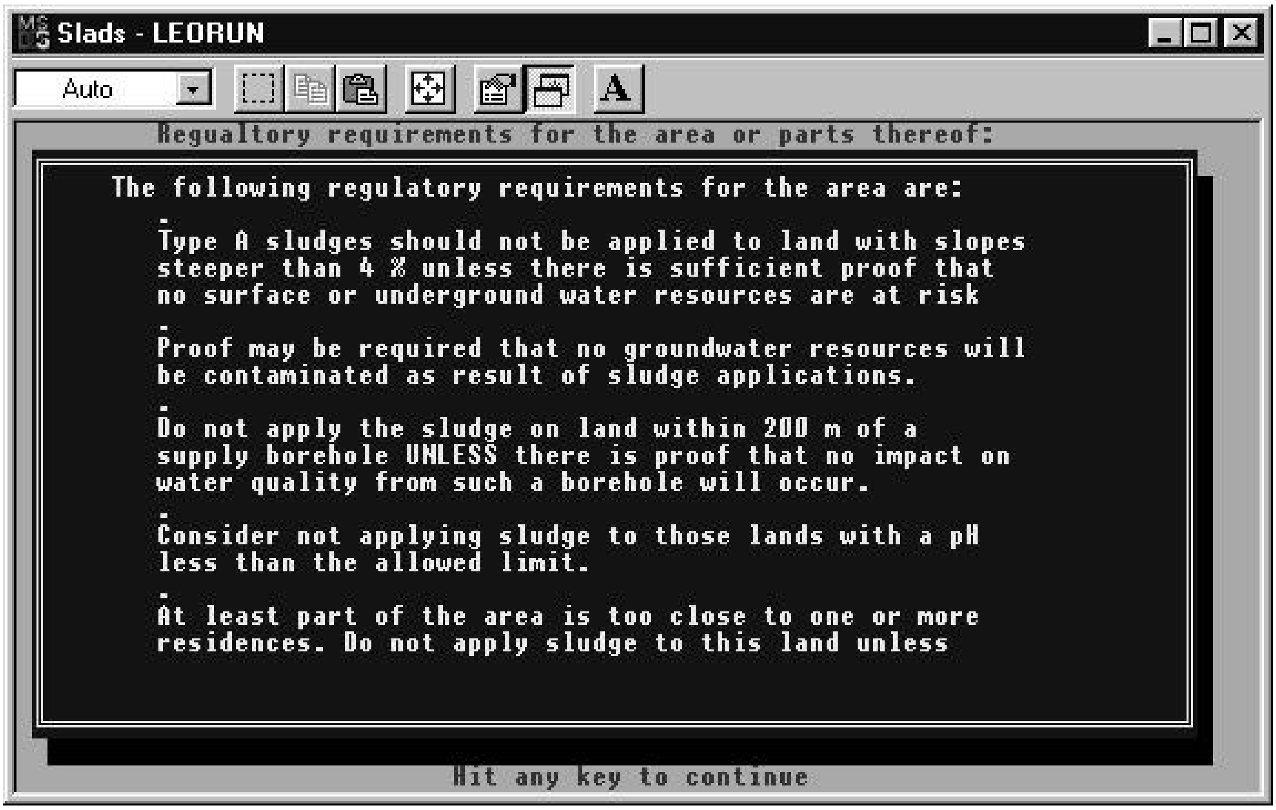


Figure 13: Site/area selection: Applicable requirements addressed by the published health guidelines.

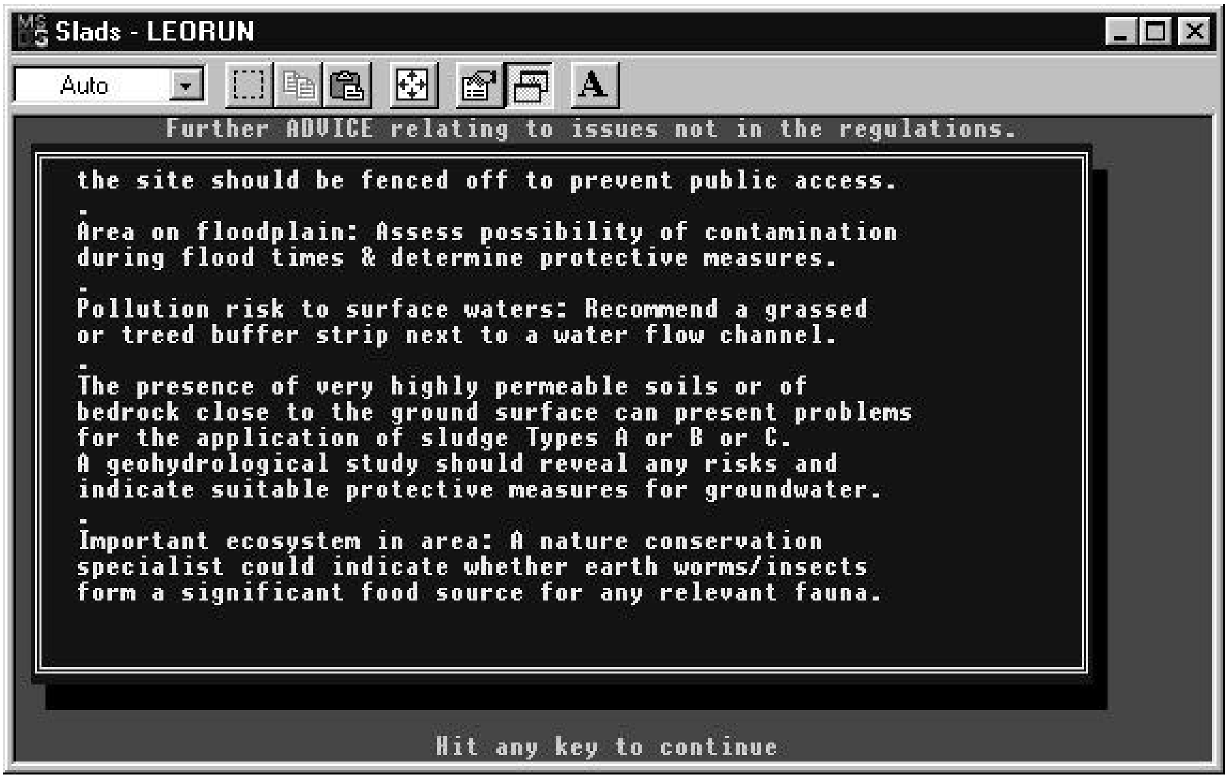


Figure 14: Site/area selection: Recommendations which are not diectly addressed by the published health guidelines.

3.4 A site-suitability ranking tool

This expert system is designed to be used as a site/area relative-evaluation aid or ranking tool when more than one site or area is being considered for sludge application. Based on input from the user, it first assigns importance weightings to key issues applicable over several sites or a region (See **Figure 15** for an example of selection of important issues for a region, from a list of likely issues). Next, it assigns ratings to individual sites in terms of the key issues (See **Figure 16** for a rating evaluation request, in terms of ponding on a specific site). Results take the form of sums of products of weights ratings for the sites, to be used for comparative purposes.

Results are written into a text file on disk, and an option to view this file is presented when all the sites have been assessed.

An example of information in a report for site/area "ONE" is given below:

Sludge-Application Site Evaluation Aid. Vers. 1 20-Aug-96 15:45

EVALUATION OF AREA/SITE REF: ONE DATE: 20-Aug-96 15:45

DESCRIPTION	WEIGHTINGS	RATINGS
Groundwater:	9	6
Steep slopes:	5	4
Ponding:	6	7
Surface water:	4	1
Soil pH:	8	7
Soil conts:	3	3
Residence dists:	2	8
Other parties:	3	3
Environment:	2	6
Other issues:	1	2

* RESULTS FOR SITE *

Methods used	Sum all values (1).	Product summation (2).
Total assessment value:	90	224
Percentage of maximum possible:	45	22
Number of issues addressed:	10	

(1) Sum all wts. & ratngs. (2) Sum of products of indiv. wts. & ratngs.

NB (a): The site info. does not address soils analysis data. In terms of the permitting guidelines and the 9 issues addressed, application of Type A sludge to the site is: NOT PERMISSIBLE.

NB (b): Sum-of-products is the usual indexing method used for sitecomparative purposes. If, for each component: * a high weighting is assigned a low rating or vice versa, * or if all weightings and ratings are low, then please note that this method gives a very small value compared with the plain summation method.

NB(c): Sites with the lowest resultant values are considered likely to have lowest negative environmental impact for the issues addressed. Suggestion: Take the sites with the lowest summation method index and lowest sum-of-products index and compare these sites further before making a final decision.

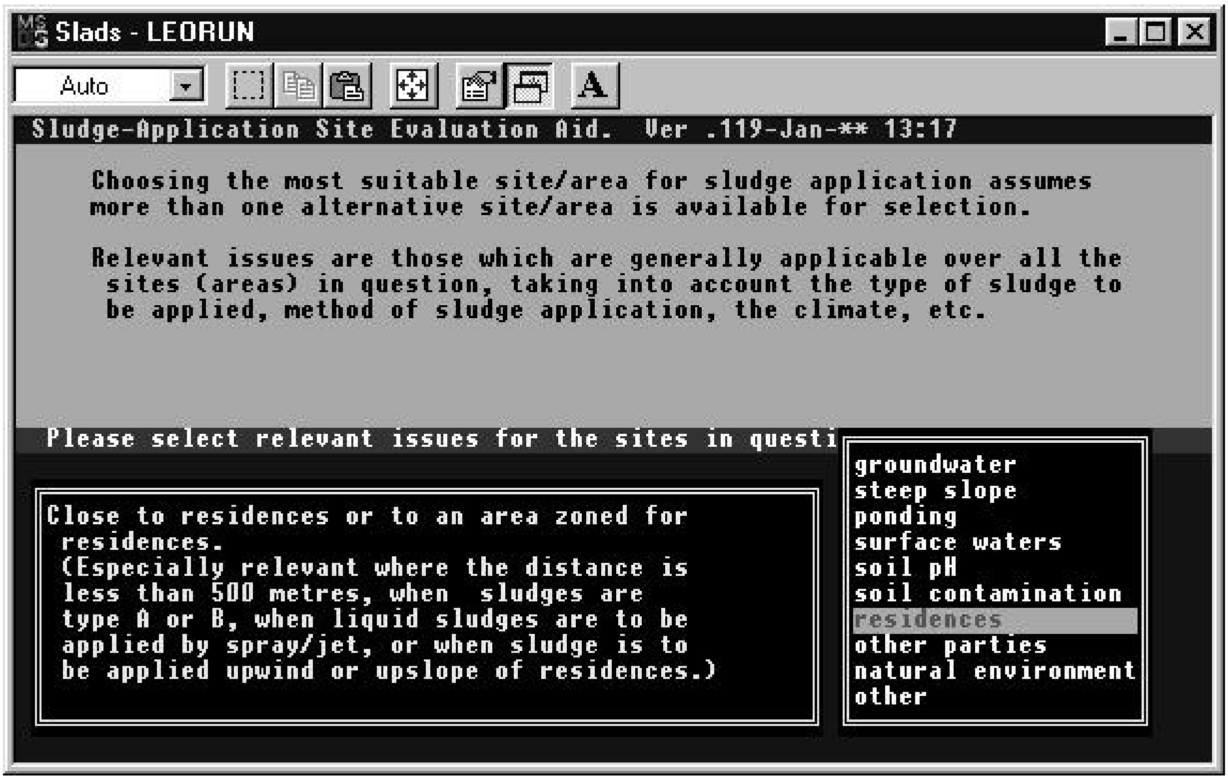


Figure 15: Selection of important issues for the region/area in which sites are located.
(The item “residences” is highlighted).

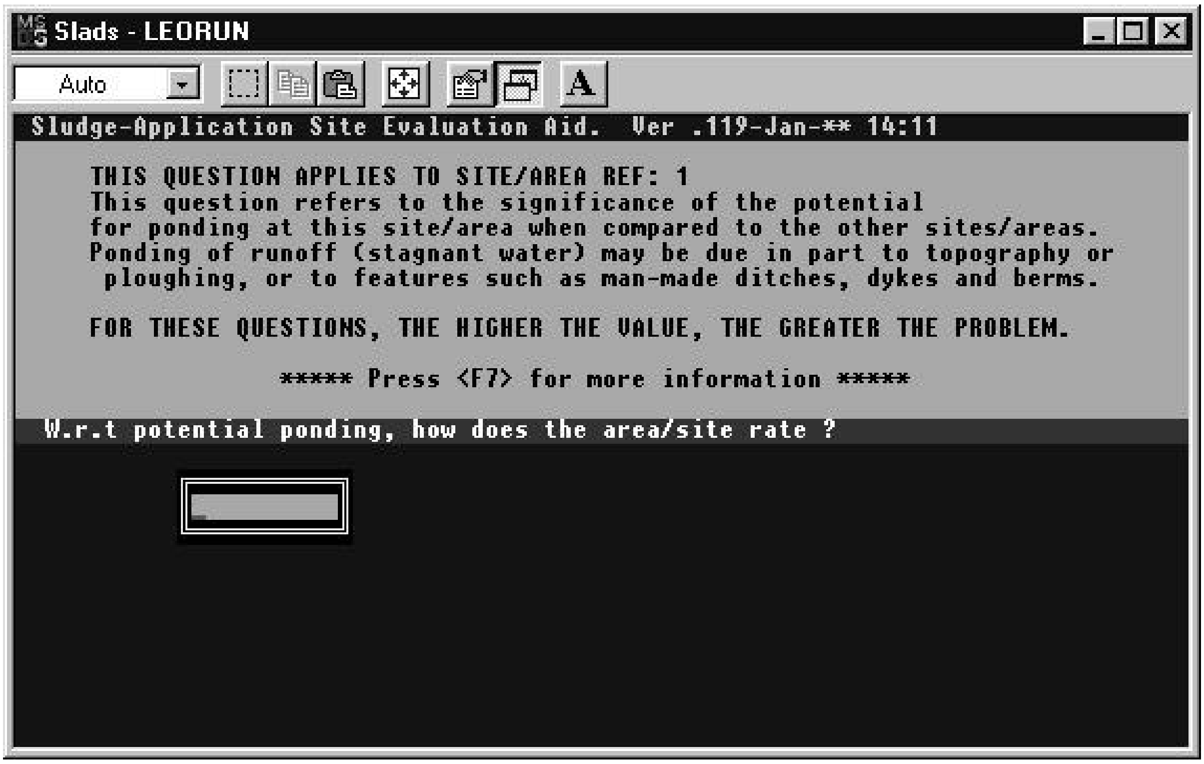


Figure 16: Request for a rating value for site in terms of ponding.

3.5 Water balance and run-off storage estimation aid

This expert system evaluates the surface water balance for a site.

Monthly precipitation-evaporation, disposal area and liquid disposal information is addressed by an expert system using one screen form per month. Excess contaminated run-off is stored on a month-by-month basis and is utilised when there is spare evaporative capacity for any month.
Input data for each form are: the area of land available for sludge application, monthly evaporation, monthly precipitation, and the quantity of liquid sludge to be applied for the month. Output data address the net monthly evaporation, likely available capacity for liquid sludge application with no runoff; the total depth of moisture for the month (applied + precipitation), excess runoff (if any), and run-off storage capacity required. Extra area required for liquid sludge application is estimated when monthly evaporation exceeds precipitation and total applied moisture is in excess of monthly evaporative capacity.
For any month, all moisture applied to land during the month is assumed to be available for evapotranspiration (Future upgrades may take into account leaching factors). Also, no account is taken of the evaporative crop factor.
When all the months of data are complete, the final screen presents a table of monthly input and output data and presents further information. An example of the latter follows:

Excess total annual vol. of liquid runoff is:	237 cub.m.
Excess NETT annual vol. of liquid runoff is:	-58 cub.m. (capacity is available for more liquids in some months.)
Extra area required is (for evaporation is):	1.5 ha
Maximum storage for excess contaminated run off is:	150 cub. m.

WARNING: Liquid sludge is being applied for a month when average precipitation is greater than evaporation.

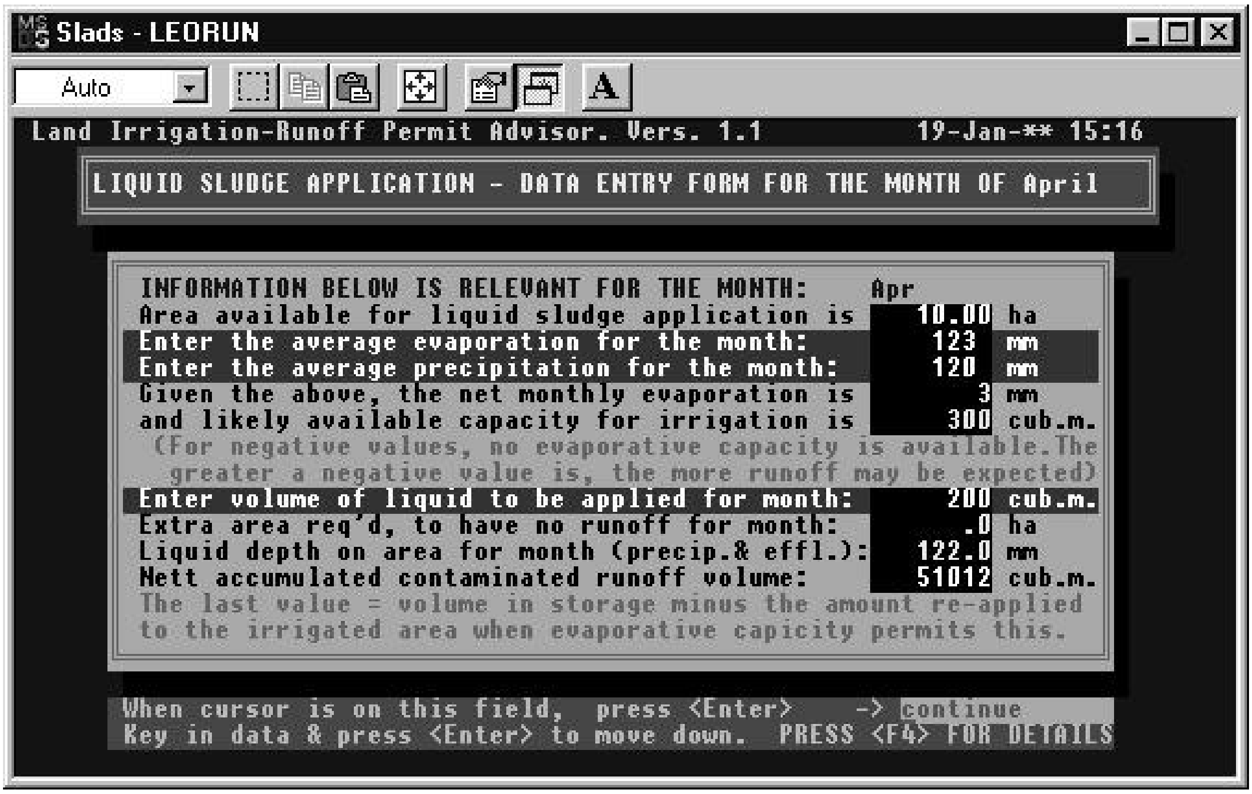


Figure 17: Water balance calculation aid: Monthly data input/calculation form.

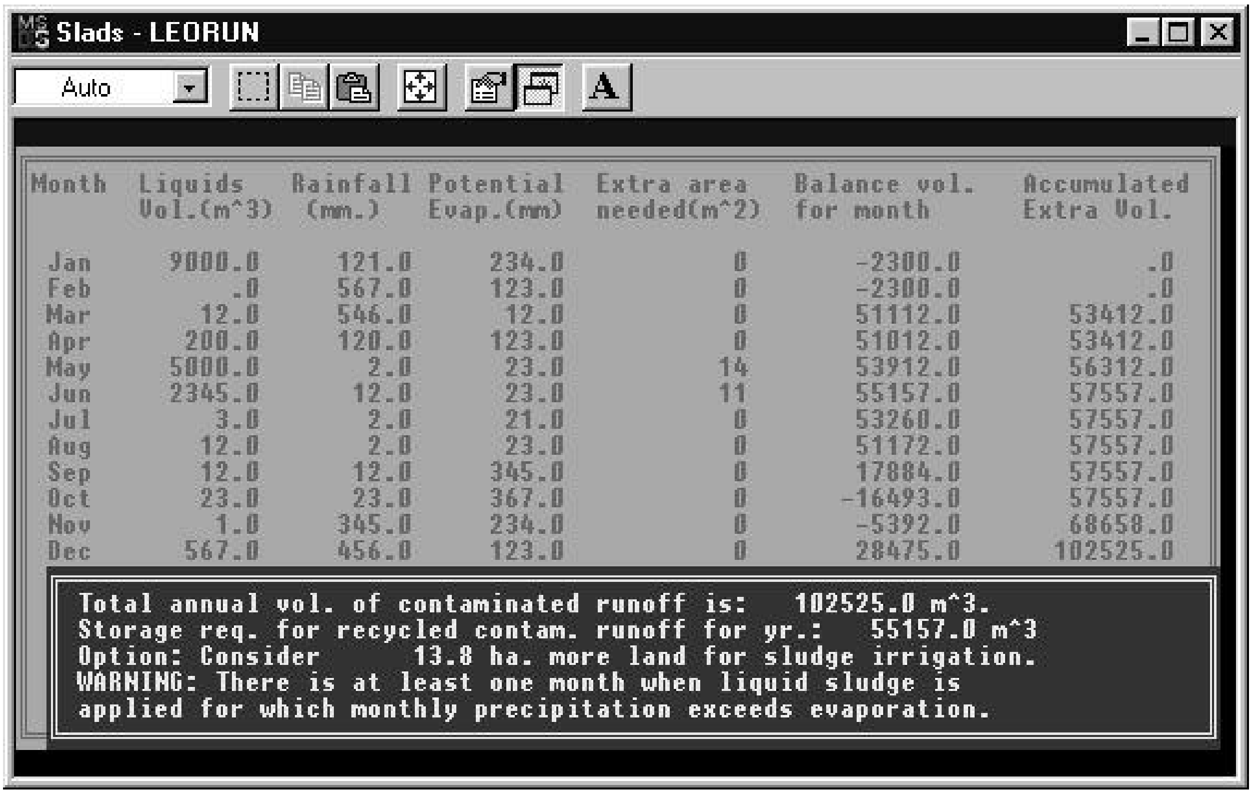


Figure 18: Water balance calculation aid: Display of the result for 12 months.

Figure 17 is an example of a monthly water-balance data input and calculation form and **Figure 18** is an example of the summarised results for a year, shown together with a display of key results and some advice in a separate box.

4 CONCLUSION

Expert systems have been used in this project both to model decision-making processes and to provide fully fledged computer-based decision support relating to sludge application to land. Expert systems facilitate the interpretation of guidelines so as to help users to plan and manage sludge-to-land application and similar tasks in environmentally effective ways. This is especially relevant as the guidelines are complex to administer, and staff who are in a position to administer them effectively are few.

The **SLADS** decision-support software system described in this document consists of a suite of expert-systems based programs, designed to provide help to those who are involved with tasks related to the application of sludge to land. Tasks include permitting as well as site/area identification, assessment and planning. The following expert-systems based computer programs make up **SLADS**:

The coordinating expert system
This presents some preliminary information and calls up the other expert systems when they are required.

Sludge permitting assistant
This addresses sludge-to-land permit requirements. It incorporates the latest guidelines, methodologies and permit regulations for sludge application to land.

Site/area identification aid
This is designed to help identify suitable areas for sludge application as well as planning/design measures and set-back distances from environmentally sensitive features. Planning constraints regarding set-back distances, topographical features and other aspects are incorporated. Mitigatory measures are addressed. The information is derived from the latest guidelines as well as from overseas literature.

A site-suitability ranking tool
This is designed to be used as a site/area relative-evaluation aid or ranking tool. It uses a weighting-and-rating algorithm to assess impact importance and site relevance for comparative evaluation purposes when two or more alternative sites or areas need to be assessed.

Surface water balance and run-off storage estimation aid
This is designed to help determine the capacity of an area of land to accept liquid sludge on a monthly basis taking into account monthly precipitation-evaporation, disposal area and liquid sludge volume data and the size of available land. It calculates monthly surface "water balance" values and storage requirements for contaminated run off.

APPENDIX I

The sludge permitting aid - Log file and report files

Log. file

Consultation with SLUDGE started at 6-Dec-96 14:12
What is the application reference name or number ? : one
What does the sludge application relate to ? : vines and fruit trees
What type of sludge is to be applied?: Type C
Does the site have an average slope >8.0 % ? : yes
Is the average soil pH less than 6.0 ? : yes
Is the depth to groundwater >2.0 m ? : no
What is the CADMIUM content of the site soils (mg/kg) ? : 1
What is the COBALT content of the site soils (mg/kg) ? : 1
What is the CHROMIUM content of the site soils (mg/kg) ? : 1
What is the COPPER content of the site soils (mg/kg) ? : I
What is the MERCURY content of the site soils (mg/kg) ? : .1
What is the MOLYBDENUM content of the site soils (mg/kg) ? :
What is the NICKEL content of the site soils (mg/kg) ? : .1
What is the LEAD content of the site soils (mg/kg) ? : .I
What is the ZINC content of the site soils (mg/kg) ? : .1
What is ,the ARSENIC content of the site soils (mg/kg) ? : .1
What is the SELENIUM content of the site soils (mg/kg) ? : .
What is the BORON content of the site soils (mg/Kg) ? : 1
What is the FLUORIDE content of the site soils (mg/kg) ? : 1
What is the CADMIUM content of the sludge (mg/kg) ? : 91
What is the COBALT content of the sludge (mg/kg) ? : 13
What is the CHROMIUM content of the sludge (mg/kg) ? : 678
What is the COPPER content of the sludge (mg/kg) ? : 234
What is the MERCURY content of the sludge (mg/kg) ? : 12
What is the MOLYBDENUM content of the sludge (mg/kg) ? : 345
What is the NICKEL content of the sludge (mg/kg) ? : 56
What is the LEAD content of the sludge (mg/kg) ? : 23
What is the ZINC content of the sludge (mg/kg) ? : 789
What is the ARSENIC content of the sludge (mg/kg) ? : 12
What is the SELENIUM content of the sludge (mg/kg) ? : 123
What is the BORON content of the sludge (mg/kg) ? : 123
What is the FLUORIDE content of the sludge (mg/kg) ? : 234
Do you want to assess the sludge for organic contaminants? : yes
What is the ALDRIN content of the sludge ? : 1
What is the BENZO-b'-PYRENE content of the sludge ? : 1
What is the CHLORDANE content of the sludge ? : 1
What is the DDT content of the sludge ? : 1
What is the DIELDRIN content of the sludge ? : 1
What is the DIMETHYL NITROSAMINE content of the sludge ? : 1
What is the HEPTACHLOR content of the sludge ? : 1
What is the HCB content of the sludge ? : 1

What is the LINDANE content of the sludge ? : 1
What is the PCB content of the sludge ? : 1
What is the TRICHLOROETHYLENE content of the sludge ? : 1
What is the max. plant-available N from the sludge ? : 20
What is the % solids content of the land-applied sludge ? : 3
NitrSAR set by ComputeValue: to: 11.6
SludgeDepth set by ComputeValue: to : 25.9
TotArea set by ComputeValue: to: 432.9
What is the annual sludge application rate (t/ha.yr, dwt) ? : 8
Do you want to revise the sludge application rate ? : yes
What is the annual sludge application rate (t/ha.yr, dwt) ? : 2
Do you want to revise the sludge application rate ? : no

THIS COMPLETES THE CONSULTATION.

Consultation with **SLUDGE** ended at 6-Dec-96 15:33

Report file

SLUDGE PERMIT REPORT 6-Dec-96 15:26

Application Reference: one

SLUDGE-TYPE to be applied: Type C

Crop or land-use type: vines and fruit trees

Sludge application rate: 2.0 t/ha..yr

Summary of Key Results:

Application of the sludge for the INTENDED USE is: PERMISSIBLE

Application of the sludge to the SITE is: NOT PERMISSIBLE

The required application-rate o£ 2.0 t/ha.yr
is considered to be: TOO HIGH

Limits for Sludge Application Rates:
Based on crop needs of 231.0 kg/ha,
the recommended sludge application rate is: 11.6 t/ha.yr

For INORGANIC contaminants:

The maximum allowed application rate is: 0.6 t/ha.yr.

The required rate of 2.0 t/ha.yr is 345.0
of the most restrictive threshold limit, that of: MOLYBDENUM.

For ORGANIC contaminants:

The maximum allowed application rate is: 1.6 t/ha.yr.

The current 2.0 t/ha.yr is 123.8 of the most restrictive threshold limit, that of: ALDRIN.

Sludge Permit Restrictions and Recommendations

The following PERMIT RESTRICTIONS are applicable:

. All sludge must be mixed or covered with soil as soon as possible.

Although using Type C sludges for vines and fruit trees is allowed the following SITE-RELATED problems make the SITE unsuitable:

1. The site slope is too steep.
2. Site soils are too acidic (pH is too low).
3. The groundwater table is too high.

Although using Type C sludges for vines and fruit trees is allowed the following SLUDGE APPLICATION problems need attention: Sludge application threshold limits are exceeded for the following contaminant(s) –

CADMIUM
COPPER
MOLYBDENUM
SELENIUM
ALDRIN

High cadmium concentrations in sludge-amended soils may present a health risk to humans eating grain or fruit or sugar products. However, this is only likely for cadmium levels which are more than twice that of the present limit set for cadmium in South Africa. High cadmium concentration levels may present a health risk to young children who are in the habit of eating soil (a habit called PICA). For other people this risk is very much lower.

High cadmium concentration levels could present a serious problem for animals which eat earthworms especially if that is their sole diet for a lifetime. Very high cadmium concentration levels are known to be toxic for most plants.

INORGANIC CONTAMINANTS Maximum exceedance is attained by MOLYBDENUM (zootoxic).

Using Type C sludges for vines and fruit trees is permissible.

These SITE recommendations are presented for consideration:

ADVICE: Sludge storage facilities are likely to require special consideration to ensure that no highly-polluted surface run off or seepage water will pollute any surface water resource (dam or river or stream) or any aquifer. Please check under what conditions such facilities may become subject to the MINIMUM REQUIREMENTS LEGISLATION for waste disposal.

Slope requirements could be relaxed on condition that no contaminated run off or seepage water will pollute any dam or river or stream or any aquifer.

pH requirements could be relaxed on condition that no contaminated run off or seepage water will pollute any dam or river or stream or any aquifer.

Slope requirements could be relaxed if no contaminated run off or seepage water will pollute any surface water resource (dam or river or stream) or any aquifer.

APPENDIX II

The site weighting and rating evaluation aid - Log file and report files

Log. File

Consultation with SL_W&R started at 6-Dec-96 15:48
Please select relevant issues for the sites in question. : groundwater, steep slope, ponding, surface waters, soil pH, soil contamination, residences, other parties, natural environment
How important is groundwater depth ? : 2
How important is slope steepness ? : 1
Generally, how important is ponding ? : 4
How important are water features ? : 5
How important is soil acidity ? : 2 How important are soil PTSs ? : 4
How important are residential areas and /or houses ? : 5 How important are interested and affected parties (I&AP) ? : 6
How important is the natural environment ? : 2
What is the reference name or number for the site/area ? : one
What type of sludge is to be applied?: Type A
Does the site have an average slope >4 % ? : yes
Is the average soil pH less than 6 ? : yes
Is the depth to groundwater >5 m ? : no
Is a dam/river/borehole within 200 m of the site?: yes
Is there a house within 500 m of the site ? : yes
W.r.t groundwater depth, how does the area/site rate ? : 3
W.r.t slope steepness, how does the area/site rate ? : 5
W.r.t potential ponding, how does the area/site rate ? : 8
W.r.t surface water features, how does the area/site rate ? : 3
W.r.t soil acidity, how does the area/site rate ? : 8
W.r.t soil PTSs, how does the area/site rate ? : 3
W.r.t residences, how does the area/site rate ? : 7
W.r.t other parties, how does the area/site rate ? : 9
W.r.t natural environment, how does the area/site rate ? : 6
Do you want to assess another site or area ? : no

Report file

SITE/AREA COMPARISON REPORT 6-Dec-9615:52

EVALUATION OF AREA/SITE REF: one

SLUDGE-TYPE to be applied: Type A

DESCRIPTION	WEIGHTINGS	RATINGS
Groundwater:	2	3
Steep slopes:	1	5
Ponding:	4	8
Surface water:	5	3
Soil pH:	2	8
Soil conts:	4	3
Residence dists:	5	7
Other parties:	6	9
Environment:	2	6
Other issues:	unknown	unknown

* RESULTS FOR SITE

Methods used	Sum all values (1).	Product summation (2).
Total assessment value:	83	187
Percentage of maximum possible:	46	21
Number of issues addressed:	9	

In terms of the permitting guidelines and the 9 issues addressed, based on current data the site-permit status is: NOT PERMISSIBLE.

APPENDIX III

Crop Nitrogen Requirements:
(Copy of text file from computer disk)

ESTIMATING CROP NITROGEN NEEDS

Crop fertiliser requirements are dependent on crop yields, soil type, climate and other factors.

> A first approximation for estimating crop nitrogen (N) needs can be made by assessing the amount of N removed when a crop is harvested. When assessing an amount of N to be applied to land, account must be taken of the percentage of N lost due to leaching of N beyond the root zone, by denitrification, by volatilization of ammonia, or by other means. Account must also be made of the nitrogen contributed to the soil by leguminous crops such as beans.

EXAMPLES OF CROP YIELDS AND NITROGEN REQUIREMENTS

(These figures are highly variable and should only be used for first-pass approximation/comparative purposes)

CROP COMPONENT	AVE.YIELD	APPROX N REMOVAL	1st. ESTIMATE OF CROP N NEEDS
	t/ha	kg/t	kg/ha
Alfalfa hay	13	32.5	420
Barley grain	4.5	21	94
Barley straw	5.6	8.5	48
Beans, dry beans	3	39	117
Corn grain	10	16.5	165
Corn silage	56	4.5	252
Corn stover	4.5	10.5	47
Cotton seed	1.9	39.5	75
Cotton stalks	1.4	57.5	80
Oats grain	3	21	63
Rice grain	7.4	15.5	115
Rice straw	7.8	5	39

CROP COMPONENT	AVE.YIELD	APPROX. N REMOVAL	1 st. ESTIMATE OF CROP N NEEDS
	t/ha	kg/ton	kg/ha
Safflower grain	3	34.5	104
Sorghum grain	4.5	2	95
Sorghum stover	4	10.5	42
Soyabeans grain	2.8	67	188
Soyabeans stover	2.8	23	64
Sugarbeets beets	67.2	2	134
Sugarbeets tops	67.2	2	134
Wheat grain	4.5	19.5	88
Wheat grain straw	7.8	9	70
Mixed grass: hay	4.5	23.5	106
Irrigated pasture	4.5	17	76

CROP COMPONENT	AVE.YIELD	APPROX. N REMOVAL	1 st. ESTIMATE OF CROP N NEEDS
	t/ha	kg/t	kg/ha
FRUIT and NUTS			
Apricot fruit	18	2	36
Cherry fruit	9	2.5	22
Grapes fruit	22.4	1	22
Peach fruit	35.8	1.5	54
Pear fruit	3.6	1	34
Plum fruit	18	3.5	63
Prune fruit	18	3.5	63
Almond nut	2	33.5	67
Walnut nut	2.2	26.5	58
Grapefruit fruit	24.6	2	49
Orange fruit	18	2.5	45
Lemon fruit	29	2	58
Avocado fruit	5.8	4	23
Olive fruit	4.7	2	9
Strawberry fruit	42.6	2	85

CROP COMPONENT	AVE.YIELD	APPROX. N REMOVAL	1st. ESTIMATE OF CROP N NEEDS
	tlha	kg/t	kg/ha
VEGETABLES			
Broccoli heads	11.2	6.5	73
Carrots roots	42.6	2	85
Potato tubers	44.8	4	179
Tomato fruits	56	2	112
Tomato vines	67	1.5	100
TURF GRASSES			
Bent	4.9	34.5	169
Bermuda grass	9	31.5	284
Kentucky bluegrass	5	31	155

Source: Pettygrove & Asano (eds.), 1990: "Irrigation with reclaimed municipal wastewater", Lewis, MI

************ E N D ****************

K. O'H. MURPHY

MUNICIPAL SEWAGE SLUDGE DISPOSAL:
DEVELOPMENT OF GUIDELINES AND EXPERT SYSTEMS

BACKGROUND INFORMATION

AND LITERATURE SURVEY

Report to the
WATER RESEARCH COMMISSION

by the
CAPE WATER PROGRAMME
DIVISION OF WATER, FORESTRY & ENVIRONMENTAL TECHNOLOGY
CSIR, STELLENBOSCH

WRC Report No. 605b/1/97

CONTENTS

LIST OF TABLES AND TERMS

Term	Description applicable to this report
I & AP	Interested and Affected Parties
Scoping	Framework for defining the extent and depth of study
DWA&F	Department of Water Affairs & Forestry
DNL &PD	Department of National Health & Population Development

FOREWORD

i) Acknowledgements

This report forms an executive summary of a project funded by the Water Research Commission entitled:

Sewage Sludge Disposal: Development of Guidelines and Expert Systems for Decision-Support Purposes in South Africa.

The Steering Committee responsible for this project consists of the following persons:

Dr S. Mitchell	Water Research Commission (Chairman)
Mr C.S. Crawford	DWA&F
Prof G.A. Ekama	University of Cape Town
Mr P. King	Cape Metropolitan Council
Mr A.R. Pitman	Johannesburg City Council
Mr W.E. Scott	Department of Environment Affairs
Mr H.J.C. Smith	Institute of Climate, Soils and Water
Mr G. Steenkamp	Department of Agriculture
Mr K.P. Taylor	Department of Agriculture
Mr W. van der Merwe	DNH&PD
Mrs C.M. Smit	Water Research Commission
Mr A.C. Fritz	Water Research Commission

Grateful acknowledgements go to:

The Water Research Commission for funding the project and providing facilities for steering committee meetings.

The Research Managers: Dr S. Mitchell, for his friendly support and guidance of the project, and Mr Jay Baghwan, for editing the final draft document.

Prof. G. Ekama and Mr W. van der Merwe for their enthusiastic backing and for "going the extra mile" in terms of time and effort expended.

To all the members of the steering committee for their enthusiasm and support.

Pannie Engelbrecht for his sought-after advice and my colleagues in the Cape Water Programme for their backing.

Roxanne Murphy and Christine Colvin for reviewing the draft report.

ii) Background to study

This project is concerned with collating relevant expertise and other information regarding the application of sewage sludge to land, and encoding the functional aspects into expertsystems based software for decision-support purposes.

More specifically, the project involved:

* The collation of information which may be used to modify or update the current sludge application to land guidelines for South Africa.

* The investigation of permitting frameworks and regulatory limits for sludge application to land for countries which have conducted many years of research into these aspects. Comparing these with the current permitting framework and limits in South Africa.

* The incorporation of current and updated South African guidelines for sludge application to land into expert-systems based decision-support software.

* The development of expert-systems based, decision-support software tools to aid in identifying and ranking suitable agricultural areas for sludge application purposes.

iii) Objectives of the study

The objectives of the study may be summarised into:

- Review of applicable literature, and consult with experts regarding permitting and impact assessment re: sludge application to land.

- Development of expert-systems based, decision-support software to assist in sludge-to-land permitting and the selection of suitable sludge application sites and areas.

The study objectives for the project are as follows:

a) Gather information on current guidelines, regulations and applicable research results from local and international sources in order to develop/modify applicable guidelines and methodologies for decision-support purposes regarding:

    * permit applications, permit assessments and the attachment of applicable conditions to permits for the application/disposal of sewage sludge to land;

    * the establishment of design and planning constraints for impact assessment purposes relating to the disposal of sewage sludge to land.

b) Use expert systems in order to:

* model current and proposed (1997) guidelines and administrative procedures with the aim of identifying loopholes and indicating possible improvements or changes;

- help formulate new or amended guidelines (where needed);
-

* provide regulatory authorities and/or consultants with user-friendly decision support software for regulatory compliance and impact control purposes.

1 INTRODUCTION

1.1 Municipal sewage sludge application to land

Worldwide, institutions involved in waste and water resource management are under pressure to provide better services at lower cost, involving more complex planning and operational activities, with the availability of fewer professional staff (Fiddes, 1985). This is true in South Africa, especially with regard to the scarcity of expertise in disciplines related to waste, water and the environment. In the field of waste management, there is increasing pressure on countries to reduce waste production, to beneficially utilise the wastes that are produced, and to minimise the environmental impact from waste processing, storage and disposal.

Sewage sludge is produced by municipal sewage treatment systems, and is usually seen as a waste product requiring disposal. Sludge can present a health risk and often produces obnoxious odours. When treated properly, and provided certain industrial contaminants are restricted from entering the incoming sewage, the resultant sewage sludge can become a relatively innocuous organic fertiliser and soil conditioner of significant value for growing trees, crops and grass. Much evidence now exists to show that the response of plants to sludge-amended soils is far superior to that of plants grown on soils supplied with commercial fertilisers (U.S. EPA, 1994c; Smith, 1996; WHO, 1995).

South Africa faces a two-fold problem: its sludge production is rapidly increasing and its soils have deteriorated significantly (Lötter and Pitman, 1993). Application of high-quality sludge to land for beneficial purposes can help crops to grow, reduce fertiliser requirements and improve soil conditions, as well as significantly reduce South Africa's current and impending future problem of sludge disposal (Chaney, 1990a ; Ekama, 1993a; Ekama 1993b). Hence the solution to the sludge-disposal problem can be used, albeit in a small way, to help ameliorate South Africa's soil degradation/food-growth problem. f all the sludge produced by South Africa's sewage treatment works could be applied to land at 8 tons per hectare per year (sufficient for the nitrogen needs of most crops), then about 500 square kilometres of land would be required (Smith and Vasiloudis, 1989; Ekama, 1993a).

In order to apply sewage sludge to land for beneficial purposes, the quality of a large portion of sewage sludge which is currently produced needs to be improved, especially in terms of priority pollutants such as cadmium (Smith and Vasiloudis, 1989; Ekama, 1993b). Further, certain of the South African guideline limits could be relaxed and the guidelines could be applied in a way that promotes the beneficial use of sewage sludge on land (Steyn et al, 1996; Smith, 1996; Ekama, 1993b; U.S. EPA 1994c; Chaney, 1995).

1.2 Expert-systems based decision support

The permitting procedures for sludge application to land are complex to assess and administer, and there is an expressed need for decision support to assist officials in granting permits (McConkey, 1995). Professional and administrative staff need to have convenient access to relevant expertise and other types of information. Desktop and portable computers are being used more and more to fulfill the abovementioned needs through the application of user-friendly decision-support software.

Expert systems are computer programs which are designed to provide certain types of expertise and other forms of decision support. A computer-based decision-support system, consisting of a suite of expert systems, has been developed in terms of this project to provide the required decision support for permitting officials and others who are involved in tasks relating to the permitting of sludge application to land for beneficial purposes. The overall system is called **SLADS: S**ludge **L**and-**A**pplication **D**ecision-Support **S**oftware (See Part II: Software Documentation).

Some examples of what expert systems are useful for:

* making routine expertise readily accessible to users in a form suitable for decision support, guidance and educational purposes;
* guiding a computer user to provide relevant information;
* helping a user to select relevant programs to run and to input data for those programs;
* interpreting results from programs, and presenting the derived information as further advice for decision-making purposes.

2 APPLICATION OF MUNICIPAL SEWAGE SLUDGE TO LAND: PERMITTING ASPECTS.

2.1 Permitting philosophies: Precautionary and environmental sustainability approaches

One of two approaches has been used by countries regarding permitting land application of sludge and wastewater (WHO, 1995; U.S. EPA, 1994c; Ekama, 1993a,b; Williams, 1989; Smith, 1996):

(i) Precautionary approach

This requires that potential pollutants be prevented from accumulating in waste receiving soil. This approach guarantees the integrity of the soil's ecological and chemical characteristics, and ensures that the transfer of contaminants to the food chain is minimised. The chief drawback to this approach is that the numerical limits on pollution input are so stringent that only the most advanced technical nations are able to achieve the limits required. For less advanced nations, the alternative options in this case are for sludge to be disposed at waste-disposal sites, at sea, or else to be kept in some form of storage such as holding lagoons. (WHO, 1995; Smith, 1996)

(ii) Environmental sustainability approach

This takes into account the soil's capacity to assimilate, attenuate and detoxify contaminants. Under this philosophy, nutrients supplied by sludge can be beneficially utilised by crops, thus saving on fertiliser costs, and the organic content of sludge can be used to build up soil structure and the organic carbon content of agricultural soil, thus improving its agronomic suitability. The chief drawback of this approach is that it requires effective management to ensure that contaminants do not build up in soil to levels that are considered harmful to human or ecological health. (WHO, 1995; Smith, 1996; U.S. EPA, 1994c)

With a few exceptions, all countries with a sludge-to-land permitting system have adopted the second approach (WHO, 1995; Smith, 1996).

The U.S. EPA sludge regulations (Part 503 Biosolids Rule) incorporate a permitting framework and contaminant limit specifications which reflect an environmentally sustainable approach to sludge permitting (WHO, 1995). The World Health Organisation (WHO, 1995) recommends the world-wide adoption of this permit framework and accompanying limits for sludge application to land because:

* it is applicable world-wide, especially in developing nations;

* to date, human health has not been shown to be compromised by its use.

Sludge should be applied to land at rates which do not exceed those which are needed to supply required plant nutrients (agronomic rates). The potential impact of sludge application at agronomic rates on water resources is addressed by the U.S. EPA in the following statements (U.S. EPA, 1983):

(1) The prescribed sludge application method along with recommended practices for the control of soil erosion -will essentially eliminate the potential contamination of surface waters or adjacent lands by sludge constituents.

(2) If sludge-application system designs are based on sound agronomic principles, the utilisation of sludge based on those designs should pose no greater threat to groundwater resources than current agricultural practices would.

The second statement is also considered true in terms of threat to the environment and to public health (U.S. EPA, 1994c).

The above statements assume that regulatory requirements applicable to a site and to sludge management, for different types of sludge, are met.

2.2 Contaminant exposure pathways for land-applied sludge

The U.S. EPA has used various risk-assessment procedures to develop limits for contaminants for 14 pathways, and for the most highly exposed individuals. The calculations were done separately for agricultural lands, forests, public contact and recreation sites. Research carried out on sludge application to land shows that the contaminant pathway for potentially toxic elements with the highest risk factor for human health is the soil/human-ingestion route. (Chaney, 1990a,b; U.S. EPA, 1995) Although the soil-water-resource pathways have been subjected to research, these generally do not represent the greatest risk. The regulatory limit for each contaminant was based on the exposure pathway found to be the most limiting for that contaminant (See **Tables 1, 2 & 3).** (U.S. EPA, 1995; WHO, 1995).

Table 1 shows contaminant exposure pathways for land applied sludge (U.S. EPA, 1995).

Table 2 shows the most limiting exposure pathway for each inorganic sludge contaminant in the latest U.S. EPA regulations (Final Part 503 Rule) (U.S. EPA, 1995).

Table 3 shows the most limiting exposure pathways for organic contaminants in earlier U.S. EPA regulations, which no longer appear in the current regulations (U.S. EPA, 1995).

Table 1 Contaminant exposure pathways for land applied sludge (U.S. EPA, 1995)

PATHWAY		DESCRIPTION
1	Sludge-Soil-Plant-Human	Consumers in regions heavily affected by landspreading of sludge.
2	Sludge-Soil-Plant-Human	Farmland converted to residential home garden five years after reaching maximum sludge application.
3	Sludge-Soil-Human	Farmland converted to residential use fiveyears after reaching maximum sludge application with children ingesting sludgeamended soil.
4	Sludge-Soil-Plant-Animal-Human	Households producing a major portion of their dietary consumption of animal products on sludge-amended soil.
5	Sludge-Soil-Plant-Human	Households consuming livestock that ingest sludge-amended soil while grazing.
6	Sludge-Soil-Plant-Animal	Livestock ingesting food or feed crop grown in sludge-amended soil.
7	Sludge-Soil-Animal	Grazing livestock ingesting sludge/soil.
8	Sludge-Soil-Plant	Crops grown on sludge-amended soil.
9	Sludge-Soil-Soil Biota	Soil biota living in sludge-amended soil
10	Sludge-Soil-Soil Biota-Biota Predator	Animals eating soil biota living in sludge-amended soil.
11	Sludge-Soil-Airborne Dust- Humans	Tractor operator exposed to dust from sludge-amended soil
12	Sludge-Soil-Surface Water/ Humans Fish-Humans	Humans eating fish and drinking water from watersheds draining sludge-amended soils.
13	Sludge-Soil-Air-Human	Humans breathing fumes from any volatile pollutants in sludge.
14	Sludge-Soil-Groundwater- Human	Humans drinking water from wells surrounded by sludge-amended soils.

Table 2 Most limiting exposure pathway for each inorganic sludge contaminant in the latest U.S. EPA **regulations (Final Part 503 Rule) (U.S. EPA, 1995**)

Sludge pollutant	Highly exposed individual	Most limiting pathway
Arsenic	Sludge ingested by child	3
Cadmium	Sludge ingested by child	3
Chromium	Phytotoxic	8
Copper	Phytotoxic	8
Lead	Sludge ingested by child	3
Mercury	Sludge ingested by child	3
Molybdenum	Animal eating feed	6
Nickel	Phytotoxic	8
Selenium	Sludge ingested by child	3
Zinc	Phytotoxic	8

Table 3. Most limiting exposure pathway for organic contaminants (Now deleted from the U.S. EPA regulations) (U.S. EPA, 1995)

Sludge pollutant	Highly exposed individual	Most limiting pathway
Aldrin	Eating animal fat/milk	5
Dieldrin	Eating animal fat/milk	5
Benzo(A)Pyrene	Sludge ingested by child	3
Chlordane	Sludge ingested by child	3
DDT/DDD/DDE	Eating fish	12
DimethylNitrosamine	Sludge ingested by child	3
Heptachlor	Eating animal fat/milk	5
Hexachlorobenzene	Eating animal fat/milk	5
Hexachlorobutadiene	Eating animal fat/milk	5
Lindane	Sludge ingested by child	3
PCBs	Eating animal fat/milk	5
Toxaphene	Eating animal fat/milk	5
Trichloroethylene	Sludge ingested by child	3

2.3 Moves to relax contaminant limits in sludge applied to land in the USA, based on long-term findings

The U.S. EPA Part 503 Biosolids Rule (U.S. EPA 1994b; Smith, 1996) reflects the latest thinking regarding sludge application to land in the United States of America: there is now enough information derived from risk-based research available to allow a significant relaxation on many of the regulatory limits applicable to specific contaminants in sludge, dependent on application/land-use type (Chaney, 1995; Asano, 1995). Earlier limits on potential contaminants in sludge were emplaced at a time when there was little evidence available to prove what the safe limits should be, and so a precautionary approach was used in defining and applying these limits (Chaney, 1995). It is believed that many years (more than 25) of intensive land-application research have now produced sufficient information to allow an environmentally-sustainable approach to the land application of sewage sludge to be adopted (Chaney, 1995; Davis, 1995; Chaney, 1990a).

The U.S. EPA Part 503 Rule now gives the sludge producer, land applier and the individual states more options to follow to achieve compliance with the Rule than previous legislation did (U.S. EPA, 1995). However, sludge application to land requires strict management and monitoring (U.S. EPA, 1994a; U.S. EPA, 1994b). Over recent years, contaminant limits for land application rates in the U.S.A. have been relaxed to the extent that they are far more lenient than the existing limits for land application of sludge in South Africa and European countries. Further, pH limits are now no longer stipulated for soils (U.S. EPA, 1995).

The approach and new limits set by the U.S. EPA for sludge application to land is believed to have merit for the United Kingdom and the rest of Europe (Smith, 1996; Davis, 1995; Hall, 1995). The U.S. EPA approach lines up with the BPEO (Best Practicable Environmental Option) principle applied in the United Kingdom (Davis, 1995).

2.4 Contaminant limits in South Africa and a comparison with other countries

The 1991 South African guidelines (DNH&PD, 1991) have fairly conservative limits when compared with Europe, Australia and New Zealand (Smith, 1996; Steyn et al, 1996; also see **Table 4 and Table 5).**

The limits specified in the 1991 South African guidelines (DNH&PD, 1991) are on average about ten times more restrictive than those of the U.S. EPA, and some limits are lower than natural background levels of trace elements in some soils (See **Table 4 and Table 5).**

A critical, extensive review of sludge application to land has recently been carried out (Smith; 1996). Based on results of contaminant bioavailability studies, Smith (1996), Chaney (1990a) and Allen (1997) warn against the imposition of unnecessarily restrictive contaminant limits on sludge. The imposition of overly restrictive limits tends to preclude agricultural use of sludge and forces sludge to be disposed of in other more environmentally costly ways (Smith, 1996; Chaney, 1990a). If sludge cannot be beneficially used, it becomes a waste product requiring disposal. The Part 503 sludge regulations encourage the beneficial reuse of sewage sludge on land as well as the production by sewage works of an "exceptional quality" sludge which is fairly free of regulatory restrictions. Approximately 70 % of sewage sludge in the United States is now "exceptional quality" sludge (Chaney, 1995). "Exceptional quality" sludge is of lower quality than the South African "Type D" sludge in the 1991 sludge guidelines (DNH&PD, 1991): Nine of the ten limits prescribed for "exceptional quality" sludge by the U.S. EPA are less stringent than those set for Type D sludge in the 1991 South African guidelines, and one (chromium) is slightly more stringent. Approximately 37% of the sewage sludge produced in South Africa is of sufficient quality to be classed as Type D sludge according to the 1991 guidelines (DNH&PD, 1991; Ekama, 1993b).

According to the South African sludge guidelines (DNH&PD, 1991; DNH&PD, 1997), permission to apply sludge to land is principally dependent on the intended sludge use, sludge type, site conditions and current soil contaminant levels. The proposed sludge application rate is limited principally by prescribed limits on the application rate of individual contaminants in the sludge, and secondly by the nitrogen (N) needs of the crops to be grown (DNH&PD, 1991; DNH&PD, 1997).

The South African sludge guidelines incorporate a permitting framework which is on a level with, if not exceeding, the most sophisticated in the world (Ekama, 1993b; WHO, 1995). The framework is similar to that used by the U.S. EPA, which is the one recommended by the World Health Organisation for world-wide adoption (WH0,1995).

The inorganic trace element concentration limits for South African sludges are amongst the most comprehensive in the world, addressing a total of 13 inorganic contaminants (See **Tables 4 & 5).** They are also amongst the most restrictive, with relatively low limits being defined for nearly all the elements addressed (Steyn et al, 1996; also **Table 4 & Table 5).** In many cases the specified concentrations are lower than natural background levels for soils (Pierce et al, 1982; also see **Table 4).**

As for guideline limits for most countries, South African guideline limits are set for the total content of trace elements in sludge and in soils, rather than the soluble or bio-available content. However, inorganic trace elements in sludge are primarily in a form that is not bioavailable to plants, being in many cases similar in chemical form to those found in natural soils (Chaney, 1990b; Bell et al, 1991; Fey, 1990; Allen, 1997). At issue is the fact that:

> the total concentration of a trace element in a soil or sludge is neither a good indication of that element's availability to plants, nor of its water-resource contaminant potential (Steyn et al, 1996; Smith, 1996; U.S. EPA 1995; Allen, 1997).

It is therefore logical to recommend that limits for soluble and/or bio-available trace elements in sludged soils be specified for permitting and impact assessment purposes (Davis, 1987; Bruemmer and Van der Merwe, 1989; Allen, 1997).

Steyn et al (1996) presented an argument for significantly raising (relaxing) the South African limit for nickel from 15 mg/kg (DNH&PD, 1991) to 50 mg/kg (DNHPD, 1997), based on tests which show that observed bio-available Ni concentrations in soils are likely to be safe for plants even when the total Ni concentrations are far above the prescribed limit.

The argument by Steyn et al (1996) for raising South Africa's nickel limit could be extended to address other contaminant limits.

For sludge application permitting purposes, it is recommended that water-soluble or bio-available trace element concentrations limits be specified to complement total-extractable trace element concentration limits, for those trace elements whose total-extractable limits are likely to impose severe restrictions on land application of sludge. This should be made applicable to concentation limits in sludged soils and also to land application-rate limits.

Bruemmer and Van der Merwe (1989) recommend the following limits for bio-available element concentrations for South African soils

Element		Concentration in soil (mg/kg)
Cadmium	(Cd)	1
Cobalt	(Co)	10
Chromium	(Cr)	50
Copper	(Cu)	60
Mercury	(Hg)	1
Nickel	(Ni)	20
Lead	(Pb)	100
Zinc	(Zn)	100

We now address information which relates specifically to Tables 4 and 5. The tables are presented on the pages which follow.

Table 4 shows the maximum permissible soil concentration limits allowed for soils on which sludge is applied, for the following countries and authorities: United States EPA, European Economic Community (EEC), Belgium (Flanders), France, Germany, Italy, Spain, United Kingdom, South Africa (1991 guidelines), South Africa (1997 guidelines). Most countries listed give limits dependent on pH range. One gives limits dependent on textural class.

Also shown, in the two rows at the bottom of the table, are background values for shales (worldwide) and for soils in the United Kingdom.

Table 5 shows the maximum permissible land application rates of potentially toxic trace elements for the United States EPA (EPA Part 503 Rule, 1993), European Economic Community (Dir.86/278/EEC, 1986), United Kingdom (DoE, 1989) and South Africa (DNH&PD, 1991; DNH&PD, 1997).

Also shown are the limits on the application rate of sewage sludge to land in South Africa, based on the new South African trace element limits (DNH&PD, 1997) and assuming average values for trace elements in South African sewage sludge (Smith & Vasiloudis, 1989). Trace elements in South African sewage sludges which are likely to significantly restrict the application of sewage sludge to land in terms of the new limits are Cu, Pb and Zn. These are about ten times more restrictive than the next five: Ni, Cd, Hg and As.

Table 4. **Maximum permissible soil concentrations (mg/kg) (Smith, 1996; DNH&PD, 1991; DNH&PD, 1997; U.S. EPA 1994b)**

Country or Authority	pH range	Soil texture class	Cd	Co	Ni	Pb	Zn	Hg	Cr	F
U.S. EPA	No limits specified		20	775	230	190	1500	9	1540	
EC (Rec. Limits)	>6		1-3	50-140	30-75	50-300	150-300	1-1.5		
Belgium (Flanders)		Sandy. Clay/silt.	1 3	50 140	30 75	50 300	150 300	1 1.5	100 150	
France			2	100	50	100	300	1	150	
Germany	5 - 6 >6		1 1.5	60 60	50 50	100 100	150 200	1 1	100 100	
Italy			1.5	100	75	100	300	1		
Spain	<7 >7		1 3	50 210	30 112	50 300	150 450	1 1.5	100 150	
United Kingdom (s - statutory; a - advisory)	5 -5,5 5,5-6 6 - 7 >7		3(s) 3(s) 3(s) 3(s)	80 (s) 100(s) 135(s) 200(s)	50 (s) 60 (s) 75 (s) 100(s)	300(s) 300(s) 300(s) 300(s)	200(s) 250(s) 300(s) 450(s)	l(s) l(s) l(s) Ks)	400(a) 400(a) 400(a) 400(a)	500(a 500(a 500(a 500(a
SA(1991)	>6		2	100	15	56	185	0,5	80	50
SA(1997)	>6		2	6,6	50	6,6	46,5	0,5	80	200
Mean U.K. soil concs.(Smith, 1996)			0,62	25,8	33,7	29,2	59,8	0,098	84	270
Mean cones, in shale. (Tanji & Valoppi, 1989)			0,3	50	80	20	90	0,3	100	600

Table 5. Maximum permissible annual application rates (kg/ha.yr) (Smith, 1996; U.S. EPA, 1994b; DNH&PD, 1991; DNH&PD, 1997)

Country or Authority	Allowed pH range	Cd	Cu	Hi	Pb	Zn	Hg	Cr	F
U.S. EPA (EPA Part 503 Rule, 1993)	No limits specified	1.9	75	21	15	140	0,85	150	
EEC (Dir.86/278/EEC, 1986)	>6	0,15	12	3	15	30	0,1		
U.K. (DoE, 1989)	>5	0,15	7,5	3	15	15	0,1	15	20
SA (DNH&PD, 1991)	>6	0,16	6	1,6	3,2	22	0,08	14	3,2
SA (DNH&PD: 1997)	>6	0,126	0,404	1,6	0,404	2,828	0,08	14	3,2
Sludge application rate limits, (S.A.: 1991) See (i) below.	ton/hectare (dry weight)	*13.33*	9.77	*10,39*	7,05	*10,71*	*16,0*	25,47	25,0
Sludge application rate limits, (S.A.: 1997) See (ii) below.	ton/hectare (dry weight)	*10,5*	*0,62 (See v)*	*10,39*	*0,89*	*1,38*	*16,0*	*25,41*	*25,0*
Equivalent N application rate for the data in the row above. See (iii) below.	kg/hectare	*315*	*18,6 (See v)*	*311,7*	*26,7*	*41,4*	*480*	*762,3*	*750*

(i) Maximum sludge application rate allowed, based on the current (1991) South African trace element limits and average values for trace elements in SA sludge: (Smith & Vasiloudis, 1989).

(ii) Maximum sludge application rate allowed, based on the new (1997) South African trace element limits and average values for trace elements in SA sludge: (Smith & Vasiloudis, 1989).

(iii) Nitrogen (N) application rate (kg/ha per year) assuming the sludge application rate in (ii) and that one metric ton of dry sludge contains 30 kg of nitrogen.

(iv) Average value for cobalt in South African sludges is not available.

(v) Interpretation example: Based only on the new Cu limits, about half of the sewage sludge produced in S. A. may not be applied to land at an annual rate greater than 0,62 ton/ha (~ 18 kg

3 COMMENTS ON CONTAMINANT-LIMIT SPECIFICATIONS, SAMPLING, MONITORING AND OTHER REQUIREMENTS

A risk-based approach to determining a health impact on humans and animals, along various contaminant pathways, is recommended as a basis for formulating limits for regulations relating to potentially toxic contaminants in sludge (WHO, 1995; U.S. EPA 1994c; Allen, 1997). Application constraints based on limiting pathways should be specified for various contaminants/nutrients/etc., and for various land uses. Contaminant limits, sludge application rates and applicable management methods are then dependent on these (U.S. EPA 1994c; U.S. EPA 1995; Chaney, 1995; Davis, 1995) . Caution should be exercised in the selection of "worst-case" scenarios for a risk-based approach, as their use is likely to result in very restrictive limits (Chaney, 1990b; U.S. EPA, 1995; Smith, 1996; Allen, 1997).

Certain contaminants in sewage sludge should get special attention, both because they are commonly found in significant quantities in sewage sludge and because they present a potentially significant health hazard to animals and plants at above certain concentrations. However, some elements which are potentially toxic at relatively high concentrations cause serious health effects if they are not available to plants or animals at certain, albeit very small, quantities (Smith, 1996).

* Cadmium is the contaminant of major concern for sludge application to land purposes, worldwide. It is generally followed by lead, mercury and PCBs in importance (U.S. EPA 1995; Chaney, 1990b). This prioritisation is the result of the toxic and carcinogenic effects on animals and humans of these contaminants, and their relatively high concentrations in sludges from industrialized towns and cities (Smith and Vasiloudis, 1989; U.S. EPA, 1995; Williams, 1989).

* Certain inorganic trace elements are potentially toxic at high concentrations and beneficial (if not critically important) for human and animal health if they are available in very small quantities such as, for example, arsenic, nickel and fluorides (Smith, 1996). Cadmium, lead and mercury are examples of toxic/carcinogenic trace elements that have no known beneficial use for either plants or animals, even in very small quantities (Smith and Vasiloudis, 1989).

* For farm animals, molybdenum (for cattle/sheep) is another trace element of major concern (Chaney, 1990a; Smith, 1996), followed by copper (for sheep) (Chaney, 1990a; Smith, 1996). However, copper deficiency is considered to have a greater negative effect than an excess of it (Smith, 1996).

* For crops, zinc, copper and nickel are potentially toxic at high concentrations. However, generally they have been found to be not bio-available in sufficiently high concentrations in sludge to have a significant impact on crops (U.S. EPA 1995; Smith, 1996). Some potentially toxic inorganic trace elements are important for plant health in very small quantities (Smith and Vasiloudis, 1989; Korentajer, 1991; Smith, 1996), and

their lack of availability to plants has been found to be more detrimental to crop health than when they are present in excessive amounts in sludge (Smith, 1996). Examples of such elements are boron, copper, molybdenum, selenium and zinc.

* Chromium is not considered a contaminant of serious concern for land application of sludge principally because it is found only in its non-toxic trivalent form (Chaney, 1990b; Smith, 1996; Smith and Vasiloudis, 1989; Dean and Suess, 1985).

A factor considered to be of great significance to South Africa is soil erosion. The research literature is in agreement about the benefits of sewage sludge in reducing soil erosion. If sludge is buried under the topsoil, there appears to be little likelihood of it contaminating surface water resources (Chaney, 1990a; U.S. EPA, 1994c; Smith, 1996).

There appears to be no evidence to substantiate the `Time Bomb' theory in which potentially toxic trace elements in land-applied sludge become more available as organic matter degrades (Smith, 1996; Chaney, 1990b; Bell et al, 1991; U.S. EPA, 1995; Chaney,1995). Evidence exists to show that the reverse may be true, that heavy metal elements in soil become less bio-available over time (Bell et al, 1991; Fey, 1990). These arguments assume that soil pH does not change over time.

It is recommended that consideration be given to prescribing limits according to the contaminant of concern and the intended use for sludge:

(i) Limits set for cadmium in sludge and soils should be most conservatively set and strictly regulated, followed by those for lead, PCBs and mercury. This is especially relevant when sludge is to be used for tobacco and vegetable crop production, for private gardens and nurseries, and for playgrounds. Tobacco is more effective than the most sensitive vegetable (lettuce) for accumulating heavy metals in leaves (Chaney, 1990b). Lungs are an extremely sensitive pathway for trace elements to enter the body, and so the application to tobacco plantations of sludge or any other source of trace elements such as fertilisers needs careful assessment and strict control.

(ii) Applicable limits for contaminants could also depend on the intended use for the sludge (Davis, 1987). Davis (1987), for example, recommends that in the United Kingdom, applicable limits for cadmium for home gardens should be based on a maximum concentration of 20 mg/kg in sludge, whereas for pastures and crops the total loading rate should be limited to 5 kg/ha.yr over a minimum of 30 years. (The UK regulations specify a loading rate limit of 0,15 kg/ha.yr for ten years, for all land uses).

(iii) According to the South African guidelines, Type D sludge may be used by public nurseries and in private gardens. Small children may be at risk if they are allowed to come into contact with high concentrations of the sludge, as soil-ingestion by small children represents the highest risk category (U.S. EPA, 1994c). For example, it is possible that high concentrations of Type D sludge might be used in potting soil for plants intended to be used around the home, or sludge could be applied to the surface of home lawns and gardens where small children play. Lead, cadmium and PCBs are likely to be the trace elements of most concern (U.S. EPA, 1995). A notice could be made out for nurseries that (Type D) sludge should be mixed with soil in a certain ratio before use, and for home users that sludge should be covered with sufficient soil in the garden or on lawns. Another option to consider is that no sludge be allowed for home/garden use or for public nurseries.

(iv) Relaxing the limits set for lead in sludge should not represent a problem for certain land applications which have limited access for humans and animals, provided the land does not become available for certain uses (e.g. for residential purposes) at a later stage (Chaney, 1990b). When sludge is not utilised for pastures or for fodder crops, limits for molybdenum could be relaxed. Limits for phytotoxic elements such as nickel, copper, zinc and boron should be taken into consideration for crops sensitive to them, otherwise their adherence could be given some latitude (U.S. EPA, 1995). In the latter case, it makes sense to supply information to farmers/landowners on whose land sludge is to be applied, on the probable response of specific crops to high levels of phytotoxic elements in particular sludges (Davis, 1987).

Recommendations which have relevance in terms of sampling, monitoring, timing of sludge applications, storage requirements, setting of prescribed limits for sludge and soils, and comments relating to pollution risk, follow:

(v) Requirements for sampling and testing soils could depend on the contaminant and intended land use. Soils should be sampled to different depths for different land uses (e.g. crops, grassland, forests) in order to get representative samples (Smith, 1986; Davis, 1995). Sludge applied to agricultural land is applied into the top 15 to 30 cm of soil, whereas sludge on pasture is often applied on to the surface, affecting the top few centimetres of soil only, and so is more concentrated. Sampling in grasslands (on undisturbed soils) should be down to 5 - 7,5 cm soil depth and for agricultural soils, down to bottom of ploughed layer, or 30 cm (Smith, 1996; Davis, 1995). These aspects need to be considered when defining sludge application rates, especially when pastures are used for grazing purposes (Davis, 1995).

(vi) Restrictions on sludge application to land could be made dependent on monitoring data, site ownership and land access restrictions, amongst others.

(vii) Contamination of groundwater or surface waters by potentially toxic trace elements and by pathogens in sludges applied at agronomic rates to agricultural land has been found to be highly unlikely (U.S. EPA, 1995; Smith, 1996). However, contamination by macro-nutrients (principally nitrates) when sludges are applied in excess of a crop's ability to take up the nutrients, is possible (WHO, 1995; Smith, 1996). Timing of large volume sludge applications for agronomic purposes in areas which have important and/or vulnerable aquifers needs to be done at a time when crops can make maximum use of the nutrients (MAFF, 1991; Smith, 1996).

(viii) Due to seasonal requirements for nutrients and the restricted times when sludge may be applied to certain croplands, sludge is often required to be stored or stockpiled near the application area. The potential for contamination of water resources is generally high from manure and sludge storage areas, and special requirements regarding sludge/manure storage management as well as the siting and design of facilities to store sludges/manures should be specified, such as to ensure that stockpiles are covered during wet weather, etc. (MAFF 1991; U.S.EPA, 1983).

(ix) An important aspect to consider regarding trace element contamination of sludged soil, is the portion contributed by other potential sources. Such souces include atmospheric deposition near coal-fired power stations, refineries, ore smelters, cement factories and highways, and the application of fertilizers. These need to be considered when setting limits for sludge-application to land. In many such situations, sludge forms a relatively minor contribution of trace elements to soils (Smith, 1996; Davis, 1995).

(x) For sludge application permitting purposes, it is recommended that water soluble or bio-available trace element concentrations limits be specified to complement total extractable trace element concentration limits, for certain trace elements.

(xi) Sludge application limits can be made dependent on soil type or soil pH (See **Tables 4 and 5).** This could be made applicable for trace elements referred to in point (x), above.

(xii) Some test limits could be removed from the list of those required for sludge application rate limit assessments, and kept in the list of those limits required for soils (WHO, 1995).This is relevant for those elements which are prone to build up in soils to levels that become dangerous in terms of ingestion by humans and animals, such as lead and PCBs (Chaney, 1990a). The World Health Organisation (WHO, 1995) considers that limits set for sludged soils to be more important than limits set for sludge application rates.

(xiii) Sewage sludge from a town with no industries, or one with industries which are known not to produce potentially toxic/carcinogenic trace elements, holds little risk of contaminating soils with potentially toxic or carcinogenic trace elements (Ekama, 1993b). Tests for the limits in question could be removed from the list of those required for sludge.

4 CONCLUSIONS

South Africa, with its burgeoning population and concomitant sludge production problem, needs to beneficially utilise as much of its sludge as possible. In view of South Africa's significantly deteriorated soils and growing need for food, it is believed that the promotion of sewage sludge for crop growth and soil improvement purposes should have a high priority on this nation's agenda. In order to help utilise sewage sludge on land with minimal impact on the environment, a complex permitting, planning and monitoring process needs to be effectively administered.

In order to help facilitate the complex administration process, there is an expressed need for decision support to assist officials in granting permits (McConkey, 19). Professional and administrative staff benefit from having convenient access to relevant information, whether it be descriptive or functional information and whether it be static (unchanging) or dynamic (changing according to the requirements at the time) Desk top and portable computers are being used more and more to supply this information in the form of user-friendly decision-support software.

Expert systems are computer programs which are designed to provide certain types of expertise and other forms of decision support, and have been developed as part of this project with the aim of providing help to those who are involved with tasks related to the application of sludge to land. A decision-support system called **SLADS (Sludge Land-Application Decision-Support Software),** which consists of a suite of expert-systems based programs and which attempts to provide the required decision support, has been developed. It addresses tasks which include permitting, site/area identification, site assessment and planning. Expert systems have been shown to be highly suitable to model typical decision-making processes and to provide fully-fledged computer-based decision support, including those which incorporate functional aspects, relating to sludge application to land.

The most significant findings from the literature and discussions with overseas experts for sludge application to land are as follows:

* Cadmium is the contaminant of greatest concern in sludge and sludge-amended soils, worldwide. The organic contaminant group of greatest concern in countries which do not control their use are **the PCBs (WHO,** 1995; Chaney et al., 1995).
* Ingestion of sludge-contaminated soil by toddlers represents the pathway with highest risk to humans, and ingestion of sludge-contaminated soil and grass by grazing animals represents the pathway with highest risk to animals (Chaney, 1990a; Smith, 199
* A risk-based approach for various contaminant pathways is the recommended approach for specifying contaminant limits and for determining which contaminants need to be tested for. Caution should be used when adopting worst-case scenarios for defining limits, as this may result in the definition of highly restrictive values.

* In the South African sludge permitting guidelines, trace element limits specified for some elements are lower than their natural levels in some types of soil.

* For agronomic rates of sludge application and with the possible exception of cadmium and lead, potentially toxic substances are generally available to plants and other biota in quantities very far below a level considered hazardous to health.

* Sludge storage facilities are potential sources of pollution for water resources.

Concluding remarks:

The setting of contaminant limits so that they are dependent on sludge type, land use, soil type and soil pH allows more options to be available for land application of sludge. However, this makes the permitting process more complex, requiring either:

* commitment of more time from permitting officials
  and/or
* convenient access to relevant, low-cost expertise and to other forms of decision support.

Expert systems and other computer software may be used to help provide the latter.

5 RECOMMENDATIONS

The beneficial use of sewage sludge on land should be actively promoted (Steyn et al., 1996; Ekama, 1993). In order to facilitate the beneficial application of sludge to land at a large scale in South Africa, the following comments and recommendations are presented:

(a) The risk-based sludge-permitting methodology used by the United States EPA and applied to contaminant pathways is a highly advanced method and it is considered to be applicable world-wide, because:

> The U.S. EPA permitting guideline framework, the risk-based approaches used for the various contaminant pathways, and the resulting contaminant limits, have been very well researched in the USA. The methodology and accompanying limits have been endorsed by world-renowned experts, and have been recommended for world-wide adoption by the World Health Organisation (WHO, 1995). The permitting framework is believed to be compatible with environmental screening and scoping procedures (DoE, 1992).
>
> The *methodology* adopted in South Africa is similar in many respects to the U.S. EPA's, but is more comprehensive and conservative. The *contaminant limits* used in South Africa are comprehensive and very conservative, being far more so than those of the U.S. EPA and more so than most, if not all, of the European and Commonwealth nations.

(b) When using a precautionary approach, derived limits are often based on "worst-case" scenarios. Specifying limits based on "worst-case" scenarios which have a low probability of occurrence, for trace elements with a low toxicity to humans/animals and a medium/low toxicity to plants, would seem to be unwise. This is especially relevant for trace elements which are vital for the health of humans, animals and plants (e.g. copper, zinc, boron, selenium). The impact on human, animal and plant health is sometimes worse for a lack of particular trace elements than for a limited excess of them.

(c) Trace element limits specified for total concentrations of an element in sludged soils may be lower than natural levels in some types of soil. Although total concentrations in soil may be high, they may be only available to plants and other biota in very low quantities. For the South African guidelines, it is recommended that limits for plant-available elements or water-soluble elements in soils be specified for at least some trace elements, and be used in place of, or to complement current limits.

(d) Ingestion of soil by toddlers represents the pathway with highest risk to humans. The application of sewage sludge to public places such as public lawns, or its use in public nurseries and in private gardens, therefore needs very careful monitoring and/or control.

(e) Ingestion of soil by grazing animals represents the pathway with highest risk to animals. The application of sludge to pastures should therefore be carefully monitored/controlled.

(f) The degree of monitoring and control required could depend on the integrity of the landowner and sludge treatment/land-application operators, and the accessibility to the site of the people or animals at risk.

(g) Certain of the South African guideline limits could be safely relaxed taking into account recommendations made elsewhere in this report, and efforts should be made to improve the quality of sewage sludge at sewage works especially in terms of acknowledged "priority pollutants" which are found to limit the application of sludge to land at agronomic rates.

(h) Sludge storage facilities are potential sources of pollution. It is recommended that the location, design and monitoring of sludge storage facilities have high priority. (This is also true of manure storage facilities). Stockpiling of sludge in the open, on unprotected ground, is not recommended.

(i) Provide and promote the use of computer-based decision-support facilities, so as to facilitate the interpretation of guidelines and so as to help users plan and manage sludge-to-land application and similar tasks in environmentally effective ways. This is especially relevant when the guidelines are complex to administer effectively, and the staff who are in a position to administer them are few.

6 REFERENCES

Adriano, D.C. (ed) 1991: *Water, Air and Soil Pollution.* Kluwer Academic Publishers, Dordrecht

Allen, H.E 1997: Personal communication. Department of Civil and Environmental Engineering, University of Delaware, Newark, Delaware, USA

Asano, T., 1995: Personal communication. Deptartment of Civil Engineering, University of California at Davis, California, USA.

Bell, P.F., James, B.R. and Chaney, R.L. 1991: Heavy Metal Extractability in Long-Term Sewage Sludge and Salt-Amended Soils. *Journal of Environmental Quality, Vol. 20,* no 2.

Bruemmer, G.W. and Van der Merwe, D., 1989: Report on a Visit to the Soil and Irrigation Research Institute. Pretoria, Department of Agricultural Development, Pretoria

Chaney, R.L., 1995 : Personal communication. United States Department of Agriculture, Beltsville, Washington D.C., U.S.A..

Chaney R.L., 1990(a): Twenty Years of Land-Application Research. *BioCycle, Vol. 31,* No. 9, pp 54-59.

Chaney R.L. 1990(b): Twenty Years of Land-Application Research. *BioCycle, Vol. 31, No.* 10, pp 68-73.

Chaney R.L., Ryan, J.A. and O'Connor, G.A., 1995: Organic Contaminants in Municipal Biosolids: Risk Assessment, Quantitative Pathways Analysis and Current Research Priorities. *Proc. Int. Symp. on Organic Contaminants in Sewage Sludge,* Lancaster, U.K.

Davis, R.D., 1995: Personal communication. WRc, Medmenham, U.K.

Davis, R.D., 1987: Use of Sewage Sludge on Land in the United Kingdom. *Water Science Technology, Vol 19,* no. 8, pp 1-8.

Dean, R.B. and Suess, M.J., 1985: The Risk to Health of Chemicals in Sewage Sludge Applied to Land. *Waste Management & Research, Vol 3, pp* 251-278.

DWA&F, 1995: *Minimum Requirements for Waste Disposal by Landfill.* Department of Water Affairs and Forestry, Pretoria

D.N.H.& P.D., 1991: Guide: Permissible Utilization and Disposal of Sewage Sludge, Department of National Health and Population Development, Pretoria. Ref: Al 1/2/5/4

D.N.H. & P.D., 1997: Guide: Permissible Utilization and Disposal of Sewage Sludge, Department of National Health and Population Development, Pretoria.

Ekama, G.A., 1993a: Some Background to Sludge Management Situation in South Africa. In: Ekama, G.A. (ed): *Sewage Sludge Utilization and Disposal,* Water Institute of Southern Africa.

Ekama, G.A., 1993b: Sludge Management for Land Disposal. In: Ekama, G.A. (ed): *Sewage Sludge Utilization and Disposal,* Water Institute of Southern Africa.

Ekama, G.A.., 1995: Personal communication. Department of Civil Engineering, University of Cape Town.

Engelbrecht, J.F.P., Nell, J.H. and Steer, A.G., 1981: *`n Opname van Bestaande Rioolslykbeskikkingspraktyke in die Kaapprovinsie.* NIWR,CSIR, Pretoria. Ref: WAT 61.

Fey, M.V. 1990: Land Treatment of Hazardous Wastes. In: *Survey of Hazardous Waste Technology,* Report for Foundation for Research Development, Pretoria.

Fiddes, D. A. 1985: *Expert Systems in Water Supply and Sanitation* in *Developing World Water.* J.Pickford & B. Leedham (eds.),London, pp 224-228.

Hall, J., 1995: Personal communication. Personal communication. Researcher, WRC, Medmenham, U.K.

Korentajer, L., 1991: A Review of the Agricultural Use of Sewage Sludge: Benefits and Potential Hazards. *Water SA,* Vol. 17, No.3, pp 189-196.

MAFF, 1991: *Code of Good Agricultural Practice for the Protection of Water.* Ministry of Agriculture, Fisheries and Food, U.K.

Pierce, F.J., Dowdy, R.H. and Grigal, D.F., 1982: Concentrations of Six Trace Metals in Some Major Minnesota Soil Series. *Journal of Environmental Quality,* Vol. 11, pp 416-422.

Policy Review Committee, 1978: Co-operative Programme of Research on the Behaviour of Hazardous Wastes in Landfill Sites., London: UK Department of the Environment.

Smith, R. and Vasiloudis, H. 1989: Inorganic Chemical Characterization of South African Municipal Sewage Sludges. Report to the Water Research Commission, Pretoria. Ref. WRC Report No 180/ 1 /89.

Smith, S.R., 1996: Agricultural Recycling of Sewage Sludge and the Environment. CAB International, Wallingford.

Steyn, C.E., Van der Watt, H.V.H. and Claassens, A.S., 1996: On the permissible nickel concentration for South African soils. *South African journal of science ; Vol*. 92, Issue 8, pp.359-363

Tanji, K., and Valoppi, L., 1989: Groundwater Contamination by Trace Elements. In: Bouwer., H. and Bowman, R.S. (eds.) Effects of Agriculture on Groundwater, Special Edition of Journal: *Agriculture, Ecosystems and Environment, Vol. 26,* Elsevier, Amsterdam.

U.S. EPA, 1983: *Process Design Manual: Land Application of Municipal Sludge.* Municipal Environmental Research Laboratory, Cincinnati, Ohio, Ref.: EPA-625/1-83-016

U.S. EPA, 1994(a): *A Plain English Guide to the EPA Part 503 Biosolids Rule.* Office of Wastewater Management, Washington, DC., Ref.: EPA/832/R-93/003.

U. S. EPA, 1994(b): *Land Application of Sewage Sludge: A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503.* Office of Enforcement of Compliance Assurance, Washington, DC., Ref. : EPA/831-B-93-002b.

U.S. EPA, 1994(c): *Biosolids Recycling: Beneficial Technologyfor a Better Environment.* Office of Water, Washington, DC., Ref.: EPA 832-R-94-009.

U.S. EPA, 1994(d): *Land Application of Sewage Sludge: A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503.* Office of Enforcement of Compliance Assurance, Washington, DC., Ref.: EPA/831-B-93-002b.

U.S. EPA, 1995: *A Guide to the Biosolids Risk-Assessments for the EPA Part 503 Rule.* Office of Wastewater Management, Washington, DC., Ref.: EPA/832-B-93-005.

Van Duijvenbooden W., van Waegeningh, H.G. (1987): *Vulnerability ofSoil and Groundwater to Pollutants,* rivm, Hague.

Williams, J.H., 1986: Regulations on Additions of Sludge-Borne Metals to Soil and Their Adaptation to Local Conditions, in L'Hermite P. (Ed): *Treatment and Use of Sewage Sludge and Liquid Agricultural Wastes.* Elsevier Applied Science.

WHO, 1987: *Technical Manual for the Safe Disposal of Hazardous Wastes,* London: UK Department of the Environment.

WHO, 1995: *Developing Human Health-Related Chemical Guidelines for Reclaimed Wastewater and Sewage Sludge Applications in Agriculture.* World Health Organisation, Geneva.