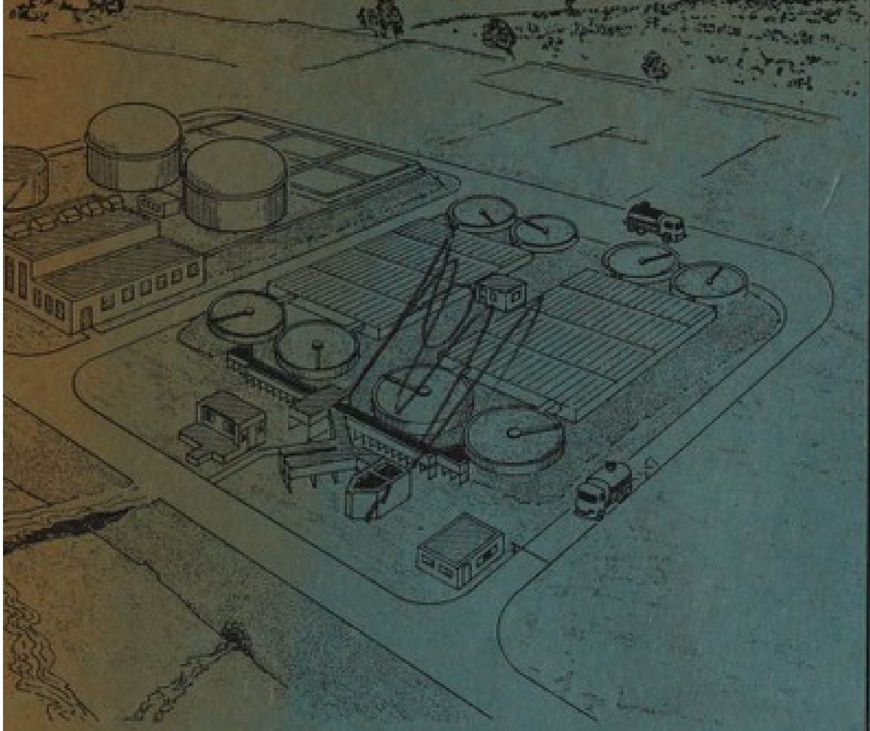
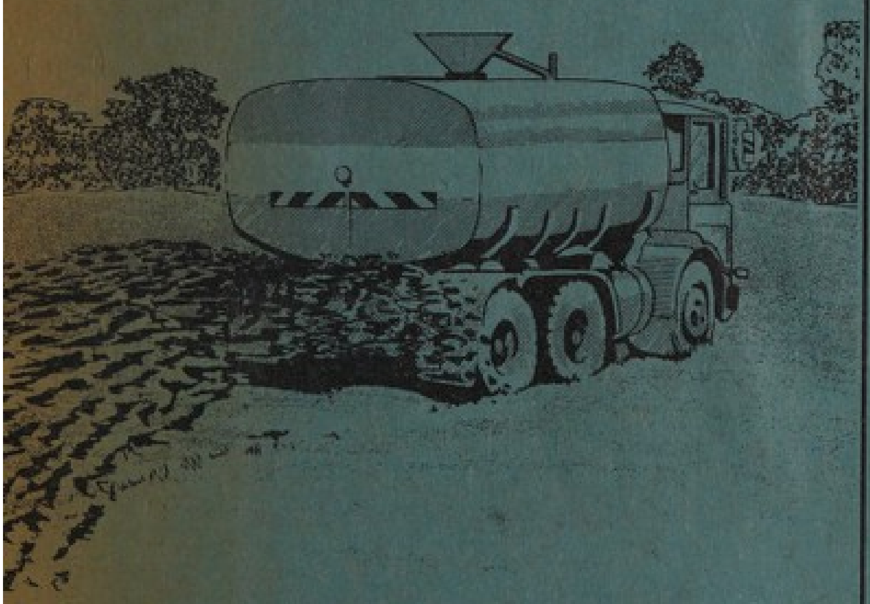
Standing Committee on the
Disposal of Sewage Sludge



Report of the Sub-Committee on the Disposal of Sewage Sludge to Land



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Number 20

This publication is issued joinly by the Department of the Environment and the National Water Council. It is one of a series which will include reports from jointly sponsored standing technical committees covering different aspects of water industry practice and national water policy. The views expressed in this document are those of the group from which it has come and not necessarily those of the Department or the Council. The object of publication is to stimulate action in the industry in the improvement of its technology and to promote greater awareness of technical factors underlying national water policy.

Early comments on the content of this publication would be helpful to the Standing Committee on the Disposal of Sewage Sludge. They should be addressed to the Standing Committee, c/o Department of the Environment WD2, 2 Marsham Street, London, SW1P 3EB.

Standing Committee on the
Disposal of Sewage Sludge

Report of the Sub-Committee on the Disposal of Sewage Sludge to Land

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CHAIRMAN'S FOREWORD

The Sub-Committee on the Disposal of Sewage Sludge to Land, one of 4 sub-committees set up by the Standing Committee on the Disposal of Sewage Sludge, was given the task of examining all aspects of that particular form of sewage sludge disposal. We are pleased to present our first report.

We inherited the duties and benefited from the deliberations of the Department of the Environment's Working Party on the Disposal of Sewage Sludge to Land. That Working Party compiled guidance on disposal to land in 1976. Although it was our intention to defer the production of further guidance on disposal to land, the Standing Committee have however, asked us to accelerate this report so that it completes the compendium of reports supporting its own recommendations. Because of the comparatively short space of time between the two publications and the lack of conclusive research our recommendations do not differ substantially from those of the Working Party.

In this report we have reviewed sludge disposal to land and made recommendations on its application which we believe are adequate to protect the environment without incurring unnecessary expense. We have reviewed the Working Party's guidelines and revised and extended them. Whilst there has been some advance in the 5 year period some of the original criteria have been accepted because there is a shortage of data on which to base an improvement.

One of the objectives of disposal to agriculture is to protect and wherever possible, nourish the plant. Theoretically, that is best achieved by ensuring that the soil concentrations of the critical elements in the sludged soil are kept within specific limits. Whilst we would like to have recommended soil concentrations for all soils, we are only able to give these for arable soils at this point in time and, even then, there are so many uncertainties that it is still necessary to have application limits.

We have removed the finite limit for nitrogen. It is widely accepted that excessive use of sludge or for that matter any other fertilizer can reduce growth and yield but the point at which this starts depends on so many variables that it is impossible to specify a general nitrogen limit. In addition, the loss of nitrogen that can occur between the application of sludge and the commencement of the growing season is so variable that any limit we prescribe would have a very restricted application unless it was very complex.

We are aware of the general concern over the input of cadmium to the human food chain. We realise that high application rates are possible to allotments and gardens and recommend that the cadmium content of such sludges should be limited. We also believe that the types of sludge used in those situations should be restricted. Users of sludge will no doubt limit appplications of nitrogen to those locations on the basis of their experience.

We have taken into account work being carried out on this topic in other countries and the results of recent monitoring and research. Information is continually being obtained and whilst we believe that this report contains the best advice, it is not the end of the story. In a world where energy and raw materials are increasing in scarcity and value the beneficial effects of sewage sludge should be utilised wherever that is economically justified.

It is our understanding that this report will be accepted in Scotland as a basis of sludge application to land there. We are aware of differences north of the border and that in some circumstances special guidance may be necessary, but believe in general the approach to sludge disposal should be similar throughout the United Kingdom.

I thank all members of the Sub-Committee, its working groups and particularly the Secretariat for their unstinting help in producing a report weighing up the benefits of sewage sludge against the risk of harmful effects.

T W G HUCKER
Chairman Sub-Committee on the
Disposal of Sewage Sludge to Land

CONTENTS

1. INTRODUCTION

Formation of the Sub-Committee

1.01 At its first meeting in 1975 the Standing Committee on the Disposal of Sewage Sludge (the Standing Committee) formed four Sub-Committees to study sewage sludge disposal to land, to sea and by incineration and the economics of disposal. The Sub-Committee on the Disposal of Sewage Sludge to Land (the Sub-Committee) was given terms of reference to examine all aspects of disposal to land. It also took over work started by the Department of the Environment Working Party on the Disposal of Sewage Sludge to Land (the Working Party) whose report (Standing Technical Committee Report No 5, 1977) contained preliminary guidance on the disposal of sewage sludge to land.

1.02 Reports by the other three sub-committees have been published in the joint Department of the Environment (DOE) and National Water Council (NWC) Standing Technical Committee Report series and they should be consulted for information on disposal to sea, by incineration and on the economics of sewage sludge disposal.

The Report of the Sub-Committee on the Economics of Sewage Sludge Disposal (STC No 19) provides information on sludge treatment and on the determination of optimum methods for disposal to land. The Standing Committee Report (STC No 21) deals with the overall subject of disposal to land, sea and by incineration.

Membership

1.03 Membership of the Sub-Committee is drawn from persons having expertise in various aspects of sewage sludge disposal, including the protection of agriculture, health and the environment:

T W G Hucker (Chairman to February 1977 and from October 1977)	Department of the Environment
Dr R Alderslade (from January 1980)	Department of Health and Social Security
J L Arnold (from February 1977)	Yorkshire Water Authority
Dr A K Barbour (from March 1978)	Confederation of British Industry
D J Bickerton (from March 1978)	Wessex Water Authority
T G Brownlie	Department of Agriculture and Fisheries for Scotland
Dr E G Coker (from August 1977)	Water Research Centre
Dr S M Cromwell (from February 1976)	Department of Health and Social Security
T D Dampney	National Farmers' Union
J Finch	Institute of Water Pollution Control
K G Gostick (from October 1977)	Ministry of Agriculture, Fisheries and Food
W T Greer	Strathclyde Regional Council
Dr R Gregory	Severn-Trent Water Authority
J M Haseldine	John Taylor and Sons
J A Hinchliffe (from May 1978)	Association of Metropolitan Authorities

F Holmes (from June 1978)	Association of District Councils
A E Johnston (from March 1980)	Agricultural Research Council
Dr A R M Kidd (From June 1980)	Ministry of Agriculture, Fisheries and Food
V H Lewin	Institute of Water Pollution Control
Dr D G Lindsay (from March 1977)	Ministry of Agriculture Fisheries and Food
Dr P J Matthews	Anglian Water Authority
Dr E B Pike (from August 1977)	Water Research Centre
J B Senior (from August 1979)	Leicestershire Country Council
L H Thompson	Thames Water Authority
J Webber	Ministry of Agriculture Fisheries and Food (to October 1977) and independent consultant (from October 1977)
P Worthington	Department of the Environment
G C Porteous (Technical Secretary)	Department of the Environment
Mrs M E A Tippins (Administrative Secretary from July 1980)	Department of the Environment

Past members

J B Blackhurst (from July 1978 to December 1978)	National Farmers' Union
J P Giltrow (to October 1977) (Chairman from February 1977 to October 1977)	Department of the Environment
Dr D M D Lambert (from February 1978 to October 1979)	Department of Health and Social Security
Dr N P Melia (from February 1977 to February 1978)	Department of Health and Social Security
Dr H A Painter (to August 1977)	Water Research Centre
W R Shirrefs (to July 1979)	Leicestershire County Council
M S Simmonds (from December 1978 to October 1979)	National Farmers' Union
A R Soskin (from October 1977 to July 1978)	National Farmers' Union
M J Tarbox (to March 1978)	Wessex Water Authority
H B Tench (to February 1977)	Yorkshire Water Authority
J F A Thomas (to February 1976)	Department of Health and Social Security
H S Tricker (to June 1977)	National Water Council
Mrs. L M Glassborow (Administrative Secretary to July 1980).	Department of the Environment

Key tasks

1.04 The Sub-Committee elected to undertake the following tasks:

1. To review the need to dispose of sewage sludge to land and to identify the medium (5 years) and long (20 years) term needs for disposal to land.

2. To survey the disposal of sewage sludge.

3. To ascertain the types, composition and quantities of sewage sludge disposed to land and predict future trends.

4. To determine the effects on agriculture, public health and the environment, of disposing various types of sewage sludges to land, including those with chemical conditioners.

5. To review the disposal rates of zinc, copper and nickel recommended in ADAS Advisory Paper No 10.

6. To recommend permissible limits for other significant substances.

7. To list ongoing and proposed research relevant to disposal on land.

8. To co-ordinate research and transmit information thereon.

9. To advise on further research necessary for the completion of the Standing Committee's terms of reference.

10. To recommend to the Standing Committee of Analysts the needs and the priorities for standardised methods of analysis for sludges, soils and crops.

11. To advise the Working Group on Waste Disposal Legislation on sewage sludge disposal.

12. To submit to the Standing Committee guidelines for the disposal of sewage sludge to land, including recommendations on the methods of applying sludge to land.

13. To review the report of the Working Party on the Disposal of Sewage Sludge to Land.

Progress

1.05 The Sub-Committee's overall programme of work has been directed towards the completion of its key tasks and the formulation of realistic criteria with the object of achieving safe and economical disposal of sewage sludge to land, taking into account the nutrient value of sludge and the possible harmful effects from its use.

1.06 In the course of its work the Sub-Committee has discussed the controversial issues which have arisen from the report of the Working Party on the Disposal of Sewage Sludge to Land and has considered the Survey of Literature and Experience (by the Imperial College of Science and Technology), the results of recent research projects on pathogens, and a number of technical papers recently published or presented at conferences.

1.07 Through its common membership, the Sub-Committee has maintained liaison with the NWC Microbiological Working Group, the Working Group on the Disposal of Sewage Sludge on Agricultural Land (Department of Agriculture and Fisheries for Scotland) and the DOE Standing Committee of Analysts (SCA). Requests have been placed with this last committee for consideration to be given to the standardisation of a number of analytical techniques, and some studies have subsequently been undertaken and others are planned.

1.08 The Sub-Committee advised the Working Group on Waste Disposal Legislation on the exemption from licensing of land used for the application of sewage sludge for agricultural purposes.

1.09 An additional task undertaken by the Sub-Committee on behalf of the Standing Committee was the preparation of evidence, relevant to the disposal of sewage sludge to land, for the Royal Commission on Environmental Pollution.

1.10 The Sub-Committee decided that the best means of completing its key tasks was to assign certain of them to appropriately constituted Working Groups and to undertake the remainder itself. Working Groups were thus formed to study the following subjects.

1. Data collection
2. Effects
3. Research

1.11 The Working Group memberships (see Appendix A) were constituted to give a balanced representation of interests, with individual members being selected for their expertise in particular aspects of sludge disposal. Regular Working Group progress reports were presented and discussed at the Sub-Committee meetings.

1.12 So that all members could have the opportunity of seeing sewage sludge applied to agricultural land by various methods, visits to disposal sites were arranged through the helpful co-operation of the Anglian, Thames and Yorkshire Water Authorities. A visit was also made to the Wanlip plant operated by Leicestershire County Council where sewage sludge is composted with municipal solid waste.

1.13 Through the efforts and assistance of the Working Groups, the Sub-Committee has completed its key tasks as far as present knowledge permits and has prepared this report. It is believed that the report makes a valuable contribution to the knowledge on sewage sludge disposal to land in the United Kingdom and will benefit future practice. In some areas of the Sub-Committee's work insufficient evidence was found for firm recommendations to be made or existing guidance to be amended, but research has been initiated or recommended which, it is hoped, will provide some of the data needed. With the wide range of interests represented by the Sub-Committee's large membership, it was inevitable that much discussion and debate took place before general agreement was reached on acceptable degrees of emphasis and on the guidance contained in the report.

Working Group 1

1.14 The experience gained by the Working Party provided a useful base for the development of a comprehensive questionnaire for data collection in a form suitable for computer processing by the Water Data Unit. This questionnaire was circulated to all sludge disposal authorities in the United Kingdom and the data obtained for the year 1975 were checked, processed and the principal results presented in tabular form. This was the most comprehensive sludge disposal survey ever carried out in the United Kingdom. The Standing Committee considered that the more important data should be made widely available in advance of their main report and these were published in DOE/NWC Standing Technical Committee Report No 8.

1.15 The sludge disposal survey was a major undertaking which placed a considerable workload on the water authorities, the Water Data Unit and the committee secretariat, and it was thought that a repetition would not be warranted within about 5 years. However, the Group was asked to check the amounts of sewage sludge disposed to land, to sea and by incineration in the year

1977 and to seek an indication of the probable future trends. The amounts of sludge disposed for both the years 1975 and 1977 are given in Chapter 3 of this report, together with information from the 1975 survey on the extent of use of various sludge treatments and the amounts of sludge disposed to various types of land.

1.16 Working Group 1 also carried out a survey of the amounts of septic tank and cesspit wastes produced in 1975, but found that only very limited and approximate data were available.

1.17 The survey of sludge disposal in 1975 did not include sludge analyses but it did record which sewage treatment works analysed their sludges regularly or occasionally. With this information Working Group 1 was able to extend the survey of disposal in 1977 to include analyses of sludge disposed to land. Analytical results for nutrients and the more important metals are given in Chapter 2.

Working Group 2

1.18 The Group's main tasks were to examine the effects of disposing sewage sludge on land and to recommend limiting rates of sludge application. In order to elicit information on latest research and experience and to initiate discussion on the more controversial issues, members were asked to prepare short papers on the benefits of applying sewage sludge to agricultural land and on possible adverse effects.

1.19 The Working Group was given the opportunity of discussing each of the sections of the Survey of Literature and Experience as they were drafted by the Imperial College of Science and Technology under contract to the DOE (Doyle, Lester, Perry 1978). This provided a useful feed-back of comment for the editors of the survey and, for the Group, recent information from world-wide sources on the effects of metals in sludge on crops.

1.20 From its own internal papers, the Imperial College survey, water authority reports and codes of practice and reports on recent research, the Working Group accumulated extensive up-to-date knowledge as a necessary preliminary to reviewing the guidelines recommended by the Working Party on the Dispoal of Sewage Sludge to Land.

1.21 The Working Group completed its immediate tasks by discussing and editing a paper drafted by the Group Chairman on the effects of sewage sludge disposal on land and recommended practice. This was then submitted to the Sub-Committee and formed a valuable basis for a large part of this report.

Working Group 3

1.22 The first main task was to circulate colleges, universities, research organisations, water authorities and government departments with a request for information on their current research relevant to the disposal of sewage sludge to land. Particulars of all projects notified were compiled in an inventory which was submitted to the Sub-Committee in June 1976 and made available to the contributors. This inventory served to inform all workers in the field of sludge research on the nature and the extent of research in hand or programmed, and to encourage co-operation in the co-ordination of plans for future work.

1.23 The Working Group organised a series of seminars at which papers were presented by some of the foremost workers in the United Kingdom on research relating to manurial value, pathogens and toxic metals in sewage sludge and on crop trials. These seminars created considerable interest and were well attended particularly by people involved in research and operational management; much useful information, which was subsequently used as reference by the Sub-Committee in its deliberations, was contributed in the papers and discussions.

1.24 The research inventory and seminars, together with the conferences on Inorganic Pollution and Agriculture (Ministry of Agriculture, Fisheries and Food ADAS 1977) and Utilisation of Sewage Sludge on Land (Water Research Centre 1978), widened the interest and knowledge in the field of sludge research and led to a number of additional projects being brought to the notice of the Working Group. A revised research inventory containing 58 projects, 25 more than in the first issue, was prepared and made available to those interested. The projects covered by the inventory are listed in Appendix C.

1.25 The Working Group advised the Sub-Committee on areas where research was needed and proposed suitable projects which the Standing Committee has recommended for Government and other funding at the annual review of finance for research in the UK. The areas of greatest concern in the utilisation of sewage sludge are the effects of toxic metals, particularly uptake of cadmium by crops, and pathogens. Specific research projects on these subjects have been initiated.

1.26 The Working Group has regularly reviewed the progress and results of ongoing Government and water industry research projects, and discussion by its specialist membership has led to valuable feed-back, advice and co-ordination of effort.

1.27 The Working Group undertook the collection of data on salmonellae from water authority records of 925 sludge samples and arranged for this data to be analysed by the Water Research Centre. This is referred to in the following chapter on Sludge Characteristics.

2. SLUDGE CHARACTERISTICS

General

2.01 The classification of sewage sludges into the broad categories of untreated and treated has previously been used as an indication of their suitability, in regard to pathogen content, for utilisation in agriculture, but this over-simple classification has been found unsatisfactory for this purpose. Sludges are treated to render them more amenable for disposal and it is incidental that most treatments reduce the numbers and types of pathogenic organisms. Since the pathogen content of sludges is very variable, depending on the source and inputs of contaminating materials, some sludges which have been subjected to treatment may still contain more pathogens than some raw sludges. Therefore, in the absence of microbiological analysis, the origin and treatment of a sludge need to be considered in addition to the chemical analysis before specific agricultural uses are recommended.

Sludge types

2.02 Most sludges applied to land are of the types described below, although mixtures may occur and in some cases a sludge may have been subjected to a combination of treatments. The extent to which some sludge treatments were used in the United Kingdom in 1975 is shown in Table 5, page 23. The report of the Sub-Committee on the Economics of Sewage Sludge Disposal provides information on the processes commonly used in sludge treatment.

Raw

2.03 Sludges removed from primary settlement tanks within about 2 weeks of the influent entering the tanks are usually termed raw. They may be primary sludges (the sediment from sewage) or co-settled primary with recycled secondary sludges (the product of biological treatment of sewage). Raw sludges generally have a dry solids content of between 2 and 7 per cent according to the tank design and desludging routine, and are usually odorous.

Stored liquid

2.04 Sludges retained in settlement or storage tanks for over two weeks may be considered as stored liquid sludges. Even with short storage periods, counts of some pathogens are often reduced and sludge solids spread on land tend to be less objectionable.

Thickened

2.05 The volume of liquid sludge can be significantly reduced by thickening. The consolidation of solids and removal of water may be effected, with or without the addition of chemicals, in gravity tanks, by means of solids flotation or by centrifuge. Sludges may be thickened to between 3 and 12 per cent and exceptionally to 16 per cent dry solids. Activated sludge cannot be thickened to the same extent, but if it is well nitrified, 3 to 5 per cent dry solids can be achieved.

Lagooned

2.06 Liquid sludges stored in open lagoons for long periods undergo decomposition by anaerobic bacterial digestion whereby a substantial proportion of the original organic matter may be destroyed. Retention periods in lagoons vary widely, but periods of several years are common. Lagooning is effective in reducing odour and periods of two years or more reduce pathogens to a level at which there is a very low risk of transmission of disease to animals and man through the use of sludge on land.

Cold anaerobic digested

2.07 Liquid sludges retained in open tanks for longer than normal liquid storage periods undergo varying degrees of cold anaerobic digestion. Cold digestion periods vary, but 4 to 6 months according to season may reduce upwards of 40 per cent of the original organic matter or about 30 per cent of the total solids to carbon dioxide and methane.

Heated anaerobic digested

2.08 Mesophilic anaerobic digestion at 25°C to 35°C in closed tanks, usually provided with mixing facilities, achieves an equal or better and more uniform reduction of solids than cold digestion in only 2 to 5 weeks. Both cold and heated anaerobic digestion reduce sludge odour and pathogens to a low level, but increase the ratio of heavy metals to dry solids.

2.09 The level of pathogens in the raw sludge-feed to a digester can vary widely from hour to hour so it is possible on occasions for the levels in sludge discharged to exceed those in the feed sludge. However, there is considerable evidence that mesophilic digestion substantially reduces the numbers of pathogens in sludge. In single stage digestion there is a possibility of some short circuiting, particularly if mixing is inadequate and stratification occurs, and of sludge being discharged in less than the nominal retention period

2.10 In some installations heated anaerobically digested sludges are subsequently stored in open tanks or lagoons for thickening and the removal of supernatant liquor. There is a further die-off in pathogens during the additional time period but some nitrogen is lost in the removed liquor.

Aerobically digested

2.11 Liquid sludges subjected to bacterial digestion in the presence of air undergo a reduction of solids and pathogens, but periods of aerobic digestion are usually shorter than for anaerobic digestion and it is believed that most parasites remain viable. The product is inoffensive but often difficult to dewater. Where unsettled sewage is treated by an oxidation ditch type of process the pathogen content of the sludge produced will be reduced with increased time of aeration.

Lime stabilised

2.12 The addition of lime (as calcium oxide or hydroxide) to raw sludge, in sufficient quantity to raise the pH to 11, greatly reduces offensive odour, but can give rise to the release of ammonia and a reduction in the nitrogen content of the sludge. Lime stabilisation destroys most pathogenic bacteria. Research is in progress to determine to what extent it destroys viruses or inactivates parasite eggs.

Air dried

2.13 Liquid sludges of all types may be air dried on under-drained beds to give a cake with 25 to 50 per cent dry solids. Reduction of pathogenic organisms is related to duration of drying which varies widely with type of sludge and climatic conditions. The ratio of metal to nitrogen content is increased when sludge is dried because nitrogen is lost in the water removed.

Mechanically dewatered

2.14 After conditioning with suitable chemicals, sludges may be dewatered by filter pressing, belt pressing, vacuum filtration or centrifuging. Filter presses can produce sludge cake with 30 to 60 per cent solids but the other equipment produces wetter cake with solids in the range 20 to 30 per cent. Where lime is used in the conditioning process there can be an addition of up to 25 per cent in the weight of dry solids for disposal.

Stacked cake

2.15 Prolonged stacking of sludge cake from drying beds or mechanical dewatering processes reduces all pathogens to levels where the risk of transmission of disease is very low. After stacking for a period, cake becomes more friable and easier to distribute on land. Under some conditions degradation of organic nitrogenous matter to ammonia occurs, which renders the nitrogen more rapidly available to crops, but may cause some small loss to atmosphere.

Biological

2.16 Biological secondary sludges from the full treatment of sewage in biological filter beds or activated sludge plants, if kept separate from other sludges, usually have much lower pathogen contents than raw primary sludges, but they may contain viable parasite eggs. Sludges from partial biological treatments are likely to be unstable and give rise to serious odour nuisance.

Disinfected

2.17 Sludges may be disinfected at considerable cost by intensive irradiation or heat treatment, but they can become reinfected unless precautions are taken.

Septic tank and cesspit waste

2.18 These wastes should preferably receive treatment at a sewage works. If they are applied to land they are likely to be strongly odorous and may contain unsightly solids which, unless ploughed into the soil, can cause offence and present a higher pathogen risk than sludges which have received some degree of treatment.

Sludge analyses

2.19 Most surveys of sludge analyses have been confined to a limited number and type of sludges. A comprehensive survey of analyses conducted in 1978 for the Standing Committee covered sludges analysed in 1977 from 195 sewage works. Although the results were determined using a variety of analytical methods, the number and size distribution of the works and the quantity of sludge produced by them, amounting to approximately 31 per cent of the total of all sludges disposed on land, make this survey the best overall assessment available in the United Kingdom at present. Some of the results are referred to in paragraphs 2.20 to 2.37.

Nutrients

Table 1 Total nutrients in sewage sludge

Sludge	Nitrogen			Phosphorus (as P)			Potassium (as K)		
	Mean*	No of Works	No of Samples	Mean*	No of Works	No of Samples	Mean*	No of Works	No of Samples
Liquid digested	5.1	32	509	1.6	29	551	0.4	25	343
Liquid undigested	3.5	25	198	1.3	22	191	0.2	20	
Undigested, lime conditioned, mechanically dewatered	2.1	11	96	1.0	7	70	0.1	9	74
Undigested, conditioned with other chemicals, mechanically dewatered	3.3	11	67	1.0	12	69	0.2	9	60
Digested, drying bed cake	3.0	8	19	1.0	7	17	0.1	6	17
Undigested, drying bed cake	3.2	7	37	1.8	5	28	0.5	5	27
All types in survey	4.1	118	1 026	1.4	102	1 011	0.3	90	781

Note:
* = Means are weighted according to population served by works and given as per cent of dry solids
Conversions: P x 2.3 = P_2O_5
K x 1.2 = K_2O

2.20 Sewage sludge contains useful amounts of nitrogen and phosphorus, a small amount of potassium and trace quantities of other elements, some of which are essential in small quantities to crop growth. Data on the nutrients in various types of sludges disposed to all types of land from 1977 analyses are given in Table 1.

Nitrogen

2.21 The proportion of nitrogen present and the chemical forms in which it occurs in sewage sludge depend on the sewage treatment process and subsequent treatment of the sludge.

2.22 From the sludge analysis survey (1977) the range of total nitrogen in all the sludges considered was 0.6 to 8.2 per cent of the dry solids. The median and mean values were 3.7 and 4.1 per cent respectively. Reliable values for ammoniacal nitrogen cannot be given as results were obtained from only eleven works.

2.23 In undigested sludges most of the nitrogen is combined in the organic form. It is thought that 20 to 35 per cent of the nitrogen becomes available to crops in the first season following application of undigested sludge, but experimental work is in hand to evaluate the availability of the nitrogen present. Activated sludge is richer in nitrogen than primary sludge and much of that present is contained in the bacterial floc which on application to soil rapidly breaks down with mineralisation of the nitrogen.

2.24 The digestion process converts rather more than half the total nitrogen into soluble forms, mainly ammonium compounds, which are readily available to crops.

2.25 When sludges are dewatered much of the nitrogen in soluble form is removed, so that both the proportion of remaining nitrogen relative to the total solids content, and its availability are reduced. Whilst loss from undigested sludge is small, that from digested sludge can be substantial, depending on the degree of dewatering.

Phosphorus

2.26 The phosphorus in sewage sludge is largely in the solid matter and its form depends on the type of sludge treatment. Where iron or aluminium compounds are used as conditioners or where large amounts of heavy metals are present, they may combine with the phosphates to form insoluble compounds which do not readily release phosphorus as a nutrient. Lime also precipitates phosphate but calcium phosphates are rather more soluble and available to crops than those of iron, aluminium or heavy metals.

2.27 From the survey of sludge analyses (1977) the range of phosphorus content (as P) was found to be 0.1 to 5.1 per cent, with median and mean values 1.5 and 1.4 per cent of the dry solids respectively.

Potassium

2.28 The potassium content of sewage sludge is usually low because potassium salts are generally soluble in water and discharged in the sewage treatment works effluent. According to the 1977 analysis survey the range of potassium content (as K) was 0.02 to 0.9 per cent, with median and mean values of 0.2 and 0.3 per cent of dry solids respectively.

Calcium

2.29 Where lime has been used as a stabiliser or conditioner, the calcium content (as CaO) in sewage sludge may be as high as 25 per cent of the dry solids.

Magnesium
2.30 The magnesium content of sewage sludges varies in the range 0.6 to 1.7 per cent of the dry solids (E G Coker 1971).

Trace elements
2.31 Sewage sludges contain some essential trace elements, such as manganese, cobalt, copper and boron, in concentrations higher than are found in most soils.

Organic matter

2.32 The organic content of sewage sludges depends on their origin and type. Undigested primary sludge dry solids may contain 60 to 75 per cent organic matter and secondary sludges, which are products of biological treatments, may contain 75 to 85 per cent organic matter. The organic dry solids content of sludges is reduced by digestion by 35 to 50 per cent of the original dry solids. Drying or dewatering liquid sludges concentrates the solid matter, including the organic content.

Potentially toxic contaminants

Metals
2.33 Surveys of sewage sludge composition completed in many countries show the presence of a wide range of elements. (Berrow and Webber 1972, Page 1974, Williams 1974, Sommers 1976). Some elements are always present at higher concentration in sludge dry matter than normally found in soils and others show wide variations in concentration usually depending on the kind of industrial wastes being discharged into the sewers. In one study in the United Kingdom (Berrow and Webber 1972) the concentration of zinc, copper and tin in 42 sludges with industrial content appeared to be about 40 times that found in soils, while concentrations of cadmium, silver, bismuth, lead and mercury exceeded those in soils by a smaller, but still significant, factor. The origin of elements such as copper and zinc, often present at relatively high concentrations even in domestic sludge, is not always known. Usually less than 10 per cent of the zinc in domestic sludges originates from human diet. Some zinc from galvanised ironwork, rubber tyres and cosmetics finds its way into sewers, as does copper dissolved from pipework, lead exhausted from car engines and boron from domestic detergents. Industry is usually the main source of elements found in sewage sludge at concentrations higher than normal background levels and it is usually possible to identify the processes involved and the sources of much of the metal found in the sludge. Improvements in trade effluent control effected by water authorities during the past five years have been reflected in the lower metal content of some sludges being used for agricultural purposes.

Table 2 Metals in sludges disposed to land

Metal	Min mg/kg ds	Median mg/kg ds	Mean mg/kg ds	Max mg/kg ds	No of works	No of samples
Zinc	199	1 270	1 820	19 000	193	2 386
Copper	36	546	613	2 889	193	2 379
Nickel	5	94	188	3 036	192	2 343
Zinc equivalent	507	3 440	4 550	40 502	192	2 343
Chromium	7	335	744	10 356	188	2 310
Cadmium	0.4	17	29	183	180	2 319
Lead	19	324	550	3 538	164	2 189

Note:
Medians and means are weighted according to population served by works. See also paragraph 2.19 and Appendix B, which shows in a series of graphs, the range of concentrations of metals in cumulative percentages of the sewage sludges in the survey, weighted according to populations served by sewage works.

2.34 The metal contents of all the sludges covered by the survey of analyses (1977) which were disposed to land, including landfill are given in Table 2.

2.35 With the exception of nickel and chromium values, which are higher, the median and mean metal contents are within the normal ranges of metals in liquid digested sludges given in the report of the Working Party (1977), and generally slightly lower than the values given by Berrow and Webber (1972) based on 42 samples. It will be noted from Table 2 that the median concentration of cadmium, the toxic metal of most concern in the utilisation of sewage sludge in agriculture, was 17 mg/kg of dry solids (ds).

2.36 The metal concentrations ascertained from the survey, of sludges disposed to agricultural land and to landfill, were compared and, with some exceptions, the concentrations in the sludge put to landfill were seen to be higher. However, from the limited data available it is not possible to be sure that this trend reflects the situation for all sludges.

Persistent organic compounds

2.37 Attention in the past has been focused on metals in sewage sludge and much less work has been done on organic compounds, partly because of the analytical problems involved. Recently however a number of examples have been seen of organic compounds persisting in the environment. Of these, the substituted organohalogens, which are relatively resistant to chemical and biological degradation processes, have been most widely studied. Examples are polychlorinated biphenyls (PCBs), dieldrin and DDT. Although the use of some of these compounds has been largely phased out in the UK, some still have a limited use in certain industries and find their way into sewage sludge. Fortunately most herbicides appear to degrade in time and lagooning of sludge reduces the amounts present to levels where the sludge can be used on land for growing farm crops. There are very limited data available on the up-take of organohalogens by crops.

2.38 Work in Canada and in the United States (Lawrence 1976, Furr 1976) shows a wide range of concentrations of organohalogens in sewage sludge, varying from less than 0.1 mg/kg dry solids to, in the case of PCBs, some hundreds of mg/kg. Routine determinations are not normally made by water authorities in the UK. The few data that were available in 1978 for UK sludges suggested that concentrations were usually low (see Table 3) but high levels of dieldrin were found in one sludge which contained industrial waste. Changes in the use of organohalogens are tending to reduce these concentrations.

Table 3 Organohalogen compounds in sewage sludge (1978) mg/kg dry solids

Constituent	Range
Dieldrin	<0.05–17.0
gamma – BHC	0.1–0.5
DDT	0.02–0.8
PCB	<0.004–5.0

Pathogens

2.39 It is known that a wide range of pathogens find their way into sewage sludge, but there is continuing debate on their survival through sewage and sludge treatments. Many uncertainties have arisen because the prevalence of pathogens in sewage sludge varies with the size of treatment works, the incidence in the human population and also the season. The uncertainties are compounded by the lack of precision and standardisation in the methods used for isolating and enumerating pathogenic organisms.

2.40 Four groups of pathogens have been identified as potential causes of infection in the UK, but only the transmission of the beef tapeworm has been implicated with the use of sewage sludge. The groups are: —

1. Bacteria, especially *Salmonella* species.

2. Eggs of parasitic worms, particularly the tape worms, *Taenia saginata,* and *Taenia solium,* but also *Ascaris* and *Trichuris.*

3. Viruses, in particular Enteroviruses.

4. Protozoan cysts such as *Giardia intestinalis.*

Salmonellae

2.41 Salmonellae, when ingested in sufficient numbers, are capable of infecting a wide range of animals and also man.

2.42 A survey of salmonellae in sewage sludges conducted in 1977 for the Standing Committee and analysed by the Water Research Centre showed that although the number and serotypes of salmonellae in raw sludges vary greatly, there tend to be more in sludges from medium sized works (10 000 to 100 000 population) than from the very small works. In one water authority with a large number of small works, no salmonellae were found in 87 per cent of raw sludge samples. Even though many sludges from larger works may receive some treatment which reduces salmonellae, the numbers remaining can be higher than in some raw sludges. The wide variation in the counts, even in samples from the same works, the changes with age of the sample and the different methods used for salmonella enumeration by different authorities make comparison of sludges difficult. Investigation of the performance of the digestion process in reducing salmonellae is made even more difficult by the inefficient feeding and mixing of sludge in some digesters. In the survey of salmonellae in sludge the records of 11 works, which had data on sludge before and after mesophilic anaerobic or aerobic digestion, were examined and it was found that at 9 of these works digestion reduced the count to between 13 and 84 per cent of the level in the raw sludge. The reductions through anaerobic or aerobic digestion were of a similar order. Sludge dewatering after conditioning with lime or lime and copperas reduced salmonellae to undetectable levels, but polyelectrolyte conditioning had no significant effect.

2.43 Jones P W et al (1980) reported that in an examination of sludges at 8 works, mesophilic anaerobic digestion was shown to be less effective in killing salmonellae than other sludge treatments such as aerobic digestion, dewatering and stacking, long-term lagooning or lime dosing.

2.44 The majority of water authorities now analyse sludges for salmonella either as part of routine monitoring or for special investigations.

Parasitic worms

2.45 Eggs of numerous parasitic worms have been found in sewage sludge in some countries where they are endemic, but of those found in United Kingdom sludges only the eggs of the beef tapeworm (*Taenia saginata*) are of concern at present. They are resistant to most sewage and sludge treatment processes. Although experiments involving the use of live animals have shown that anaerobic digestion of sludge at 35°C for 5 days inactivated the eggs (Silverman and Guiver 1960), it has been reported by others (Newton et al 1949) that digestion at 25°C for 35 days affected only about 25 per cent of eggs. The factors in anaerobic digestion which affect egg viability are not all fully understood, but eggs are most likely to be inactivated when the digester operation destroys at least 40 per cent of the original organic matter in the sludge. Egg viability is also reduced by prolonged storage of sludge. *Ascaris* ova appear to be even more resistant to sewage treatment processes than those of *Taenia saginata.* Monitoring of sludges for parasitic worm eggs is impracticable at present, but a technique for the recovery of eggs has been devised and is to be tested by a number of water authorities.

Viruses

2.46 Viruses may be found in sewage sludge but little is known of their survival through sludge treatment processes. Research is in hand to determine the effectiveness of lime stabilisation and digestion in reducing virus populations.

Protozoa

2.47 Protozoan cysts, especially *Giardia intestinalis* which are very infective to man, are now more common in the United Kingdom. They can appear in sewage sludge in great numbers (Crewe and Owen 1977) and are believed to survive mesophilic anaerobic digestion, but there is no evidence to suggest that sewage sludge disposed on land is a vector in the transmission of infection.

3. SLUDGE DISPOSAL PRACTICE

Objectives of good practice

3.01 Good practice in sewage sludge disposal, whether to land, to sea or by incineration, involves striking a balance between economic constraints and the avoidance as far as possible, of adverse effects on man, animals and the environment. Low cost is not always compatible with limited adverse environmental effects and sometimes compromises have to be reached. The best option of treatment within a disposal method may change with time due to changing costs, improved knowledge of treatment processes and environmental effects, experience and research. Options may be influenced by national or international pressures.

3.02 Disposal of sewage sludge involving application to agricultural land has the benefit of resource recovery and the value of the nutrients utilised should be taken into account in assessing the minimum cost to the nation. Disposal of sludge to land can have greater environmental impact than other options and in assessing the likely benefits and potential adverse effects, consideration should also be given to amenity, formal and informal recreation and wildlife.

Quantities and trends

3.03 The survey of sewage sludge disposal, summarised in DOE/NWC Standing Technical Committee Report No. 8, provides statistics for the year 1975. It was not thought necessary to update all these statistics before 1981 but the important data on disposal to land, sea and by incineration were updated for 1977. Table 4 gives the sludge quantities for both 1975 and 1977 by disposal authority and as totals. This shows that allowing for minor errors or omissions in the earlier survey, there has been a small overall increase in the quantity disposed to sea, and an even smaller increase in incineration through the commissioning of the Coleshill plant by the Severn-Trent Water Authority. The distribution of sludge to various land uses in 1975 is shown in Table 6 on page 24.

3.04 As far as can be determined from water authority predictions the overall distribution of sludge disposed to land, to sea and by incineration is unlikely to change significantly in the near future unless more stringent constraints are placed on one or other of the methods. The total quantity of sludge produced is likely to rise as new and improved sewage treatment works are commissioned and in some regions the quantity disposed to sea may increase. From those water authority returns made in the 1977 sludge analysis survey, the predicted effect of improved trade effluent control over the following five years was for a general small reduction in the heavy metal content of most of the sewage sludges disposed to land, with some exceptions where increases were forecast. There will be little improvement in the highly contaminated sludges, most of which are tipped.

Degree of treatment for acceptability

3.05 The costs of sludge treatment have increased greatly in recent years and methods are being re-examined to see if less sophisticated and cheaper treatments can be used which still produce agriculturally useful and environmentally acceptable sludges. The trend over the past few years towards disposing sludges as liquids, which has reduced the need for costly dewatering equipment or drying beds with their seasonal labour requirements, has perhaps resulted from economic appraisal following area-wide reorganisation within the water industry rather than from a radical change in fundamental attitudes to sludge treatment. Rising cost of

Table 4 Sewage sludge disposal quantities

	Year	Sludge disposal authorities														
		Thames	North West	Northumbrian	Severn-Trent	Yorkshire	Anglian	Southern	Wessex	South West	Welsh	Eng & Welsh	Scotland	N. Ireland	Others	UK Total
Sludge production 1 000 tonnes ds per year	1975	266	172	26	225	156	94	76	45	13	43	1 116	102	20	7	1 245
	1977	280	174	26	225	151	104	69	45	15	47	1 136	128	29	7	1 300
Per cent disposal to: Land	1975	62	60	100	98	76	92	84	83	66	76	77	41	60	100	74
	1977	60	50	100	94	64	92	78	81	64	63	72	24	58	100	67
Sea	1975	37	40	0	0	6	8	15	17	34	24	20	58	40	0	23
	1977	39	49	0	0	17	8	21	19	36	37	24	74	42	0	29
Incineration	1975	1	0	0	2	18	1	1	0	0	0	3	1	0	0	3
	1977	1	<1	0	6	19	0	<1	0	0	0	4	<1	0	0	4
Land disposal ratio agriculture: tip	1975	77:23	57:43	68:32	50:50	51:49	73:27	36:64	57:43	58:42	79:21	60:40	58:42	56:44	100:0	60:40
	1977	77:23	62:38	68:32	50:50	77:23	80:20	55:45	57:43	58:42	73:27	67:33	64:36	49:51	100:0	66:34

vehicles and fuel could change this trend. Dewatered sludges are often produced for historic or locally applicable reasons or because there is a particular agricultural demand for such products. In some cases the treatment involved in dewatering, for example lime dosing, increases the acceptability of the product but in other cases the loss of nitrogen, particularly from digested sludges, will reduce the manurial value.

3.06 The acceptability of sewage sludge for disposal on agricultural land is not only dependent on the type of land, its use and location, but on the balance between benefits from nutrients and constraints from risk of odour nuisance, water and soil contamination and pathogens. Although the purpose of sludge treatment is not primarily to reduce odour and pathogens, some treatments such as aerobic or anaerobic digestion, lime dosing, long term storage or dewatering and stacking may achieve significant reductions. Anaerobic digestion increases the acceptability of sewage sludge in situations where readily available nitrogen is required. Although the application of untreated sewage sludges to land can provide an economical means of disposal with a benefit in some instances from delayed nitrogen release, the measures necessary to prevent transmission of disease and the difficulty of avoiding nuisance are likely to limit this form of disposal.

3.07 The treatment of sewage sludge by composting with waste materials reduces the pathogen content in the sludge but also dilutes the nutrient content. The main demand for the product is as a soil conditioner in both the commercial and domestic sectors. The amount of sewage sludge utilised in composting is small, the primary objective of the process in the United Kingdom being the conversion of municipal waste into a useful material, but its use has declined because of the cost of plant operation.

Extent of sludge treatments

3.08 The DOE/NWC Standing Technical Committee Report No 8 gave, from the 1975 survey of sludge disposal, the percentages of sludges which had received some form of digestion and those which had not. The digested sludges included those which had undergone heated or cold anaerobic, or aerobic digestion. The other sludges included some which had received treatment that rendered them as acceptable as digested sludges for certain agricultural uses. In 1975 about 2.7 per cent of the sewage sludge utilised in agriculture had not been digested, conditioned or dewatered, but the percentage was over 5 in one region.

3.09 Table 5 shows the extent of use of the methods in the main stages of sludge treatment in 1975. Of all the sludge disposed to land, including landfill, about 47 per cent received some form of digestion.

Septic tank and cesspit wastes

3.10 It has been estimated that just under 5 per cent of the population is served by septic tanks and cesspits. The problems associated with the direct disposal to land of waste from septic tanks and cesspits are avoided by tankering this to a sewerage system or sewage works for treatment. A survey of the amounts produced in 1975 showed that several water authorities dealt with about 90 per cent of the wastes in this way but that in some regions a large proportion was collected and disposed by contractors and records of total amounts were not available. The revised charging systems adopted by water authorities over recent years appear to have resulted in an increasing use of private collection contractors and less control over disposal. A further survey is required to provide up-to-date information on amounts collected and how these are disposed.

Table 5 Extent of treatment of sludge disposed to land in 1975

Main stage	Method	Percentage of sludge
Digestion	Heated	41.7
	Cold	5.1
	Aerobic	0.4
	None	52.8
		100.0
Conditioning	Chemical, with lime	15.9
	Other chemical	23.1
	Heat	1.6
	None	59.4
		100.0
Dewatering	Lagoons or storage	20.4
	Mechanical dewatering	36.8
	Drying beds	21.2
	Artificial drying	1.0
	None	20.6
		100.0

Types of land used

3.11 Table 6 shows the amounts of sludge disposed on land for various uses in 1975 as percentages of the total sludge applied to land in the United Kingdom. 33 per cent of this sludge was tipped on landfill (11 per cent digested), 35 per cent was utilised on general arable land (14 per cent digested) and 21 per cent on grazing land (15 per cent digested). The other uses (horticulture, allotments, forestry and land reclamation) were relatively small. There were some significant regional differences which reflected local land use, the most obvious being the extent of horticultural applications in the Thames Water Authority, grazing land application in the South West Water Authority and arable land application in the Anglian Water Authority. Grazing land and forestry may have subsidiary uses such as informal recreation and wildlife habitats. Some water authorities have increased significantly the amount of sewage sludge applied to grazing land since the survey of sludge uses in 1975.

Use of sludge in agriculture

3.12 Grass for conservation as hay or silage is one of the most suitable agricultural crops whose growth can follow sludge application because it can fully utilise the nitrogen in sludge without risk of transmission of disease to man or animals. Forage crops for animal feed are also very suitable as they have a high nitrogen demand and, provided the sludge is ploughed in, there should be no problems with pathogens. Cereals accumulate metals to a lesser extent than some leafy crops and do not transmit disease. In southern and eastern England where grass is less important, cereal crops provide another outlet for sewage sludge although there is the difficulty that the nitrogen requirement needs to be supplied more precisely and uniformly for cereals than for some other crops. Spring sown cereals are in the ground from March/April to August so sludge application is confined to the period September to March. Winter cereals, which are becoming more important in this country, are in the ground from October to August so the period of sludge application for these is more limited, but top dressing has been successfully undertaken although special care needs to be taken to apply accurately the required amount of nitrogen and to avoid crop damage. In practice land under other crops has to be used and in many areas grazing land is chosen because of its availability throughout the year, although here the use of raw sludge may have to be limited during spring

Table 6 Percentage of total sludge disposed to land for various uses (1975)

Land Use	Sludge disposal authorities													
	Thames	North West	Northumbrian	Severn-Trent	Yorkshire	Anglian	Southern	Wessex	South West	Welsh	Eng & Welsh	Scotland	N. Ireland	Others	UK Total
Grazing	28	34	17	16	9	14	9	31	58	39	21	14	29	0	21
General arable	40	15	48	32	39	57	26	19	<1	38	35	41	27	100	35
Horticulture	7	≤1	2	>1	1	2	2	3	0	1	2	2	0	0	2
Allotments	1	8	1	1	1	≤1	≤1	4	0	0	1	<1	0	0	1
Forestry	0	0	0	0	0	0	0	≤1	0	<1	1	0	0	0	1
Land reclamation	14	6	8	4	5	1	4	33	0	<1	7	8	0	0	7
Landfill	10	37	24	46	44	26	59	9	42	20	33	35	44	0	33
Total – per cent	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
– 1 000 tonnes dry solids	168	87	26	212	98	96	54	36	10	30	817	29	12	7	865

and summer because of possible health risks to certain grazing animals due to the presence of pathogens. The utilisation of sewage sludge in forestry is limited because plantations are usually remote from sewage works and there are often physical difficulties in applying the sludge. Coniferous trees are sensitive to high levels of zinc in the soil and as the soil pH in upland forests is often as low as 4 or 5, rates of application of zinc in sludge in excess of those permissible to arable crops may affect growth. A small amount of sewage sludge is used for flower beds in parks but it is not a suitable dressing for playing fields where energetic games such as football are played owing to the risk of infection to cuts and grazes. Doyle, Lester and Perry (1978) estimated that of the 12 million hectares of land under crops and temporary and permanent grassland in England and Wales in 1975, between 140 000 and 165 000 hectares received sewage sludge.

Use of sludge in land reclamation

3.13 The utilisation of sewage sludge for land reclamation may be a useful option and one to be encouraged where, as in most cases, there is unlikely to be a risk to health or the environment. The reclamation of industrial excavations, especially on sites where no top-soil is available, usually requires large amounts of organic matter rather than nutrients and for this purpose sludge cake is more suitable than liquid sludge. Land reclamation is usually a once and for all operation but it presents the sludge disposer with the opportunity of clearing stock-piles. If the sludge is contaminated with toxic materials the application rate may be limited by the possible land after-use.

Disposal to landfill

3.14 In 1970 the amount of sewage sludge disposed to landfill was estimated very approximately at 40 per cent of the total sludge produced in the United Kingdom (Report of the Working Party on Sewage Disposal), but in 1975 the amount was about 25 per cent. The greater part of sludge disposed to landfill is in cake form but where the transport of liquid sludge to suitable agricultural land tends to become more economical than dewatering and tipping, the total amount of sludge sent to landfill may decline further. Some reduction in disposal to landfill has been forced on water authorities by lack of suitable tipping space and restrictions resulting from licensing of sites. Landfill is a simple means of sludge disposal and is often selected where sites are available within easy reach of sewage treatment works because costs are lower than for other means.

3.15 Disposal to landfill has a useful function as a standby for emergencies such as when outbreaks of foot and mouth disease prevent tanker access to farmland or when sludge treatment plant breaks down or processes fail. Lagoons or tipping areas are provided at many sewage treatment works, where space is available, as temporary facilities for possible recurring emergencies.

3.16 Air dried or mechanically dewatered sludge may generally be tipped on its own or with other waste materials without causing odour or leachate problems. Greater care is necessary in the tipping of liquid sludge to avoid contamination of surface or ground water by any harmful constituents. The spreading of liquid sewage sludge over such materials as municipal refuse utilises the capacity of refuse to absorb water and accelerates the biological decomposition of the refuse, but it makes the routine placing of cover-material unpleasant and more difficult. Where the depth of tipped refuse is adequate and the tip surface is stable and of sufficient area for vehicles to be manoeuvred freely, the forming of trenches or lagoons in the refuse allows the absorption of liquid sludge under hydrostatic head. The amount of liquid sludge that can be disposed of in this way depends on the nature of the sludge, the absorption capacity of the tip material and the tip drainage characteritics, and is usually determined by on-site trial excavations.

3.17 Sludge disposed to landfill is defined as 'controlled waste' and sites must be licensed unless the sludge is deposited inside or outside the curtilage of a sewage treatment works as an integral part of the operation of those works (see paragraph 3.27 and on).

Handling and application to land

Handling

3.18 Liquid sewage sludges from settlement tanks usually contain 2 to 7 per cent dry solids and may be pumped directly into road tankers or by pipeline to disposal points. The bulk of material can be very significantly reduced by thickening prior to transporting to the disposal site. Activated sludges may become difficult to pump if thickened to more than about 6 per cent, whereas with other sludges there would normally be no difficulty at this concentration. The maximum concentrations of sewage sludges that can be handled economically by centrifugal pumps are currently being investigated (Brit, Hydromechanics Research Association 1979).

3.19 Sludge cake from drying beds or dewatering processes may contain 20 to 60 per cent dry solids. Although the cost of producing these sludge cakes may be high, the volume of material is substantially less than that of liquid sludges and there may be a reduction in overall disposal cost where the distances to disposal sites are great.

Transport

3.20 Liquid sludge is transported from sewage works in tankers of various sizes. The use of large tankers may be more economical for the longer haul, but where they are too heavy to be allowed on the disposal site, the sludge may be transferred to storage tanks or to smaller tankers suitable for the spreading operation. Sludge cake is transported in lorries or single and multiple skip transporters.

3.21 With any sludge disposal site it is inevitable that increased traffic from the transport operation must have at least some small impact on the environment along the route. Large tankers reduce the number of vehicles used in an operation, but they can increase difficulties in narrow country roads and in urban areas. Nuisances are kept to the minimum by planning vehicle routes to avoid, wherever possible, sensitive areas and traffic congestion points.

Application to land

3.22 Ideally, agricultural sites for the disposal of sewage sludge should be situated well away from housing and buildings but close to the sewage treatment works and have good access. Consideration of stream pollution and underground water abstraction may limit the application of sludge in some areas and in some circumstances restrict the times of year at which applications may be made because of the risk of leaching or run-off. Restriction on the use of sludge on land where water pollution is likely will generally be enforced by water authorities in their own interest. Fortunately only a small proportion of the total area of agricultural land is required to take all the sludge suitable for land application so that, except in heavily built-up areas, the area available is usually adequate. Because of metal contamination the sludge from industrial areas may be less suitable for land application than that from non-industrialised towns, so that apart from the consideration of land availability, other methods of sludge disposal may have to be adopted.

3.23 The most common problem resulting from the application of raw sludge is smell. Serious nuisance can usually be avoided by careful attention to wind direction and speed, the use of equipment that does not aggravate drift of spray and smell and by not spreading near to occupied buildings on grassland which is not subsequently ploughed. In arable situations cultivation of the land immediately after spreading raw sludge not only assists incorporation in the soil but reduces odour. The injection of sewage sludge into arable land is currently being investigated and if this proves effective and economical it may permit application in areas where there would be environmental objections to other methods. Sludges from unscreened sewage disposed on grassland, which is not subsequently ploughed, are likely to give rise to objections of unsightliness and may cause problems with grazing animals.

3.24 Under wet soil conditions heavy sludge tankers may damage the soil structure. Spray lines and rain guns may be used, but these have to be moved frequently to prevent ponding and, because of the higher trajectory of sludge from this type of equipment than from downward sprays on tankers, greater care is needed to prevent offensive aerosol or spray drift contamination of adjacent buildings and roads, particularly in strong winds.

3.25 Sludge cake may be applied to land by conventional farm manure spreaders. The spreading tends to break down the larger lumps and cultivation of the soil assists incorporation.

3.26 From the farmers' point of view uniform spreading of sludge is essential to avoid undesirable variations in crop growth which may lead to financial loss. Uniform spreading is achieved through training, careful operation and the use of efficient equipment.

Legislation concerning sludge disposal to land

3.27 Part I of the Control of Pollution Act 1974 requires the licensing of sites for the deposition of sewage, which is taken to include sewage sludge, except where this is deposited inside or outside the curtilage of a sewage treatment works as an integral part of the operation. Land receiving sewage sludge for agricultural purposes is exempt from licensing.

3.28 Licences for sites for the tipping of sewage sludge or screenings are issued by the county councils in England, district councils in Wales and district or islands councils in Scotland. These licences may be subject to conditions relating to work plan, quantities, analyses, record-keeping etc, and subject to the provisions of the Town and Country Planning Acts, 1971 (England and Wales) and 1972 (Scotland), under which objections to the disposal of sewage sludge on other than sacrificial land may be raised on the grounds of a 'change of use'. Disposal plant and equipment used for the tipping of sewage sludge may also be subject to authorisation by licence. Charges may be levied by tip-owners for the reception of sewage sludge.

3.29 Section 91 of the Public Heath Act 1936 (England and Wales) and Section 17 of the Public Health (Scotland) Act 1897 place a duty on local authorities to undertake periodic inspections of their districts for the detection of statutory nuisances. Sludge disposal operations could possibly be affected by this provision. Where nuisance is established the local authority must serve an abatement notice. Under the Public Health (Recurring Nuisances) Act 1969, where deposits of sludge, pollution of water or odour emission are a nuisance or prejudicial to health, a local authority may serve notice on a person responsible, or owner or occupier where the party responsible is not identifiable, prohibiting further nuisance.

3.30 Sewage sludge is not a material prescribed as a fertilizer in regulations of the Agriculture Act 1970 and may therefore be sold as a fertilizer without statutory obligations to define its nature, substance or quality. However, regard has to be taken of requirements of the Sale of Goods Act 1893 and the Trade Descriptions Acts, 1968 and 1972.

3.31 Exception may be given to heavy vehicles used by water authorities in pursuance of their statutory duties in any order made under Section 9 of the Road Traffic Regulation Act 1967 amended by the Transport Act 1968, Schedule 19 of the Local Government Act 1972, the Heavy Commercial Vehicles (Controls and Regulations) Act 1973 and the Road Traffic Act 1974.

3.32 Reference should be made to the report of the Sub-Committee on the Economics of the Disposal of Sewage Sludge for further information on the legislation relating to sludge disposal to land.

4. THE EFFECTS OF SEWAGE SLUDGE DISPOSED ON LAND

Potential beneficial effects

General

4.01 When farmers apply sewage sludge to their land it is in the expectation that they will obtain better crops or make savings in the cost of fertilizers or lime which would otherwise have to be used. Increased yields come mainly from nutrients, especially nitrogen and phosphorus contained in sludge, although in some circumstances the addition of organic matter to the soil is beneficial. Other nutrients found in sludge, such as potassium, magnesium and trace elements may also be beneficial to crops and the added lime in some sludges can be useful in raising soil pH levels.

4.02 The practice of recycling essential nutrients which would not otherwise be usefully employed is a beneficial one which may help to conserve raw materials and energy. The use of sewage sludge for crop production fits in with this concept.

4.03 It was estimated that in 1975 about 44 per cent of the total sewage sludge produced in the UK was utilised in agriculture and this contained about 24 000 tonnes of nitrogen, 18 500 tonnes of phosphorous (as P_2O_5) and 1 950 tonnes of potassium (as K_2O). These amounts as percentages of the nutrients in chemical fertilizers used in agricluture were approximately:

Nitrogen	2.5 per cent
Phosphorus	5.0 per cent
Potassium	0.5 per cent

4.04 The actual savings in chemical fertilizer nutrients are difficult to assess but they will be smaller than the above potential savings because not all the nutrients in sewage sludge are available to crops in the growing season following application and some, particularly nitrogen, are lost when sludge is applied in autumn and winter. Although on a national basis the savings are small, some farmers can satisfy at least their phosphorous fertilizer need by using sewage sludge.

Nitrogen

4.05 Experimental comparisons with fertilizers have shown that, both in terms of nitrogen uptake and dry matter yield, the effect on the first crop of the nitrogen in liquid digested sludge after application at the optimum time is 65 to 100 per cent of that produced by fertilizer nitrogen (Coker E G 1966). A figure of 85 per cent is commonly accepted as average. For undigested and dewatered sludges it is often assumed that only about 30 per cent of the nitrogen becomes available to crops in the first growing season after application (Garner HV 1966). However, some recent work on grass has suggested that nitrogen availability, particularly in dried digested sludge, may be lower than the currently accepted percentages above. More research is needed on this subject.

4.06 Where sewage sludge cake is applied to land over successive years, the apparent availability of added nitrogen will increase with time because the immediate effects from the small amount of soluble nitrogen in the cake will be supplemented by residual effects from the decomposition of organic matter added in previous applications of sludge cake. Some losses may occur however by leaching, especially under arable conditions, and possibly also by denitrification. Most of the nitrogen in liquid digested sludge, being in the water phase, is immediatley available to crops and the residual effect from previous applications is negligible.

Phosphorus

4.07 Information on the availability to crops of phosphorus in sewage sludge is limited but, based on a report by Bunting (1963), it is usually assumed that in the first growing season after application it is about half to two thirds as effective as a similar amount of water soluble phosphorus applied in fertilizer. However, Johnston (1976) found that when regular sludge dressings maintained bicarbonate soluble phosphorus in soil above 25 mg/l, this phosphorus was as effective for crop growth as a similar amount of soil phosphorus derived from fertilizers.

Potassium

4.08 The amount of potassium supplied in sewage sludge at normal application rates is negligible. For crops with a high potassium requirement, such as root and other vegetables and grass for conservation, fertilizer potassium is applied in addition. In systems such as grazed pastures much of the potassium requirement is provided through recycling by livestock and the potassium supplied by liquid digested sludge may be sufficient to maintain fertility except on potassium-deficient soils.

Calcium

4.09 Where sludges have been limed they can be used as a source of calcium for crops and to correct acidity in soils of low pH value, but over-liming can reduce the availability of nutrients.

Trace elements

4.10 Sewage sludge contains higher concentrations of several essential trace elements than are found in most soils and applications of sludge can help to maintain adequate levels of some elements in the soil. The most important trace element deficiency affecting crops in Britain is that of manganese. However, sewage sludge usually contains very little manganese and deficiencies, which are generally pH related, are not normally corrected by applications of manganese compounds to the soil. In some areas and seasons copper and boron deficiencies may occur. Sewage sludges rich in copper may be used for the correction of copper deficient soils and most liquid sludges at normal application rates will supply sufficient boron for the crop requirements even under deficiency conditions.

4.11 Most trace element deficiencies in livestock are corrected by direct treatment of the animals involved rather than by soil dressings. Cobalt deficiency is a major exception but concentrations of cobalt in sewage sludge are usually too low to be of benefit on cobalt-deficient land.

Organic matter

4.12 Organic matter is a valuable component of the soil where its acts as a source of nutrients for crops and has beneficial effects on structure, water holding capacity and other physical characteristics which can affect cropping capacity. The break-down rate depends on soil texture, soil pH and the cropping system used. In grassland there is a tendency for soil organic matter levels to increase until, after a long period, equilibrium is reached. Under very acid or wet conditions the rate of biological breakdown is low and the increase in organic matter continues. A peaty layer may form at the surface.

4.13 Soil organic matter levels can decline on farms without livestock where a high proportion of root and vegetable crops are grown, especially if the crop residues are removed, but in rotational farming, where arable crops alternate with grass and where animal manures are used, soil organic matter levels are usually quite adequate.

4.14 Application of organic matter in addition to fertilizers is more common on market gardens with intensive vegetable production than on farmland as it is necessary to maintain soil structure which can affect crop yields. This is best achieved by returning crop residues and adding organic matter such as farmyard manure. Sludge cake can supply significant amounts of organic matter to the soil, but liquid sludges applied at normal rates will not usually have any noticeable effect on soil organic content.

4.15 Heavy applications of sewage sludge over many years may completely alter the characteristics of a soil and may convert a mineral soil to an organic one, with the result that the general agricultural value of the soil may be improved and a greater range of crops may be grown. However, increases in the metal content of the soil, discussed later, may occur concurrently and nullify these beneficial effects. It has been suggested that crops may tolerate higher concentrations of metals in the soil when the soil cation exchange capacity (CEC) has been increased by the addition of organic matter. Chelation of the metals by organic matter may reduce the availability to crops.

Economy

4.16 An important benefit from the disposal of sewage sludge on land and one which has a major influence on the selection of this option is the financial saving to the community. If all the sewage sludge that is currently applied to agricultural land was to be disposed of by other means there would be some increase in expenditure on fertilizer and probably a substantial increase in the cost of sewage treatment and sludge disposal.

Potential adverse effects

General

4.17 If sludges are applied to land carelessly or indiscriminately there may be adverse effects such as physical nuisances, spread of disease or pollution of water sources. Also soils may be contaminated and this may affect crop yields or result in toxic residues in crops. With proper precautions and care in treatment, handling application and monitoring, such effects can be avoided or kept to acceptable levels.

Nuisance

Direct physical contamination

4.18 Direct contamination of buildings, roads, footpaths and growing crops can occur, particularly when drift of spray or aerosols is aggravated by strong wind in an unfavourable direction, unless suitable margins are allowed around land receiving sludge.

Smell

4.19 Raw sewage sludge is more likely to give cause for complaint when applied to land than digested, lime stabilised or dried sludges, but the odour from sewage sludge can be reduced by cultivation immediately after spreading on arable land. Odour problems tend to be worse in warm weather and during atmospheric inversion conditions or when winds are light and smells are not readily dispersed. Safety margins allowed between sludged areas and buildings and roads to prevent direct spray contamination may on occasion need to be increased to avoid odour nuisance.

Flies

4.20 Nuisance from flies can sometimes occur following field application of sewage sludge. The problem is most likely to occur during and after spreading of raw sludge if it is allowed to remain on the soil surface in pools or thick layers. Precautions taken to avoid complaints of odour from sludge disposal operations normally prevent fly nuisances.

Water contamination

Direct contamination

4.21 Contamination of underground water is likely to occur only if sewage sludge is applied to land in situations where an aquifer is close to the surface or is in highly fissured rock.

4.22 Contamination of watercourses is best avoided by leaving adequate margins, dependent on the method of application, between the land being sludged and the watercourse. On coarse-textured, well drained soils liquids soak in rapidly but on heavy, poorly drained soils percolation is slower and run-off to streams is more likely, particularly if the land is steeply sloping. The risk of run-off is increased if sewage sludge is applied to soils which are at field moisture capacity or where the surface is deeply frozen or sun-baked.

4.23 In severe drought, soils with a heavy clay content become cracked to a considerable depth and if such land is tile-drained, applied sludge, especially of low solids concentration, may run down to the drains and reach a watercourse.

Contamination with nitrate

4.24 There may be a possible risk of nitrate contamination of aquifers such as chalk, some limestones and sandstones. Contamination of rivers may also occur from nitrate in water draining through the soil.

4.25 Nitrate is produced in soils from mineralisation of organic matter, from nitrogen fixation by symbiotic and free living bacteria, from precipitation and from applications of fertilizers, manures and sewage sludge. Nationally, sewage sludge is a minor source of nitrate contamination.

4.26 Production of nitrate is more rapid from liquid digested sludge than from other types of sludge. The risk of water pollution from nitrate is at its greatest following autumn applications of digested sludge to arable land when the soil remains warm enough for nitrification to take place and when there is usually no crop present to utilise the nitrate. Bacterial nitrification ceases in winter when soil temperatures are low and in the spring and summer problems are unlikely to occur if sludge dressing rates are related to the nitrogen requirements of the crop. Grass continues to take up nitrates during the autumn until the soil temperatures fall, so losses from grassland to underground water are negligible under most conditions. Nitrate losses do occur to some extent in high rainfall areas but dilution keeps nitrate concentration low in the groundwater.

Soil contamination—nitrate

4.27 Excessive nitrate concentrations in crops may be harmful to animal and human health, but no problems should arise from the use of sewage sludge as a source of nitrogen if dressings are related to crop requirements.

Soil contamination—toxic metals

Solubility of metals

4.28 There is at present no certain way of predicting the metal uptake by crops from the 'total' metal analyses of soil. Attempts have been made to relate crop uptake and the 'extractable' metal analyses of soil, but these have met with varied success because the amounts of metals assimilated by crops depend on the plant, soil, metal and its form and the extractable determinations depend on the reagent used. Metals exist in different chemical forms in the same sludge or soil and reagents, such as 0.5 M acetic acid and 0.05 M ethylenediaminetetra-acetic acid (EDTA), used to determine extractable metal contents, tend to discriminate in the form of the metal extracted. Strong extractants dissolve most of the different forms of metals and are used for total metal determinations in a sample. Zinc, copper and nickel are relatively soluble in the weaker solvents, while other metals such as lead and chromium have a low solubility except in strong solvents.

Effects on crop yield

4.29 Adverse effects of sewage sludge on crop yield may become apparent in the short term if crops are sown immediately after sludge application or in the long term only after many years of sludge application.

4.30 The short term effect has been noted in some experimental work where heavy dressings of sewage sludge were applied and crops sown immediately afterwards, resulting in poor germination of seeds and reduced early growth of the crop (Webber J 1972, Jones R L et al 1973). This may be due either to salinity effect caused by high concentrations of soluble salts present in the sludge or to the presence of excessive amounts of some ammonium compounds which, in alkaline conditions, release ammonia to the soil. Inhibition of growth may also, under anaerobic conditions, be caused by methane. These effects are unlikely to occur at normal rates of application and with heavy rates can be avoided by allowing an interval of about two weeks between sludge application and seed sowing.

4.31 It has been demonstrated experimentally (Webber J 1972) that phytotoxic effects from metals can appear after single very heavy applications of sewage sludge, equivalent to 100–200 tonnes per hectare dry solids. In practice, sludges with high metal contents would not be used and rates of application in terms of dry solids would rarely exceed 5 tonnes per hectare for liquid sludges or 20 tonnes per hectare for sludge cake and phytotoxic effects in crops are not likely to appear until many applications have been made. These effects first became apparent from patches of poor growth followed by a gradual decline in crop yield varying from year to year with few obvious visible symptoms. Experience by MAFF prior to 1971 (ADAS.10.) indicated that yield reductions could occur in some crops when the level of extractable metals in soil exceeded 250 mg/l zinc equivalent. Subsequent experiments (Marks, Williams and Chumbley 1977) have indicated that loss of crop yield may occur in some circumstances with levels lower than this, but Davis R D (1979) quoted, for a range of crops, phytotoxic threshold levels of 440 to 900 ppm available zinc equivalent in soil. The extractable zinc equivalent in uncontaminated soils is usually below 15 per cent of the total and frequently close to 1 per cent, but Wood, King and Norris (1978) reported that the extractable zinc equivalent of sludge amended soil in an area to the west of London was typically 45 per cent of the total. The chemistry of metals in sludge and sludge amended soil is very complex and much work remains to be done on the subject. The effects of metals in soils on crop yield, as on crop up-take, depend on a number of factors which are discussed in the following paragraphs. Adverse effects on growth from cadmium, lead, chromium, mercury, boron and molybdenum have not been demonstrated in the field, although experimental work with metal salts has shown cadmium to be much more phytotoxic than zinc (Webber J 1972).

Uptake of metals by crops

General

4.32 Elements such as cadmium, zinc, copper and nickel are toxic to crops if their concentrations in soils are raised to high levels. With some, such as cadmium, there is a risk of toxicity if excessive amounts are absorbed by crops to be consumed regularly over long periods by animals or humans. Cadmium is normally present in soils at low concentration, under 1 mg/l, and although that present in sludge is usually at low level it is of concern in relation to the long-term addition to agricultural soil.

4.33 Uptake of metals by crops depends on a number of factors. It is now well known that different crop species (John M K 1973) and even different cultivars of the same crop (John M K 1976, Bagchi S 1976) have different capacities to absorb and translocate metals, and this has been investigated especially for cadmium and lead (John M K 1976 and 1977). Generally, the faster growing crops take up metals more readily. Doyle, Lester and Perry (1978) quoted cadmium concentrations of up to 28 mg/kg in lettuces grown on sludge treated soil containing up to 16 mg/l of cadmium. Page, Bingham and Helson (1972) reported that uptake of cadmium by lettuces from solutions containing cadmium was directly proportional to the cadmium concentration. This has been supported by Wood, King and Norris (1978) who found from field scale work at Perry Oaks that there appeared to be a linear relationship between lettuce leaf concentration and both the total and ammonium acetate extractable cadmium in sludged soils.

4.34 Work on strains of certain grasses able to tolerate high levels of zinc and other metals in the soil has shown that, in some cases at least, this tolerance is carried genetically and can be transferred by breeding to other strains (Simon E 1977). In general, roots contain much more metal than leaves, and the lowest concentrations are usually found in seeds. Elements vary in their mobility within the plant; cadmium and zinc move more readily into the shoots than chromium and lead which are scarcely translocated at all.

4.35 Little is known of the forms in which metals occur in soils, but in the short term, the effects of metals on plants depend on the form in which they are added, so experiments with simple salts may not be completely relevant in relation to the use of sewage sludge (Cunningham et al 1975). In the long term the effects will be similar whatever the metal source and will depend largely on soil characteristics.

Effect of soil reaction on metal uptake by plants

4.36 The availability to crops of trace elements in soils is markedly affected by soil reaction (Anderson & Nilsson 1974). Soil pH values in Britain are in the range 3.8 to 8.3 although, at the lower end of this range, growth of most crops is reduced or even prevented by acidity effects, such as the excessive absorption of manganese or aluminium. The recommended pH value for arable crops is 6.5 although many soils, especially in eastern and southern England, have higher values than this due to their derivation from calcareous parent materials or to liming. In the west and north soils tend to be more acid because of their different origin, and because of the generally high rainfall which leaches calcium and magnesium. Also grassland occupies a larger proportion of the land in these areas and it is customary to maintain soils under grass at pH values of around 6.0, which has been found to be optimal for the growth and mineral composition of herbage (Bolton J 1975).

4.37 The availability of most elements is reduced as the soil pH rises, although molybdenum and selenium are exceptions and become more available to plants at higher pH levels. High pH values, which may be necessary to reduce availability to crops of other elements, will only aggravate the position as regards molybdenum which may then be taken up by herbage in amounts harmful to grazing livestock (Lahann R W 1976). Sewage sludges with high molybdenum contents are uncommon, but if any of these are to be utilised on grassland, special consideration needs to be given to pH and soil reaction.

Effect of soil cation exchange capacity and organic matter on uptake of metals by crops:

4.38 It has often been suggested, and American workers (Chaney 1975, Haghiri 1974, Latteral 1976) in particular have put forward the view, that soils with high cation exchange capacity (CEC) can safely accept larger amounts of toxic metals than can soils with low CEC. For a specific pH value, soils with higher CEC contain larger amounts of exchangeable calcium and magnesium so that a smaller proportion of their total capacity to absorb cations is used by a given addition of metals. The CEC of a soil depends on its organic matter and clay contents and on the types of clay minerals present. Under arable conditions mineral soils usually contain 2 to 5 per cent organic matter, the amount varying with the farming system and the soil texture. Grassland soils may contain up to 10 per cent or more and peaty soils can have more. While it is possible that the effect of added organic matter in reducing phytotoxicity of added metals is due to the resultant increase in CEC, it is more likely to be due to the formation of chelates, which may be insoluble, making the metals unavailable to crops in the short term. The two effects are difficult to separate.

Interactions between metals

4.39 When several metals are added at the same time, as is usual with sewage sludge applications, interaction between them may occur. It may be assumed for convenience that phytotoxic effects of zinc, copper and nickel are additive. Some experimental work with metal salts tends to confirm this, at least where the metal concentrations in the soil are high. Other work (Marks, Williams and Chumbley 1977) has suggested that the comparative toxicities of zinc, copper and nickel may vary with soil type and crop species.

4.40 Attention has often been drawn to interactions between zinc and cadmium. In animal nutrition high concentrations of zinc appear to reduce the effects of cadmium but evidence of similar interaction in the soil is conflicting. Some experiments have shown that cadmium uptake by crops is reduced by zinc, and others the reverse; the effects obtained appear to be related to the actual rates of application (Webber J 1977).

4.41 The interaction between copper, molybdenum and sulphur appears to be of importance in animal nutrition, but the matter of interactions between elements is a complex one and not yet fully understood.

Effects on human health

4.42 Direct ingestion of sludge or sludge amended soil is only likely to be a problem with a few small children. In this connection lead is the metal of most concern and the Sub-Committee supports the restriction in the Working Party guidelines on the maximum lead content in sludge to be applied to land.

4.43 Of the metals which may be taken up by crops from the soil, cadmium gives most cause for concern. The average dietary intake of cadmium in the UK is about a quarter to a third of the provisional tolerable weekly intake of 400 to 500 μg suggested by the World Health Organisation and any increase is undesirable. Leafy vegetables and fast growing crops tend to take up the most cadmium and occasionally very high cadmium contents (over 20 mg/kg in the dry matter) have been recorded following the long continuous use of sewage sludge (Webber J 1978). In particular some small groups of people who consume large amounts of produce grown locally in heavily contaminated soil may be most at risk. Cadmium levels in other crops, such as cereal grains, grown on contaminated soil may be raised, but to a lesser extent than in leafy vegetables. Grain is however normally milled in bulk so any supplies with increased cadmium contents are diluted with grain containing lower concentrations but, because it constitutes a much larger proportion of the total diet than vegetables, any general rise in cadmium content in cereals is undesirable.

4.44 In relation to human health, uptake of other elements by crops does not at present give much cause for concern. Recent results have suggested that some vegetable crops, grown in soils where the lead content has been increased by the use of sewage sludge, contain above-normal levels of lead and further study is needed in this connection. The accumulation of toxic metals, especially mercury, by edible fungi could also affect limited sections of the population. The significance of American studies showing high levels of tin and antimony in certain organs of animals fed on crops grown on sludge-treated land still has to be assessed (Furr 1976).

Effects on animal health

4.45 The contamination of soil with metals from sewage sludge applications is likely to have only relatively small effects on animal health. These could arise in two ways:

1. by direct ingestion of either sewage sludge lying on herbage or the soil, or of metal-contaminated soil; and

2. by consumption of foods containing high levels of metals absorbed from the soil.

4.46 Grazing animals unavoidably ingest soil, commonly a few per cent of their intake of herbage dry matter. Where sludge is applied to grassland, elements added will be largely retained in the surface layer of soil which may after some years contain high concentrations. Use of sewage sludges with high concentrations of lead, cadmium, mercury, molybdenum and fluorine present a possible risk in this respect. Work in the United States has shown that some grasses, notably tall fescue, retain surface contamination from sewage sludge for a long time after application in spite of further growth and the action of rain (Chaney et al 1976). As a result metal levels in grass samples were much higher than would be expected. This effect needs to be examined on the new growth of grass, since under British conditions sludge is usually applied to short grass after grazing or cutting.

4.47 Lead and mercury, the elements most likely to cause acute toxicity in animals, do not appear to be translocated by plants into leaves and shoots to any extent so problems are unlikely to arise from high concentrations other than those due to direct contamination. Cadmium however, is translocated and, although grass usually takes up less than most other crops, levels may be increased to well above normal by heavy applications of sludge containing a high concentration of the element. The effects of cadmium on animals, as on man, are likely to be long term and in most cases little or no effect would be seen during their, usually rather short, lifetime.

4.48 A copper rich diet can cause toxicity in some animals, particularly sheep and lambs. However, copper deficiency is a widespread problem, particularly in pasture areas where the natural level of molybdenum in the soil is high or has been increased by the addition of excessive molybdenum in sewage sludge. The availability to crops of molybdenum applied in sludge to land is still uncertain, but evidence from the DOE research plots at Cassington suggests that it is readily taken up by grass and that monitoring of the effects of molybdenum added in sludge on the levels in herbage may be required in some circumstances. Consumption of herbage, sludge or soil with a high molybdenum content by animals has the effect of reducing their copper absorption and this can lead to a serious loss of body weight and ill health. A level of 2 mg/kg of molybdenum in herbage dry matter is usually regarded as indicating a need to consider whether remedial measures, such as copper injection into stock, may be required. Research on the up-take of molybdenum by herbage is in hand.

Persistent organic compounds

4.49 Persistent organic compounds may find their way into the human food chain by direct contamination of crops, uptake and translocation from the soil and ingestion by grazing animals.

With heavily contaminated sewage sludge problems are more likely to arise from its use on pasture than on arable land. Organohalogens in the sludge adhering to herbage may be ingested by grazing animals and concentrated in fatty tissues and also excreted in milk. A recent MAFF survey of organohalogens in milk from cows grazed on pasture which had received sewage sludge showed that the levels were undetectable or very low in all but one sample. The possibility has been suggested that crops grown for oils such as seed rape or linseed, at present minor crops in the United Kingdom, may absorb organohalogen compounds from the soil and store them in the oil. In view of the possible risks a proposal has been made in the United States to limit total PCBs to 10 mg/kg of dry solids in sewage sludge to be applied to agricultural land. Concentrations as high as this are not found in UK sludges (Table 3). Persistent herbicides have been detected in sewage sludge in some areas, mainly where they are produced.

Risk of infectious disease

General

4.50 The potential for infection depends on, among other factors, the total numbers of pathogenic organisms present. The numbers of viable organisms reduce with time but very low numbers of parasite eggs or viruses may have the capacity to transmit infection. Although there is epidemiological evidence that infection of man and cattle can result from contamination of water, feed or pasture with crude sewage, there is no evidence to suggest that sewage sludge used in accordance with good practice presents a health hazard. Providing the recommendations in this report for its use in agriculture are followed, the possibility of disease being transmitted by sewage sludge is very small.

Salmonellae

4.51 As seen in paragraphs 2.39 to 2.47, sewage sludge contains a number of pathogenic bacteria; important among these are the *Salmonella* serotypes. The numbers and types of salmonellae in sewage sludge vary widely with the type of sludge and any included trade wastes, the size of contributing populations and the method of sludge treatment. After sludge is applied to pasture salmonellae die off rapidly in the first few days, particularly when the sludge is spread thinly and the weather is sunny, but survival on soil commonly persists for 4 or 5 weeks and considerably longer when the sludge does not dry.

4.52 Experimental work (Institute for Research on Animal Diseases 1977) in which *Salmonella dublin* was fed to healthy 10—12 months old cattle has shown that ingestion of very large numbers was required to produce disease. It was concluded that prolonged ingestion of a diet heavily contaminated with sewage sludge would be unlikely to cause disease, although the possibility of infection of especially sensitive animals could not be excluded. It is unlikely that even if cattle were to be grazed on pasture within a few days of its dressing with sludge containing salmonellae, the level of ingestion would be high enough to cause disease, but the no-grazing periods recommended by the Working Party provide safety margins.

4.53 Salmonellae whether from contaminated feedstuffs, farm slurry or sewage sludge can be carried in the gut or on the skin of healthy animals, and subsequent contamination of milk or slaughterhouse meat is possible. Consumption of unpasteurised milk can be a significant cause of human salmonellosis in those areas where it is available. The risks to man of *Salmonella* infection from the utilisation of sewage sludge are largely, if not fully, prevented by precautions against the contamination of potable water, milk or crops to be eaten raw.

Brucellae

4.54 *Brucella* has little chance of surviving in sewage sludge and is certainly destroyed by mesophilic digestion and by lime treatment but if deposited on pasture may survive there for about two months. No case of brucellosis has been attributed to the use of sewage sludge on pasture, but a risk could be created by the application of a sludge containing significant quantities of material derived from infected slaughterhouse wastes.

Anthrax

4.55 MAFF has statutory responsibilities for anthrax and investigates all reported outbreaks. These investigations have incriminated animal feeding stuffs and hides imported from countries where the disease is endemic, but no case has been attributed to the use of sewage sludge in agriculture.

Parasitic worms

4.56 The parasitic worm of most concern in the utilisation of sewage sludge in agriculture is the beef tapeworm, *Taenia saginata.* The pig tapeworm, *Taenia solium* is, of greater importance medically as both the eggs and larval form are infective to man and the infection can be serious and even fatal but fortunately cases are almost unknown in UK. A person infected by tapeworm can pass many thousands of eggs per day which may find their way on to pasture via sewage sludge or by other faecal contamination. It has also been shown that birds feeding at sewage treatment works can carry single eggs or worm segments containing eggs on to pasture which may infect cattle or pigs. The control of the route of infection via sewage sludge would not therefore eliminate the problem. Tapeworm eggs have been found to be viable for up to 12 months on pasture, but most workers have reported a usual viability of up to 6 months with an increasing number of eggs surviving for shorter periods. Periods of viability are reduced in prolonged dry weather conditions.

4.57 Eggs of *T. saginata* ingested by cattle develop into cysts known as *Cysticercus bovis* and those of *T. solium* ingested by pigs develop as cysts known as *Cysticercus cellulosae.* Eggs of the beef and pig tapeworms do not cross-infect or develop in other animals. When cysts are detected by meat inspection at slaughter, the heavily infected carcasses are condemned, but in cases of light infection, which are more difficult to detect, the meat is frozen to kill the cysts. In undetected cases the life cycle may continue unless the meat is adequately cooked before human consumption.

4.58 The number of cases of *Taenia* in humans recorded by the Public Health Laboratory Service in 1977 was only about 100, but the disease is not notifiable so the true incidence is unknown although it is thought to be low. The incidence of *C. bovis* in cattle in the UK is low and, as is shown by abattoir statistics from a sample of about one in six abattoirs, has declined generally over recent years to about 0.05 per cent. In 1977 there was an increased proportion of heavily infected carcasses (Crewe and Owen 1978) and, according to the district returns to the Environmental Health Officers' Association, the total incidence was 3337 (0.12 per cent of cattle slaughtered). In certain outbreaks of *C. bovis* cattle had been allowed to graze immediately or soon after sewage sludge had been applied to pasture. Compliance with recommended no-grazing periods will greatly reduce the possibility of risk of infection from sewage sludge and help to preserve its standing as a beneficial material. Grazing restrictions during the period when cattle are housed, (usually from November to April) create little restriction on a farmer's freedom of action, and at other times if the sludge has not received one of the recommended treatments (see 6.10) the land may be utilised for conservation crops, such as hay or silage, before grazing.

4.59 Infection of man by *Ascaris,* another parasitic worm, is usually contracted through inadequate hygiene and not, as far as is known, directly from the use of sewage sludge in agriculture in accordance with accepted good practice. The spraying of sludge carrying *Ascaris* eggs on to crops to be eaten uncooked could cause the infection of man. The species of *Ascaris* infecting man and pigs respectively do not cross-infect, so that eggs derived from human infection do not pose a hazard for pigs, and *vice versa.*

Viruses

4.60 Viruses occur widely in waste waters and are found in sewage sludge, but there is no evidence to prove or disprove that human or animal viral disease has been transmitted through the application of sewage sludge to farmland. Many viruses are host-specific and viral diseases which they cause are not passed from one animal species to another or to man. Many can survive in soil for 6 months and more in cold weather but the die-off is generally rapid in warm weather. Although viruses may be found on the surface of vegetables grown on sludge-treated soils they are unlikely to penetrate to the tissues unless the vegetable skin is damaged (Larkin et al 1976). The cooking of vegetables inactivates viruses.

Transmission of weeds and crop diseases

4.61 In general, transmission of weeds by sewage sludge is not a serious problem. Sewage sludge may contain a wide range of viable weed seeds which are not affected by the normal treatment processes. In most cases, crop weeds, such as tomatoes, which appear following sludge application will be easily controlled by the normal herbicide treatment although sometimes at extra cost to the farmer. Problems are only likely to occur when herbicide use is limited, for crops such as brassicas, and where the crops are grown in such a way that control cannot be effected by inter-row cultivation. Tomato plants are poisonous to stock animals, whereas almost any other common weed growing in fodder crops, such as kale, may be fed to stock without harm. So far as is known, crop diseases are not transmitted by sewage sludge.

Pests in crops

4.62 Potato cyst nematodes (PCN) can persist in the soil for long periods and multiply in host crops but a high proportion die within about 8 years (ADAS). They are not found widely in sewage sludge and when they do occur they usually appear in small numbers, sometimes below the detection limit. PCN are resistant to some sewage treatment processes, although numbers are greatly reduced by heated anaerobic digestion. (Southey and Glendinning (1966) showed 100 per cent kill in 20 days). Determination methods for PCN in soil are well established and a method for counting low numbers of cysts and viable eggs is being evaluated. There are strict regulations governing the export of potatoes, bulbs and nursery stock to the EC and some other countries, and certification is required that the soil in which they were grown is free from PCN.

Soil structure problems

4.63 Soil is a mixture of mineral and organic matter with air and water and has a complex structure. Even at field moisture capacity soils contain appreciable amounts of air which is essential for biological activity and plant growth. Soil structure problems increase as moisture content increases. For example bearing strength decreases as the soil gets wetter and the passage of heavy machinery can reduce pores and cracks or create ruts which can fill with water and dry out very slowly. Under arable conditions problems of these kinds can usually be remedied later by suitable cultivation but they are better avoided as they may affect the yields of subsequent crops and involve the farmer in additional costs. Problems are more likely in soils with high contents of clay and silt.

4.64 Rain guns are often used for spreading sewage sludge on land particularly when conditions are too wet for tankers. Damage may be caused to the surface structure of bare cultivated soils by continual impact of large droplets and by ponding but these problems are avoided by frequent movement of the guns.

Traffic

4.65 It is inevitable that increased traffic arising from a sludge tankering operation must have some small detrimental effect on the environment but this may be kept to the minimum by careful planning and management.

5. OPTIMISATION OF SLUDGE TO LAND DISPOSAL PRACTICE

General

5.01 Optimisation of the practice of disposing sludge to land requires the balancing of economic, health and environmental considerations.

5.02 The guidelines included in the report of the Working Party on the Disposal of Sewage Sludge to Land (1977) were directed towards improving this balance. It was inevitable that these guidelines were criticised by some disposal authorities for being unnecessarily strict and by some environmentalists for being too lax. However a broad acceptance emerged that they were practical recommendations with safety margins that, in the light of available knowledge, provided protection for the well-being of crops, animals and man. Some refinement might follow as more information became available. As the first comprehensive guidelines in the United Kingdom, they made a major contribution to good practice in the disposal of sludge to land; they stimulated thought, research and positive practical steps to improvement.

5.03 Some countries have introduced more restrictive guidelines. It is important that any new restrictions should be fully justified by adequate evidence, not least because the economic consequences of major changes in sludge disposal practice could be very severe.

5.04 The water authorities have already declared their intention of working towards compliance with the Working Party guidelines, even though complete compliance was not immediately possible in all situations. The UK probably disposes of more sewage sludge per head of population than any other country and in most cases this is dealt with effectively, economically and with little impact on the environment. There are, however, local situations where improvement is needed, where undesirable effects have occurred and where problems may arise in the future if current practices are continued and, because of this, there is concern that the best possible guidance on sludge disposal to land, based on the latest research and experience, should be made available and followed.

5.05 Since the drafting of the Working Party report, the Sub-Committee has received information that in some situations crops have been grown satisfactorily where heavy metals have been added in sewage sludge to soils in amounts considerably in excess of those recommended in the Working Party guidelines, but also in other situations metal concentrations in soils have been raised permanently to high levels and in a few cases crops have suffered or taken up undesirable amounts of metals. In reviewing the Working Party report and in the course of its own investigations, the Sub-Committee acquired an appreciation of the water authorities' sludge disposal problems and of the considerable progress made since the re-organisation of the water industry in the rationalisation and improved control of disposal operations. At the same time the Sub-Committee strengthened its understanding of the problems facing agriculturists in accepting sewage sludge on land and it has instigated research work which should lead to improvements in this practice and the protection of the environment.

Economy in sludge disposal to land

5.06 It is incumbent on water authorities to dispose of sewage sludge at the lowest cost compatible with the avoidance of harm or nuisance. Sludge treatment and disposal cost analyses by water authorities have shown that for inland works without reasonable access to the sea, disposal on land, particularly of liquid sludge, is often the cheapest option.

5.07 Although the cost of mechanically dewatering sludge is usually high this may show a saving where transport distances to final disposal would be great. Thickening liquid sludge can considerably increase the range over which transport is economical. Returned liquors from sludge dewatering and thickening may increase the biological load on the sewage treatment works.

5.08 Raw sludges can cause nuisance problems and they have lower immediately-available nitrogen contents than digested sludges but their disposal to land without treatment offers substantial economic advantage. Where odour from raw sludge is likely to be a deterrent to spreading on land, the use of equipment for direct injection into arable land may be an alternative to treatment. Sludge injection into grassland has not yet proved successful.

5.09 There is a continuing need to search for improvements in sludge treatment and disposal methods that may reduce capital and operating costs, which in 1978/79 amounted to about £160 million for England and Wales. Increased restrictions on disposal to land could have significant impact on costs and future strategy.

5.10 The production and transport of nitrogen fertilizers has a high energy demand and all phosphates have to be imported, so the contribution from sewage sludge to the national fertilizer requirement, though relatively small, is useful and can be of significant value to recipients. Any improvements in sludge quality or types available which enhance the general acceptability of sewage sludge will benefit both the disposer and user.

5.11 Many farmers are keen to take advantage of sewage sludge as a cheap source of nutrients and, in some cases, of organic matter or lime. Farmers are naturally reluctant to pay for sewage sludge and even when dried sludge products are purchased the revenue to the water authorities rarely covers the drying cost. In view of the saving in fertilizer to the farmer a charge could be justified, but to encourage sludge utilisation some water authorities provide sludge free or charge only for delivery and spreading with reduced rates in some cases when seasonal demand is low.

5.12 Sewage sludges with high phytotoxic metal contents, if spread thickly, can reduce crop yields and affect profitability. Thin spreading of such sludges will reduce these effects but then the crop nitrogen requirement may not be met and the overall cost may be increased. Outbreaks of *Cysticercus bovis* in cattle involve the owners concerned in financial losses and, if sewage sludge is the suspected cause, water authorities may be faced with finding other more costly disposal outlets.

5.13 Short-term storage capacity at the treatment works may avoid the necessity of resorting to alternative means of disposal, when, for instance, farmers are unable to accept sludge on their land. It may also provide a small reserve for meeting peak demands. It is usually uneconomic for farmers to finance the construction of storage lagoons for liquid sludge.

5.14 A sound commercial approach to the whole disposal operation is essential for minimum cost. This requires the careful selection of disposal sites, planning of routines, efficient vehicles and spreading equipment, adequate site supervision and record keeping and the establishment of good public relations by providing a beneficial service free from serious problems and by dealing with complaints with obvious willingness. The publication of articles in the local and farming press and the printing of general information on the nutrient and contaminant contents in the sludges offered will help to establish and maintain a dependable market.

5.15 The Sub-Committee, in formulating guidelines for the protection of agriculture and human health, has not lost sight of the need to take account of economic considerations and recognises that unnecessarily strict constraints on sludge disposal to land may use financial resources needed for other equally important aspects of environmental protection.

Protecting health

5.16 All parties bear a responsibility to protect crops, animals and humans from possible contamination by potentially toxic materials and from pathogens in sewage sludge. The practice of sludge disposal will be improved as more information becomes available on the effects of metals and toxic constituents in sludge applied to land and on the survival of pathogens through sewage treatment and on the land after application. It may be that, in the future, stricter limits of addition to the soil or limits of concentration in sludge will have to be recommended for some elements while, on the other hand, some current limits or precautions could be relaxed.

5.17 Where sewage sludges have high concentrations of toxic constituents emanating from industry, the levels may be reduced by trade effluent control. Organic contaminants such as organohalogens and some toxic elements found in sewage sludge derive almost entirely from industry, but other elements such as zinc, boron, lead and copper are found in appreciable quantities in sludges from domestic sources and, even though these may derive largely from consumer products, the extent to which they may be reduced is limited. Priority needs to be given to the reduction of cadmium in trade effluents, since under British conditions cadmium is believed to be mainly of industrial origin. However, published information (Klein L A et al 1974) on New York City's wastewater showed that the total cadmium contribution from the electroplating industries was significantly exceeded by the contribution from residential areas. Some of the cadmium from residential areas is likely to have come from surface drainage. Reduction of persistent organic constituents by trade effluent control is more difficult because of analytical problems and the consequent difficulty of monitoring levels in both trade effluents and sludge. In the case of organohalogens which may be transmitted by crops or animals to man, further efforts are needed to control their discharge to sewers.

5.18 To safeguard land for the future production of healthy, wholesome crops any increase in the heavy metal content of the soil must be limited and the amounts added in sewage sludge controlled accordingly. It is particularly important that where a sludge disposal operation does not accord with advice given in the guidelines the effects on crops should be monitored so that any possible indication of harm may be detected and corrective measures taken before serious effects can occur.

5.19 Few cases have been recorded of toxic effects in animals, such as reduced growth rate or milk production, arising from sewage sludge application to agricultural land, although in practice such cases are difficult to detect. One isolated case has been reported where stock was affected through the application to pasture of a high molybdenum content sludge at heavy rates over many years, and another where sludge with an exceptionally high fluoride content had been applied to land already contaminated by fluoride. However, there is a need to avoid problems arising, particularly through the ingestion of sewage sludge by grazing animals or small children.

5.20 There is a potential risk to human health from toxic contaminants in sewage sludge being taken up by crops and transmitted to man (Dowdy and Larson 1975). Cadmium accumulates in the liver and kidney and may cause serious long-term health effects, so its addition in sludge to soils must be strictly limited. Where supplies of sewage sludge to the general public are continued, only those with low cadmium content should be offered as there is no effective means of ensuring against excessive application rates (see 6.42). Other elements appear to present little hazard, although the effects of lead and mercury must be kept under observation. It is important that any toxic contaminants likely to enter the food chain are kept to the minimum and that those concerned with disposal, such as water authorities, are seen to pay regard to this in the application of sludge to land.

5.21 Except where heat or some other sterilising treatment is given, any sewage sludge may contain pathogens but, provided suitable precautions are taken, it may be used in agriculture with little risk of causing disease to crops, animals or humans. A number of sludge treatment options are available which have the effect of reducing pathogen counts and types and producing sludges which require fewer restrictions on use. Treatments such as liming, mesophilic digestion, long-term lagooning and dewatering/stacking are referred to in Chapter 2 and paragraph 6.11.

5.22 Pathogenic infection can affect milk production and the health and growth rate of stock, and the value of carcasses at slaughter can be reduced through infection by *Cysticercus bovis*. There is a need for more information on the survival of parasite eggs through sewage treatment processes and on the relationship between duration of exposure on pasture under various climatic conditions and their eventual inactivation.

5.23 The risk of spreading infectious diseases to humans through the utilisation of sewage sludge on land in accordance with recommended practice is believed to be very small. Precautions to reduce the risk of ingestion of viable tapeworm eggs by cattle or pigs, together with a high standard of meat inspection and adequate cooking of meat, will help to eliminate tapeworm infestation of humans.

5.24 Although no outbreaks of viral disease have been directly attributed to the use of sewage sludge on land, more information is needed on the survival of viruses in sewage sludge and on any potential risks from its utilisation in agriculture.

Protecting the environment

5.25 Contamination of the environment by the wastes of civilisation is inevitable and some contamination of the soil will occur through the direct application of wastes, atmospheric fallout, corrosion of metals and even through the dispersion of metals from the natural weathering of rocks. Contamination of the soil by toxic metals is virtually permanent and irreversible as only fractional amounts are removed by crops, leaching and volatilisation so there is a need to ensure that the disposal of sewage sludge on land does not add excessive amounts of metals which could lead to undesirable short or long-term effects.

5.26 There is need to avoid the creation of other environmental disturbances. With increased urbanisation, practices and conditions which were accepted and tolerated in rural communities become objectionable and give rise to complaints. Thus, heavy tanker traffic in built-up areas or unpleasant smells following sludge application are less likely to be tolerated near large towns or cities than in rural villages. Movement of urban population into villages near large towns aggravates the problem. These pressures may make sludge application to land more difficult to organise and carry out.

5.27 Where agricultural land is not available within economic transport distance from a sewage works, or where sludge is too heavily contaminated with toxic materials, tipping on authorised landfill sites may be the only other land disposal option. As tipping sites are usually carefully selected to avoid infringement of amenities, environmental problems are less likely to arise from tipping than from disposal on agricultural land. Where liquid rather than dewatered sludge is tipped, greater care is needed to avoid pollution of aquifers or streams used for water abstraction or sport.

5.28 Sewage sludge can play a useful part in improving amenities by supplying organic matter for the reclamation of derelict land. Top soil is costly and often in short supply for such purposes. Planning consents for gravel workings and other excavations increasingly include restoration clauses, and although only 7 per cent of the sludge disposed on land is at present used for reclamation, this could be extended. Heavier applications of contaminated sludge may be more acceptable on land to be reclaimed for most amenity purposes than on agricultural land.

5.29 Keeping District Environmental Health Officers informed on any unusual aspects of sewage sludge disposal will assist them in dealing with any questions that may arise.

6. RECOMMENDATIONS

General

6.01 The Sub-Committee has not found sufficient evidence to suggest major changes to the Working Party's provisional guidelines but it recommends minor amendments to the maximum permissible additions to agricultural land of boron and molybdenum and is introducing limits for fluorine and for the cadmium concentration in sludge supplied to the general public. It also recommends that metal additions should be related to background levels in the soil (see 6.24). The Working Party guidelines allowed applications of available nitrogen in sewage sludge of up to 50 per cent more than crop requirements where there was no danger of contaminating water sources, but the Sub-Committee takes the view that an arbitrary constraint of this nature is inappropriate (see 6.52).

6.02 The classification of sludges into the types, treated and untreated, adopted by the Working Party to indicate their suitability in regard to pathogen content for particular agricultural uses has been found inadequate as some intermediate sludge types or combinations cannot be placed clearly in either category. The Sub-Committee proposes, as general guidance, a classification of sludge types allied to a range of suitable agricultural uses, but makes the proviso that each case should be considered individually taking into account any special characteristics of the particular sludge and the site proposed for its application. In the light of present knowledge the Sub-Committee has recommended a longer no-grazing period following the application of lime treated sludge to pasture than for sludges having received treatment known to be effective in reducing the risks from *Taenia saginata*.

6.03 As a precaution against harm to crops and excessive uptake of toxic matter, the Working Party recommended maximum permissible additions of a number of elements likely to be found in sewage sludge to soils with normal background levels of those elements. These tentative recommendations were made in the light of the limited knowledge and analytical facilities available at the time, and they provided a practicable means of regulating sludge application to agricultural land. However, natural concentrations of metals in soils can vary considerably, with some soils already being contaminated and, as facilities for analysing soil are now far more widely available within most water authorities, the Sub-Committee recommends that soils should be analysed before sludge is applied in order to assess the maximum permissible application rates. Sludges should be analysed at regular intervals, the frequency of which would depend on any industrial effluents present, and receiving soils should be analysed from time to time over an extended period of sludge applications. Attention is drawn to the benefit of soil monitoring in augmenting information on the relationships between crop performance and the prevailing metal content of soils in field scale practice and in giving farmers confidence that operations are being carried out in accordance with good practice. Incorporation of sludge into soil is assisted by cultivation and cropping but it is difficult to obtain representative soil samples in the first year or two after sludge application.

6.04 Results of some experimental work are inconclusive and sometimes conflicting and it is still not possible to base all guidance on reliable scientific evidence but the following recommendations are founded on the best available data, experience and good sewage sludge disposal and agricultural practices. They are designed to prevent health problems arising from possible pathogenic and toxic metal contents of sludges applied to land and to protect crop yield, water supplies, amenities and wild life. It may not be feasible to conform to these recommendations in some situations at present-time and expenditure may be required for this — but all parties are urged to follow them, particularly where there is a direct relevance to human health, and to work towards a general compliance, monitoring effects where compliance is not possible.

6.05 Where conditions are substantially unusual or outside the scope of the recommendations, advice should be sought from specialist agricultural advisers. For instance, in many areas of Scotland agricultural and environmental conditions are somewhat different from those found in most other areas in the United Kingdom. As a reflection of their geological evolution, in association with incident climatic conditions, Scottish soils tend to be mainly acid. A high proportion of agricultural land is of moderate to low capability dictating a mainly grassland/livestock economy. There is a low percentage of land suitable for intensive arable and horticultural cropping, but the growing of seed potatoes is a special feature. The guidance contained in this report therefore requires interpretation and in some circumstances modification to suit Scottish conditions. Advice on the disposal of sewage sludge on agricultural land in Scotland is available from the advisory services operated by the Scottish Agricultural Colleges.

6.06 Analyses, giving typical nutrient and contaminant contents of sewage sludges available for utilisation on land, should be provided to agricultural users on request. Sludge disposers should keep records detailing the sites sludged, uses, soil analyses and dates and also the types, analyses and quantities of sludges applied and any other relevant data. Where it is not possible in the short-term to comply with the Sub-Committee's recommendations, the effects on crops should be monitored and liaison maintained with specialist agricultural advisers.

6.07 It is hoped that the results of current and proposed research will provide some of the information needed to fill the deficiencies in present knowledge and produce the necessary scientific data for further refinements to be incorporated in future guidelines for the disposal of sewage sludge to land.

Health risk from pathogens

6.08 Providing that the use of a sewage sludge on land is related to the type and extent of treatment it has received and an interval is allowed where appropriate between sludge application and cropping or grazing of the land, the risk to human and animal health is very low (see paragraph 4.50 and on). Attention is drawn to the principles of good practice presented in Chapter 3, particularly in regard to the disposal of cesspit waste, unscreened sewage sludge and the use of rainguns.

6.09 It would be difficult to produce a complete or rigid classification of sludge types and their agricultural uses because many sludges are mixtures of types and pathogen contents vary widely. In practice the origin, type, treatment and analysis of sludge should be considered in relation to the types of agricultural land available and any special characteristics of this land. Suggestions for the general suitability of the main types of sewage sludge for various uses are given in Table 7. These suggestions, which may be regarded as flexible for special conditions, are made in relation to possible risks from pathogens and are subject to environmental considerations or restrictions due to toxic contents in the sludge. Sterilised sludges are acceptable for all agricultural uses, but care has to be taken to ensure that they are not reinfected via contaminated materials or plant before use. Those sludges which have not been disinfected and contain significant amounts of wastes of animal origin should be used only for the growing of crops to be cooked before consumption or for land restoration. Those with a significant amount of waste from the processing of hides imported from countries where anthrax is endemic, should not be used for any agricultural purpose. The uses of sewage sludge suggested in Table 7 are based on the assumption that the sludge is produced from human populations at normal health levels. Water authorities should arrange with the appropriate medical and veterinary authorities to receive notice of outbreaks of serious diseases so that any necessary precautions may be taken in the disposal of sewage sludge likely to be infected and for advice on when to resume normal disposal practice.

6.10 Recent research relating to animal disease suggests that *Salmonella* is less of a problem in the controlled disposal of sewage sludge on land than parasitic worms, in particular the beef tapeworm *Taenia saginata*. Although the incidence in cattle of *Cysticercus bovis*, the larval form of *T. saginata*, is very low, where cases occur there can be financial loss. Common features of recently reported cases of *C. bovis* where sewage sludge has been implicated are the very short interval between sludge application and grazing and the use in most cases of fresh raw sludge. No cases of infection of humans by *Taenia solium*, the pork tapeworm, have been recorded in UK for many years. Most sludge treatments reduce the viability of tape worm eggs but in some cases, such as lime stablisation, the extent of the reduction is uncertain and the period of survival on pasture is still an open question, but it is clear that cattle and pigs should not be allowed on to pasture for a period after the application of sludge. Research into the effect of lime treatment of sludge on the viability of tape worm eggs is in progress and, if it is found that eggs are inactivated, the Sub-Committee will issue an addendum report with revised guidance on no-grazing periods.

6.11 It is recommended that when sludge applied to grazing land has been effectively treated by anaerobic digestion (at least 40 per cent reduction of organic matter), lagooning for at least 2 years, or drying or dewatering followed by stacking to give an overall age of at least one year, no animals should be allowed to graze there for at least 3 weeks after the application as a precaution against *Salmonella* infection. If grazing cattle are producing milk that will not be pasteurised before consumption, the no-grazing period should be at least 5 weeks. For sludges that have not received a minimum of anaerobic digestion, lagooning or stacking as defined above, the no-grazing period for cattle and pigs should be increased accordingly from 3 weeks to up to 6 months as a precaution against infection by tapeworm eggs. For raw, secondary, aerobically digested and lime treated sludges, in which tapeworm eggs may remain viable for long periods, a no-grazing period of 6 months is recommended to ensure a very low risk of infection in cattle and pigs; any reduction in this period is likely to increase the risk disproportionately.

6.12 In brucellosis eradication or attested areas or where voluntary eradication schemes are in operation, approval should be sought from the MAFF Divisional Veterinary Officer before sludges containing significant amounts of waste materials of animal origin are applied on farm premises (see 4.54).

6.13 Unless sewage sludge has been subjected to mesophilic anaerobic digestion or heat processing, it should not be applied to land already free of potato cyst nematode when this land may be used for growing seed potatoes or any potatoes, bulbs or nursery stock for export.

6.14 Any pathogens that may be carried by crops to be consumed by humans are killed by cooking but the application of sewage sludge over growing vegetables is most undesirable. A very low risk of infection from the consumption of uncooked crops is ensured by following the recommendations for the use of sewage sludge in Table 7.

6.15 The Seventh Report of the Royal Commission on Environmental Pollution (1979) expressed the view that the practice of spreading untreated sludge should not be extended pending the outcome of research work on pathogen survival and the hope that the DOE/NWC

Table 7 Recommended uses of sewage sludge in respect of pathogens

Sludge type	Land after-use						
	Crops for human consumption (cooked) Crops for conservation Forestry Land reclamation	Grazed crops	Orchards Turf	Park flower beds	Crops for human consumption (uncooked)	Seed potatoes Nursery stock for export	Gardens Allotments
Mesophilic anaerobic digested Heat processed	Yes	Yes[ab]	Yes	Yes	Yes[e]	Yes	Interim Yes See 6.41
Lagooned 2 years Cold anaerobic digested Cake – one year total age	Yes	Yes[ab]	Yes	Yes	Yes[e]	No	No
Aerobically digested Lime stabilised or conditioned From full biological treatment of settled sewage From extended aeration of unsettled sewage	Yes	Yes[c]	Yes[d]	Yes	Yes[e]	No	No
Liquid stored 2 weeks Cake without lime conditioning From partial biological treatment of settled sewage From limited aeration of unsettled sewage	Yes	Yes[c]	Yes[d]	No	No	No	No
Raw	Yes	Yes[c]	No	No	No	No	No

Note:

a No grazing within 3 weeks of sludge application, or 5 weeks if any milk is to be produced and not pasteurised.

b When less than 40 per cent of the organic matter is destroyed in anaerobic digestion, or when lagooned or dewatered sludge is less than the recommended age, no-grazing period following application should be increased accordingly from 3 weeks to up to 6 months.

c No grazing of cattle or pigs within 6 months of sludge application; other animals as footnote a.

d Fruit or turf not to be harvested within 3 months of sludge application.

e Crops for human consumption uncooked should not be sown for 12 months after sludge application; other crops may be grown in the interim.

Standing Committee would consider the matter fully. Since the publication of the report of the Working Party which recommended that the possible infective hazards to animals transmissible to man should be monitored, the Sub-Committee has initiated a number of research projects on pathogens in sewage sludge, and recommended that the work on parasites should be continued. One project which involved the direct feeding of sludge containing salmonellae to healthy young cattle has helped to demonstrate the low risk of infecting cattle with salmonellae from sewage sludge.

6.16 The Sub-Committee has a preference for the use in agriculture of sewage sludges which have had some form of treatment, mainly on the grounds that they are less likely to cause odour nuisance and some have more readily available nitrogen. Odour nuisance from raw sludge is the most common cause of complaint in disposal operations but this can be largely prevented by soil cultivation immediately following application. There is no evidence to suggest that, where existing raw sludge disposal operations are carried out in accordance with the recommendations in this report, there is a health risk.

Soil contamination

6.17 Some elements found in soils, such as zinc, copper, nickel and boron are essential to crops but excessive additions can reduce yields and must be avoided. Soils also contain small amounts of potentially toxic elements and, providing the concentrations of these elements in sludge are low, applications of sludge will generally cause no harm. However, when the metal concentrations in sludge are high relative to those in the soil, the amounts of sludge that may be added must be restricted to avoid risks to crops and to animal and human health. The fact that grazing livestock ingest soil has to be taken into account in considering the amounts of toxic elements that may be added to pasture.

6.18 Some controversy arose in the Sub-Committee over the units for expressing metal concentrations in soil, but it was decided to recommend the use of mg/l rather than mg/kg because weight per unit volume was more easily related to permissible additions of sewage sludge per unit area of land surface. Metal concentrations in soil are therefore expressed in mg/l of air-dried, ground and 2 mm-sieved soil.

6.19 Most mineral soils in the dried, ground and sieved state have a density of approximately 1.0 and there is no significant difference between concentrations of contaminants expressed in mg/l or mg/kg. However, soil densities can vary significantly, particularly with organic soils. Where densities of dried, ground and sieved soils are appreciably less than 1.0 metal concentrations will be considerably greater in terms of mg/kg than mg/l and in such circumstances agricultural advice should be sought on appropriate sludge application rates. In all experimental work densities of dried, ground and sieved soils should be measured and concentrations of metal recorded in terms of both mg/l and mg/kg.

6.20 If 1 kg/ha of metal is added and thoroughly incorporated in the soil to a depth of 200 mm, that is in 2000 m^3, the total metal concentration when determined in a laboratory air-dried, ground and 2 mm-sieved sample of the soil will be raised by approximately 0.5 mg/l. Thus for soil cultivated to a depth of 200 mm, dividing the application rate of a metal expressed in kg/ha by 2 is a very convenient conversion for estimating the increased concentration in the soil in mg/l.

Maximum addition of potentially toxic elements

6.21 The Sub-Committee's recommendations for the maximum permissible additions to non-calcareous soils in terms of kg/ha to be reached in stages over a 30 year period or more are summarised in Table 8. The annual addition of the limiting element or zinc equivalent would normally be 1/30 of the permissible addition but up to 1/5 may be applied in any one year provided that time is allowed for the running average rate of addition to fall to the 30 years average before the next application is made, and that excessive nitrogen is not applied. Additions of zinc, copper and nickel should be subject to an over-riding limitation in terms of zinc equivalent (see 6.31).

6.22 The recommended maximum permissible application rates are based on soil pH being maintained at 6.5 or over for arable land and 6.0 or over for grassland. Advice should be sought from agricultural advisers regarding the application of sewage sludge at lower rates to soil with pH lower than these values.

6.23 In calcareous soils (pH permanently over 7.0) the availability to crops of the phytotoxic metals zinc, copper and nickel is substantially reduced so, for these metals, application rates of up to double those to non-calcareous arable soil are permitted. Application rates for the other elements listed in Table 8 should be as for non-calcareous soils.

6.24 Where the background levels of elements in the soil are different from those listed in Table 8 (page 52) for normal uncontaminated soils, the permissible additions should be adjusted downwards or upwards accordingly (see Appendix D).

6.25 ADAS has under consideration the introduction of recommended limits of 'total' metal concentrations in sludge amended soils but, for the present, guidance is given in Table 9 on the provisional maximum permissible 'extractable' concentrations in arable soil for zinc, copper, nickel and boron and 'total' concentrations for other elements that may be reached in stages over a period of 30 years or more. It should be noted that the provisional 'extractable' limits for zinc, copper and nickel may be excessive for some sensitive crops.

6.26 Where sewage sludge is applied regularly over a number of years to cultivated land the concentrations of elements in the soil should be monitored periodically to ensure that none has reached the provisional maximum concentration given in Table 9. After a site has received the total permitted amount of any element over at least a 30-year period it should be rested to allow stabilisation. Subsequently, soil analysis may indicate that none of the maximum permissible extractable or total concentrations of any element has been reached. In that case, guidance from an agricultural adviser should be sought before sludge applications are continued. The Sub-Committee will be keeping this matter under review and expects to issue definitive guidance when the results of relevant research projects are available.

6.27 Metals in sewage sludge applied to pasture tend to remain in the top layer of soil and repeated additions can give rise to high metal concentrations in this soil unless it is ploughed from time to time. More information is needed on the distribution of added metals through the soil profile over relevant sampling depths before formal guidance can be given on maximum permissible metal concentrations in pasture soil. Provided that pasture land is not already contaminated and sewage sludge applications are limited as recommended in this report, herbage phytotoxicity and animal toxicity problems are unlikely to occur, but interpretation of pasture soil analysis in respect of such problems and advice on the need to plough can be obtained from agricultural experts. Particular attention should be paid to the addition to pasture of sewage sludge containing high levels of lead, molybdenum and fluorine (see 6.44, 6.46 and 6.49 respectively).

6.28 Because of the lower sensitivity of grass to zinc, copper and nickel reported by some researchers, the Working Party guidelines allowed additions of these metals to pasture, where there is no possibility of this being ploughed for crops, of up to twice those permitted to non-calcareous arable land. The Sub-Committee has some reservations on this provision because there is inadequate evidence on grass yields, and herbage such as clover is much more sensitive than grass to phytotoxic metals (Davies G R 1977).

6.29 The area of pasture land within economical transport distance of large sewage works, which qualifies under the Working Party guidelines for increased rates of addition of zinc, copper and nickel, is thought to be small. It is suggested that these guidelines may be followed in respect of sludge application to this pasture land until further research is complete and, if necessary, the recommendations are amended.

6.30 Where there is a likelihood of pasture being ploughed for crops or planted with coniferous trees, the application rates of all elements should be restricted to those permissible to arable land. Following Table 8 are some brief notes on the elements included in the Table, with particular relevance to their addition in sewage sludge to soils.

Table 8 Recommended maximum permissible additions of elements in sewage sludge to uncontaminated non-calcareous soils over a period of 30 years or more

Element	Uncontaminated soil background concentration mg/l	Maximum permissible addition of element kg/ha
	'Extractable'	'Total'
Zinc	2.5	560
Copper	5	280
Nickel	1	70
Zinc equivalent	20.5	560
Boron	1	4.5 (1st year) 3.5 (subsequent years)
	'Total'	
Chromium	100	1 000
Cadmium	1	5
Lead	50	1 000
Mercury	<0.1	2
Molybdenum	2	4
Arsenic	5	10
Fluorine	200	600
Selenium	0.5	5

Note:
Additions of zinc, copper and nickel are subject to the over-riding limitation of the zinc equivalent.
'Extractable' — Metals extracted by EDTA, boron extracted by hot water.
'Total' — Metals extracted by strong acid, fluorine determined by fusion and ion selective electrode, boron extracted by hot water.

Zinc equivalent

6.31 Zinc, copper and nickel normally occur together in sewage sludge and since their effects appear to be additive when present in high concentrations, the 'zinc equivalent' should be used for determining the maximum permissible sludge addition and soil concentration. Where zinc, copper and nickel are not present in significant amounts their effects may not be additive, but it is then likely that other metals will limit the amount of sludge that may be applied.

6.32 The zinc equivalent is a convenient way of expressing in a single figure the total level of the phytotoxic elements zinc, copper and nickel. It assumes comparative toxicities of these elements of 1:2:8, but these may not be valid for all crops under all conditions. Recent work (M J Marks, J H Williams, C G Chumbley 1977) has shown that the above comparative toxicity for nickel in particular is high for some crops but there is still insufficient data on which to base a change. The zinc equivalent concept has been dropped in the USA and has not found general acceptance in Europe, but it remains a convenient and reasonable guide for the avoidance of phytotoxic effects on the most sensitive of crops. Experimental work should be pursued with a view to improving or replacing the concept. It is recommended that the maximum addition of zinc equivalent in sewage sludge to normal non-calcareous soils should be limited to 560 kg/ha over a period of 30 years or more.

Table 9 Provisional maximum permissible concentrations of elements in arable soils to be reached in 30 years or more

mg/l

Element	Non-calcareous	Calcareous
'Extractable'		
Zinc	280	560
Copper	140	280
Nickel	35	70
Zinc equivalent	280	560
Boron	3.25	3.25
'Total'		
Chromium	600	600
Cadmium	3.5	3.5
Lead	550	550
Mercury	1	1
Molybdenum	4	4
Arsenic	10	10
Fluorine	500	500
Selenium	3	3

Note:
Maximum 'extractable' concentrations of zinc, copper and nickel are subject to the over-riding limitation of the zinc equivalent.
'Extractable' — Metals extracted by EDTA, boron extracted by hot water.
'Total' — Metals extracted by strong acid, fluorine determined by fusion and ion selective electrode, boron extracted by hot water.

Zinc

6.33 Zinc, although essential to plant life, can be phytotoxic in excessive quantitites. It is readily taken up by plants from the soil, but it has a relatively low toxicity to animals and man.

Copper

6.34 Copper is also essential to plant life, but again it can be phytotoxic to most plants. It is taken up by plant roots but translocated only to a limited extent. Currently copper is assumed to be twice as phytotoxic as zinc, but further research on this ratio is needed. Copper is also essential in animal diet but an excess can be toxic, particularly to sheep and lambs.

Nickel

6.35 Except where sewage sludge contains certain metal wastes, the nickel content of sludges is usually low. It is very toxic to most plants but it appears to occupy an intermediate position as regards uptake and translocation into shoots and leaves. For the most sensitive plants it is about 8 times as phytotoxic as zinc but again further research on this ratio is needed.

Boron

6.36 From the amounts of boron normally present in sewage sludge, toxicity to animals and man will not occur, and the risk from boron, which is entirely to crop yield, is very small. It has in the past been thought that grass was less sensitive to boron than other crops, but present evidence does not support this and the Sub-Committee recommends the same maximum permissible rate of addition of boron for all crops. The addition of hot water extractable boron should be limited to 4.5 kg/ha in the first year and 3.5 kg/ha annually thereafter. The permissible additions of boron are given on an annual basis because it does not accumulate in soils to the same extent as other elements owing to the high solubility of boron compounds. Some residue will be left from year to year and hence the amount applied after the first year needs to be reduced.

Chromium

6.37 Chromium is normally present in sewage sludge predominantly in the insoluble trivalent form. The soluble hexavalent form is unlikely to be found in significant concentrations in raw sludge and any present would be largely reduced to the trivalent form during anaerobic digestion. Toxic effects due to chromium in sewage sludge have not been observed in plants or in animals consuming crops grown on sludged land. Chromium will rarely be the element limiting the application of sewage sludge to land.

Cadmium

6.38 Cadmium is not only much more phytotoxic than zinc but it can be toxic to man and when ingested is slowly accumulated, mainly in the kidneys. Over a long period it can reach a critical concentration leading to renal tubular dysfunction. Cadmium is readily absorbed from soils and translocated by plants and the major route of exposure of man to cadmium through food is from cereals and vegetable crops.

6.39 A number of variables, such as soil type, soil pH, plant and cultivar type affect the degree of uptake of cadmium into crops and it is not yet possible to predict the effects of a given rate of cadmium application to soil on the levels in crops. It is therefore important that the rate of increase in soil cadmium levels is kept as low as practicable in order that there will be time for the results of current and planned research to provide a scientific basis for any necessary modifications to the proposed rate. The subject of dietary exposure to cadmium is at present being reviewed by the MAFF Working Party on the Monitoring of Foodstuffs for Heavy Metals and the Food Additives and Contaminants Committee. This Sub-Committee will note, for future guidance on the disposal of sewage sludge to agricultural land, the findings of these bodies.

6.40 In the interim the Sub-Committee recommends a maximum permissible addition of cadmium in sewage sludge to normal soils of 5 kg/ha over a period of 30 years or more. The case for setting an upper limit for cadmium concentration in sewage sludge used in agriculture has been considered, but since, if concentrations are high, the acceptable rates of sludge application will be too low for disposal on agricultural land to be economic, the constraint on the application rate appears to be adequate until such time as more information is available.

6.41 Private gardens, allotments and land used for intensive horticulture are particularly at risk from high applications of cadmium in sewage sludge because of the possibility that particular individuals or families might consume large amounts of vegetables grown thereon. There is no effective means of ensuring that manure is applied to gardens and allotments at recommended rates, so the Sub-Committee recommends that the supply of sewage sludge to the general public should be phased out and, in the interim, only sludges (mesophilic anaerobic digested or heat processed) with less than 20 mg/kg of cadmium in the dry solids should be provided.

6.42 Where sewage sludge is to be utilised for land reclamation, consideration should be given to the ultimate use of the land and the possible effects of cadmium in the topsoil. An Interdepartmental Committee on the Redevelopment of Contaminated Land is preparing recommendations for maximum concentrations in land to be developed for a range of uses from housing with small gardens to grassland amenity areas.

6.43 The Sub-Committee commends the efforts being made by the water authorities to reduce by means of stricter trade effluent controls the amount of metals entering sewage and recommends that these efforts should be strenuously continued with the object of improving the quality of sewage sludge particularly in regard to cadmium, and thus increasing the quantity suitable for utilisation by agriculture.

Lead

6.44 When lead is equilibrated in soil it tends to become very insoluble and is not readily taken up and translocated by plants. The element has not been shown to be particularly phytotoxic but it is both toxic and cumulative in animals and man. The main risks from lead in sewage sludge are from surface contamination of crops and the ingestion of lead-contaminated sludge or soil by animals or small children and an upper limit is recommended of 2000 mg/kg for lead in the sludge dry solids to be applied to grassland, gardens and amenity areas.

Mercury

6.45 Mercury is largely lost from the surface of soils by volatilisation and the content in soils is usually low, the average being about 0.03 mg/l. The extent to which mercury is taken up by plants is believed to be small, but it is very toxic to man and consequently the total addition in sewage sludge to land should be restricted.

Molybdenum

6.46 Molybdenum is not phytotoxic but high intakes by grazing animals can cause or exacerbate copper deficiency problems. The problems associated with molybdenum are referred to in paragraphs 4.37 and 4.48.

6.47 Copper deficiency in grazing animals is widespread and has economic implications. The Sub-Committee has reviewed the Working Party's guideline for the maximum addition of molybdenum of 5 kg/ha over a period of 30 years or more which could lead to the level in normal soil being raised to 4.5 mg/l, and recommends that the limit should be reduced to 4 kg/ha and that the concentration in soil should not be allowed to exceed 4 mg/l. It is suggested also that where the molybdenum application rate to grazing land exceeds 0.15 kg/ha during one year the herbage should be monitored and if the concentration in this exceeds 2 mg/kg specialist agricultural advice should be sought. If a typical sludge containing 7 mg/kg of molybdenum (the mean value, Berrow and Webber survey 1972) is applied to land at 4 t/ha of dry solids each year, the annual addition of molybdenum would be less than 0.03 kg/ha and herbage monitoring would not be required.

Arsenic

6.48 The average arsenic content of soils is about 5 mg/l (range 0.1 to 40 mg/l). Crop growth is known to be affected by arsenic but data on uptake is very limited. Until further information becomes available a provisional limit is suggested for the addition of arsenic in sewage sludge. Arsenic is unlikely to be a critical element in the application of sewage sludge to land.

Fluorine

6.49 The fluorine content of soils varies in different parts of the country but on average is in the order of 200 mg/l dry soil. Fluorine is taken up by plant roots to a limited extent but it does not normally inhibit growth. Sewage sludges usually contain only a few hundred mg/kg of fluorine and do not cause problems in agriculture on this account, but in one case recently reported, where sludge containing 20 000 to 30 000 mg/kg of fluorine in the dry solids was applied to grassland already contaminated with fluorine, a serious outbreak of fluorosis in cattle resulted.

6.50 Sludges with high fluorine content are rare but, to avoid possible future problems, the Sub-Committee recommends limiting the addition of fluorine over a period of 30 years or more to 600 kg/ha. It also recommends that the fluorine content of sludge applied to any grazing land should not exceed 3500 mg/kg dry solids because grazing animals, especially ruminants, can suffer from fluorosis if they consume a diet with over 30 mg/kg of fluorine for prolonged periods.

Selenium

6.51 The selenium content in soils varies considerably but probably averages between 0.2 and 0.5 mg/l. It is an essential element for livestock but toxic in high amounts and, like molybdenum, its availability to crops increases at higher soil pH and in alkaline soils a total content of 5 mg/l or more gives cause for concern.

Nitrogen

6.52 The losses of nitrogen which can occur in many cases between the application of sludge and the crop growing season and the response of crops to excessive applications of manures are very variable. The farmer should always be advised of the available nitrogen content of the sludge being supplied to him. Provided that there is no risk of drinking water contamination, the actual rates of sludge application can then be determined in relation to all relevant circumstances including the needs of the crop. Cereal crops are especially susceptible to loss of yield resulting from excessive application of nitrogen, whilst some other crops are more tolerant. Users of sewage sludge should be cautioned that excessive applications may reduce crop yields.

Persistent organic compounds

6.53 Insufficient is known on the uptake by crops of persistent organic compounds for limits of application in sludge to be recommended. Where it is known that waste discharged to sewers by industry is contaminated with organohalogens, sludge from the receiving treatment works should not be applied to pasture without first consulting agricultural advisers. A survey of the content of certain persistent organic compounds in sewage sludge is planned.

Protection of the environment

6.54 Sewage sludge disposal must be conducted so as to avoid, as far as is possible, adverse effects on the environment. This is best achieved by following good sludge disposal and agricultural practices as outlined in this report, particularly chapters 3 and 4, and with a view to the realisation of environmental quality objectives.

6.55 The recommendations on the maximum rates of application to land of sludge containing metals should be observed for the protection of soil fertility.

6.56 Sewage sludge should not be applied to land in such ways that drinking water is endangered. Noise and traffic nuisance must be carefully controlled and physical contamination of buildings and roads avoided.

6.57 The most common cause of complaint is odour and every effort must be made to prevent nuisances particularly when disposing of raw sludge and when using rain guns. Cultivation of arable land immediately following application is strongly advised. Cesspit waste should, when practicable, be discharged to a sewage treatment works.

6.58 The possibility of endangering wildlife is best avoided by following those recommendations that afford protection to the environment generally.

Research

6.59 The Sub-Committee has instigated the placing of DOE research contracts for:

1. a critical review of sludge disposal literature
2. the enumeration of potato cyst eelworm
3. the susceptibility of cattle to salmonellae in sewage sludge
4. a critical review of viruses in sewage sludge
5. a literature review on parasites and methods for enumerating and testing the viability of beef tapeworm eggs
6. a series of metal uptake crop trials on different soil types.

Much useful information has already been obtained from these projects and other current research work and incorporated in this report. It is anticipated that the last two projects listed above, which are still in progress, will provide much needed data on some of the more controversial aspects of the utilisation of sewage sludge in agriculture and give clear indication of where future research effort should be concentrated. A protocol for crop field trials developed by the Sub-Committee's Research Working Group and subsequently published by the Water Research Centre provides water authorities and others with a useful basis for planning future projects on the effects of sewage sludge in agricultural use.

6.60 The current and proposed research programme should be continued and extended, where appropriate, to provide the scientific data needed for the refinement of guidelines on the disposal of sewage sludge to land, with a view to improving safety where there is shown to be a risk in the short or long term, or relaxing restrictions where they are proved to be unnecessary and an economic burden.

6.61 Co-ordination in the planning of research and in departmental responsibilities should be continued. The regular updating of the inventory of current or proposed research work should be maintained as an aid to this co-ordination.

6.62 In order to ascertain whether further recommendations are needed for the disposal of sewage sludge to land, work is required on the uptake by crops of a number of elements and certain persistent organic compounds, and how these and their availabilities to crops change with stabilisation in various types of soil and different cropping systems. More needs to be known on comparative toxicities and additive effects of metals on various crops in different soil types.

6.63 Work on the determination of the survival of pathogens, and particularly the eggs of parasites, through sewage and sludge treatments and on pasture, and also on any potential risks from viruses in the utilisation of sewage sludge in agriculture, should be continued and extended. (It is noted that the Seventh Report of the Royal Commission on Environmental Pollution recommends that research on the extent of survival of pathogens in sludge should be given greater emphasis). Work should continue on the development of microbiological monitoring techniques.

6.64 When the results of current research on manurial value are completed, further work will be necessary to answer questions being posed about the availabilities of nutrients in various kinds of sludges to various crops.

6.65 When the current work on the standardisation of sludge sampling, preparation and analytical techniques is completed and tested, more meaningful comparisons and conclusions should be obtainable from field data and research and more authoritative guidance given.

7. CONCLUSIONS

7.01 Sewage sludge contains significant quantities of the nutrients nitrogen and phosphorus with a potential for promoting crop growth. Wherever it is economically justified and environmentally acceptable sewage sludge should be utilised on agricultural land in accordance with the recommendations of this report. Compliance with these recommendations will ensure that the risk of harmful effects is kept to a very low level.

7.02 Reduction of the contaminants in trade effluents discharged to sewers by the tightening of trade waste controls would improve the quality of some sewage sludge and increase the quantity suitable for application to agricultural land.

7.03 Where compliance with the recommended maximum permissible rates of sludge application is not possible, the effects on crops should be monitored.

7.04 Current guidance on the application of sewage sludge to land is based on limited and sometimes conflicting information and further research and information from monitoring field operations are necessary to refine this guidance. It is hoped to issue further guidance within 4 to 5 years.

7.05 Effort is needed to maintain the improvement in the co-ordination of research achieved over recent years.

APPENDIX A

WORKING GROUP MEMBERSHIP

Working Group 1

L H Thompson (Chairman)	Thames Water Authority
J L Arnold	Yorkshire Water Authority
T G Brownlie	Department of Agriculture and Fisheries for Scotland
M G Burrows	Northumbrian Water Authority
Dr E G Coker (from January 1978)	Water Research Centre
R J Draycott (from July 1976)	South West Water Authority
Dr R Gregory	Severn-Trent Water Authority
G Hall (from January 1977)	Wessex Water Authority
Dr P Hulme	Welsh Water Authority
Dr P J Matthews	Anglian Water Authority
A P Michaelson	North West Water Authority
F A de Vries (from July 1978)	Southern Water Authority
Mrs L M Glassborow (Administrative Secretary)	Department of the Environment
Past members	
M J Essex (to July 1976)	South West Water Authority
B Hewett (to July 1978)	Southern Water Authority
Dr H A Painter (to January 1977)	Water Research Centre
M J Tarbox (to January 1977)	Wessex Water Authority
J F A Thomas (to July 1976)	Department of the Environment
G C Porteous (Technical Secretary to July 1976)	Department of the Environment
J F Bonsall (Technical Secretary from July 1976 to December 1978)	Department of the Environment

Working Group 2

J Webber (Chairman)	Ministry of Agriculture, Fisheries & Food (to November 1977): then independent consultant
T G Brownlie	Department of Agriculture and Fisheries for Scotland
Dr E G Coker	Hertfordshire College of Agriculture (to August 1977) then Water Research Centre
Dr S M Cromwell	Department of Health and Social Security
T D Dampney	National Farmers' Union
A M Douglas	Thames Water Authority
J Finch	Institute of Water Pollution Control
K G Gostick (from December 1977)	Ministry of Agriculture, Fisheries & Food

Dr D Lindsay (from May 1977)	Ministry of Agriculture, Fisheries & Food
M K Lloyd	Ministry of Agriculture, Fisheries & Food
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Dr E B Pike (from December 1977)	Water Research Centre
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J L Stringer	Hertfordshire County Council
P Worthington	Department of the Environment
G C Porteous (Technical Secretary)	Department of the Environment
Mrs L M Glassborow (Administrative Secretary)	Department of the Environment

Past members

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J P Giltrow (to October 1977)	Department of the Environment
Dr D Lambert (from April 1978 to October 1979)	Department of Health and Social Security
Dr N P Melia (from February 1977 to April 1978)	Department of Health and Social Security
Dr H A Painter (to August 1977)	Water Research Centre
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Working Group 3

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Dr R Gregory	Severn-Trent Water Authority
Dr J Hudson (From March 1977)	Yorkshire Water Authority
Dr P Hulme	Welsh Water Authority
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Dr M P Melia (from March 1977 to March 1978)	Department of Health and Social Security
Dr H A Painter (to October 1977)	Water Research Centre
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J F Bonsall (Technical Secretary from March 1976 to June 1979)	Department of the Environment
Mrs L M Glassborow (Administrative Secretary to July 1980)	Department of the Environment

APPENDIX B

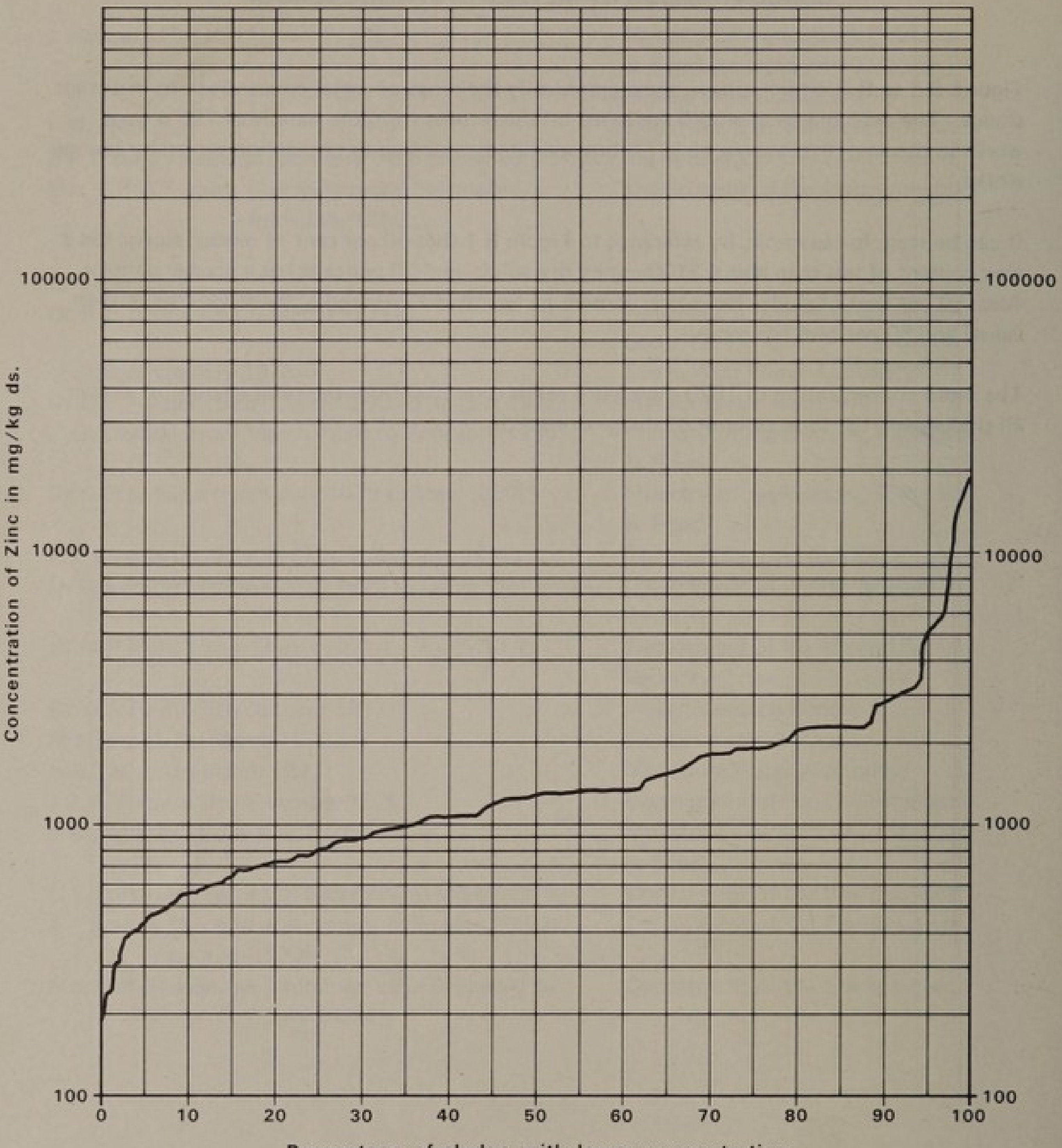
CONCENTRATION OF METALS IN SEWAGE SLUDGE

Figures B.1 to B.7, which follow, show graphically the range of metal concentrations in sewage sludge. The percentages of sludge are based on the returns from the sample of 193 sewage works in the analytical survey of 1977, but weighted according to population served by sewage works.

It can be seen, for example, by reference to Figure B.1 that 80 per cent of sewage sludge has a zinc content of less than about 2100 mg/kg dry solids, and 20 per cent has a greater content. Also, 50 per cent of sludge has a zinc content of less than 1270 mg/kg dry solids (the median value) and 50 per cent has more.

The mean concentration of 1820 mg/kg dry solids is derived from the total amount of zinc in all sludges and the total amount of sludge dry solids.

ZINC



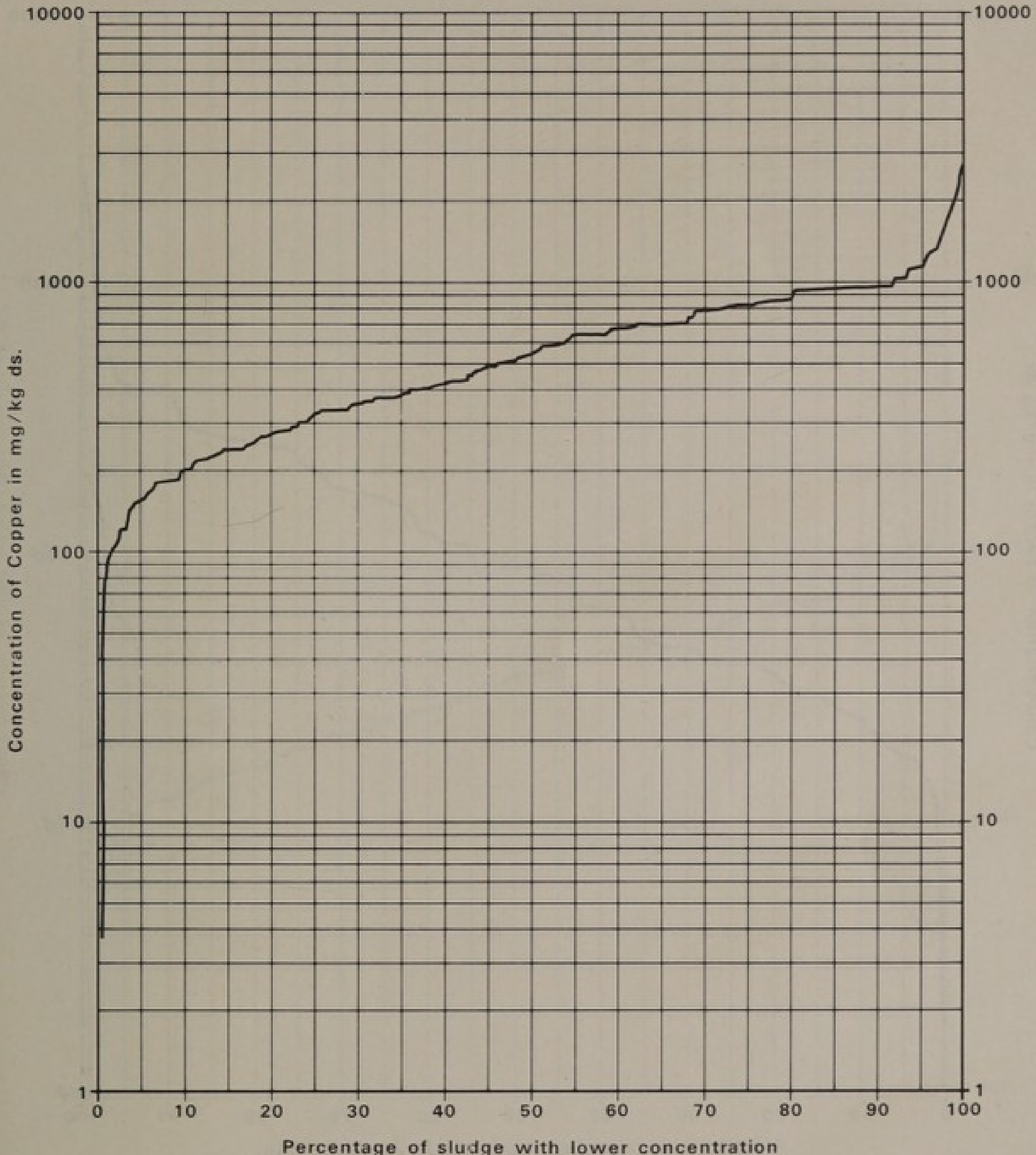
Mean concentration 1820 mg/kg dry solids

Median concentration 1270 mg/kg dry solids

Fig.1
Zinc content in sewage sludge disposed to land (including landfill)

Source: DSS survey of sewage sludge analysis 1977

COPPER

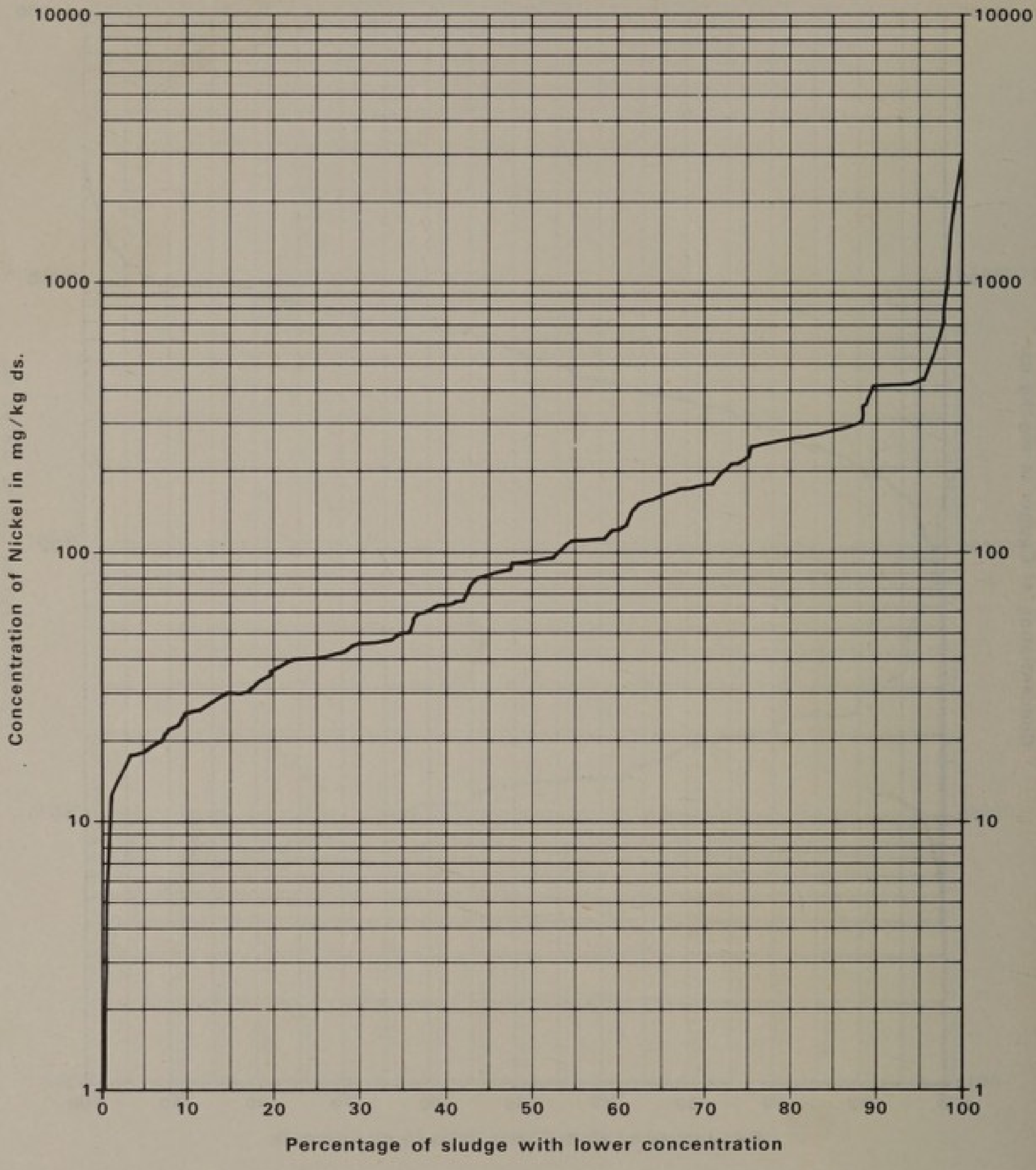


Mean concentration	613 mg/kg dry solids
Median concentration	546 mg/kg dry solids

Fig.2
Copper content in sewage sludge disposed to land (including landfill)

Source : DSS survey of sewage sludge analysis 1977

NICKEL

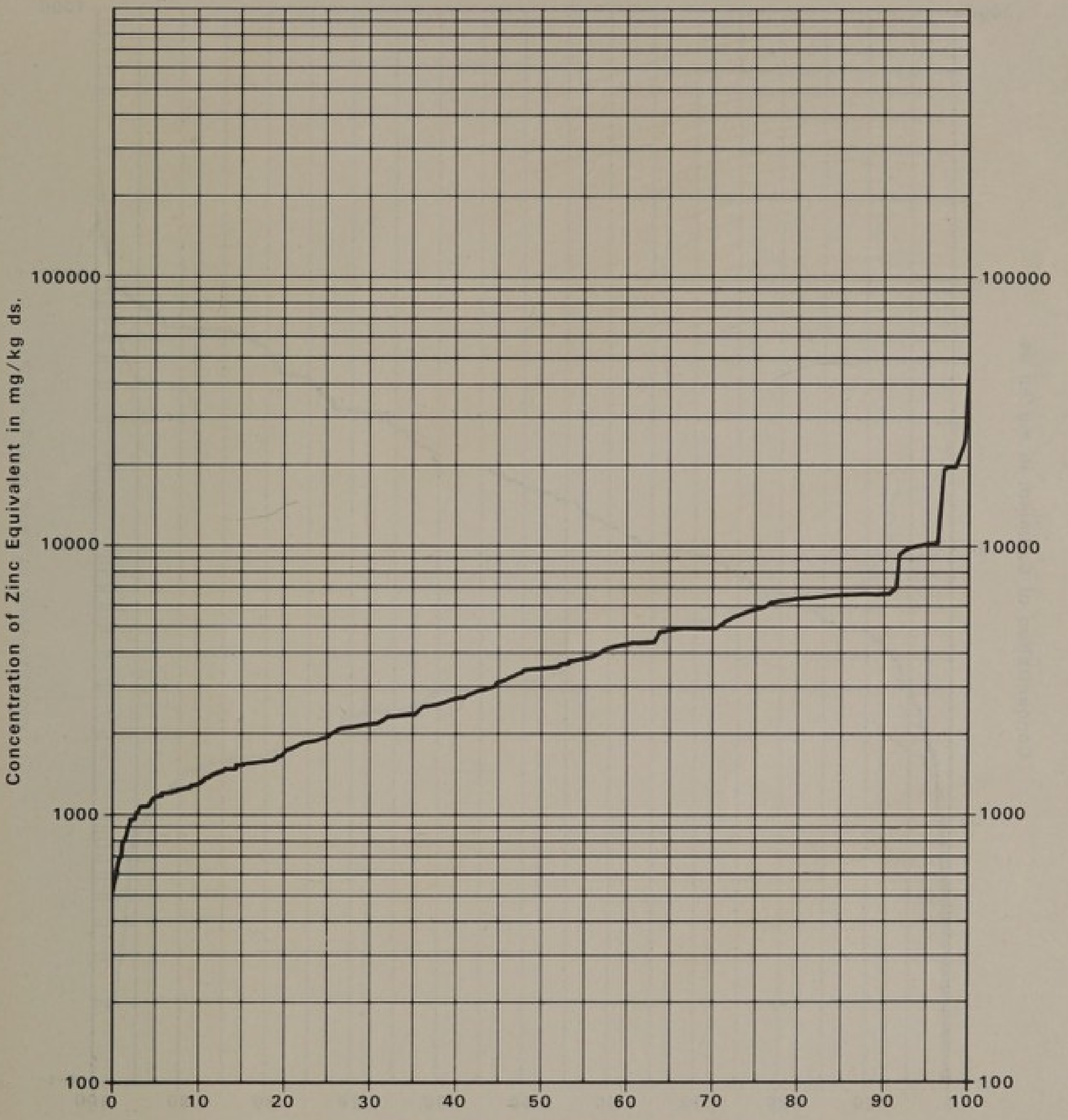


Mean concentration	**188** mg/kg dry solids
Median concentration	**94** mg/kg dry solids

Fig.3
Nickel content in sewage sludge disposed to land (including landfill)

Source: DSS survey of sewage sludge analysis 1977

ZINC EQUIVALENT



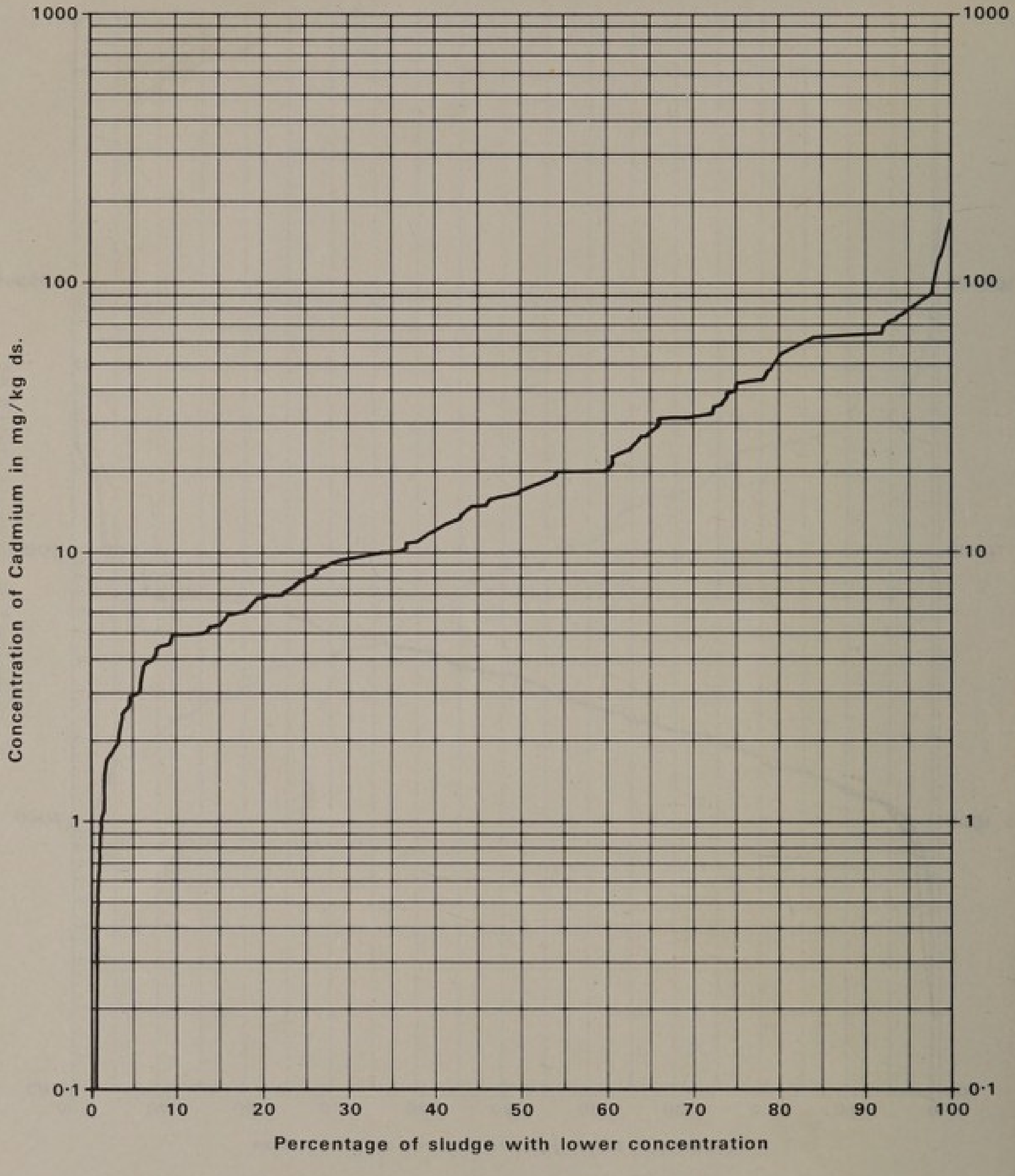
Mean concentration 4550 mg/kg dry solids

Median concentration 3440 mg/kg dry solids

Fig.4
Zinc equivalent content in sewage sludge disposed to land (including landfill)

Source : DSS survey of sewage sludge analysis 1977

CADMIUM

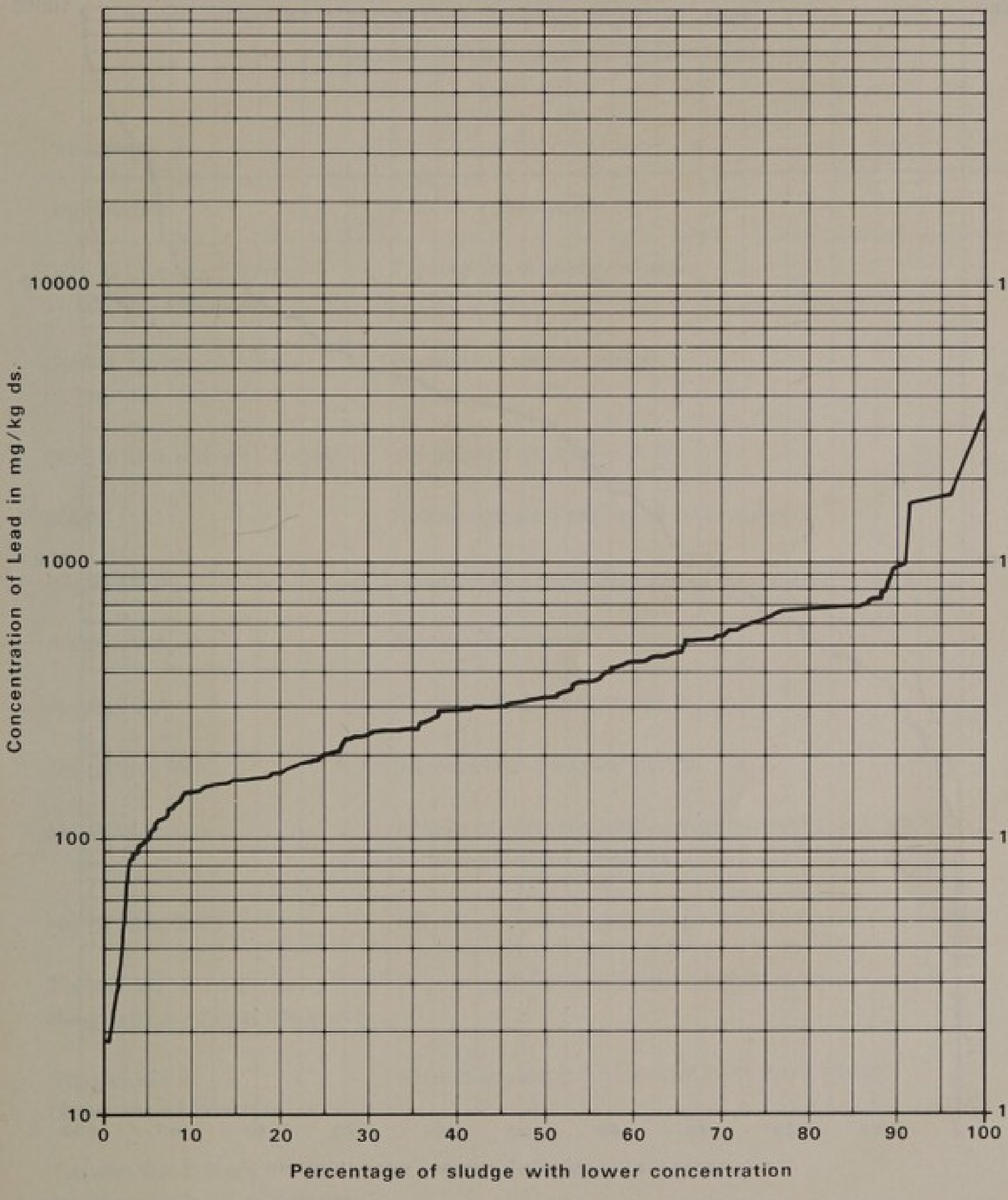


Mean concentration	29 mg/kg dry solids
Median concentration	17 mg/kg dry solids

Fig.5
Cadmium content in sewage sludge disposed to land (including landfill)

Source: DSS survey of sewage sludge analysis 1977

LEAD



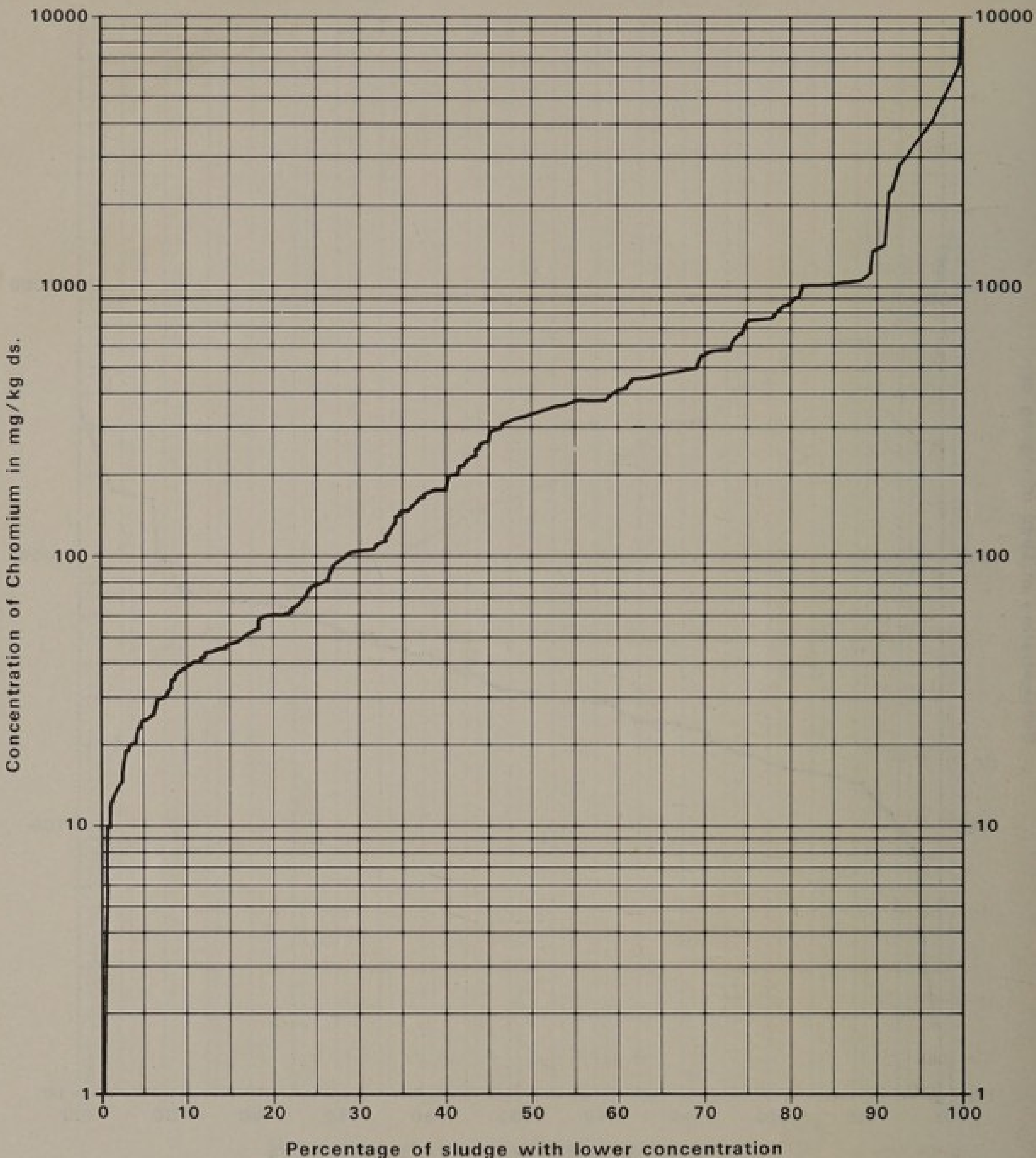
Mean concentration 550 mg/kg dry solids

Median concentration 324 mg/kg dry solids

Fig.6
Lead content in sewage sludge disposed to land (including landfill)

Source : DSS survey of sewage sludge analysis 1977

CHROMIUM



Mean concentration 744 mg/kg dry solids
Median concentration 335 mg/kg dry solids

Fig.7
Chromium content in sewage sludge disposed to land (including landfill)

Source : DSS survey of sewage sludge analysis 1977

APPENDIX C

LIST OF UNITED KINGDOM RESEARCH PROJECTS ON LAND DISPOSAL OF SEWAGE SLUDGE, 1980

(Prepared by Working Group on Research)

Pathogens

Organisation	Area of investigation
DOE & Liverpool School of Tropical Medicine	Tapeworms in sewage sludge
DOE & Liverpool School of Tropical Medicine	Parasites in sewage sludge
DOE & University of Surrey	Virology of sludges
MAFF	Epidemiological studies of salmonellosis
Anglian WA	Isolation and quantification of root eelworm cysts
Anglian WA	Salmonellae content and survival
Anglian WA	Tapeworms in sewage sludge
North West WA	Salmonellae in sewage sludge
North West WA	Effects of formalin based odour control chemicals on Salmonella and T. saginata
North West WA	Effects of lime on parasites in sewage sludge
Thames WA & Institute for Research on Animal Diseases	Fate of pathogens in treatment processes
Thames WA & University of Surrey	Viruses in sludge during treatment and disposal
Thames WA & Ross Institute of Tropical Hygiene	Virus rapid assay
Welsh WA	Viral quality of sewage sludges
Welsh WA	Lime treatment of raw sludge
Wessex WA	Salmonellae content and survival
Water Research Centre	Pathogen studies

Organisation	Area of investigation
Ross Institute of Tropical Hygiene	Health aspects of wastewater management
Stockport MBC	Salmonellae survival on grass plots

Toxic chemicals

Organisation	Area of investigation
DOE & Thames WA	Effects of metals in digested sludge on crops
DOE & Water Research Centre	Effects of metals in digested sludge on crops
DOE & Imperial College	Analysis of persistent organochlorine compounds in sewage sludge
DOE & Water Research Centre	Analysis of arsenic, selenium and molybdenum in sewage sludge
DOE & Water Research Centre	Collaborative analysis of sewage sludge
DOE & Imperial College	Analysis of sewage sludges
DOE & Imperial College	Critical review of literature
DOE & Westfield College	Accumulation, distribution and metabolism of cadmium in crop plants
MAFF	Dietary studies
MAFF	Background levels of trace elements in foodstuffs
MAFF	Persistent organic compounds in milk
MAFF (ADAS) Reading	Effects of metals on crops
MAFF (ADAS) Reading	Contamination of vegetable crops with cadmium and lead
MAFF (ADAS) Reading & Thames WA	Soil amelioration treatments on metal uptake of crops
MAFF (ADAS) Wolverhampton	Uptake of molybdenum by grass and clover

Organisation	Area of investigation
MAFF (ADAS) Wolverhampton	Uptake of cadmium by ryegrass and clover
MAFF (ADAS) Wolverhampton	Phytotoxicity of zinc, copper and nickel to crops
Anglian WA	Historic site crop trials
Anglian WA	Determination of boron in sewage sludge
Anglian WA	Lead uptake in lettuce
Northumbrian WA	Monitoring the effects of land disposal
Severn Trent WA	Uptake of sludge-borne pollutants
Thames WA & Trent Polytechnic	Fate of metals in sewage sludges
Thames WA & Oxford University	Long term effects of potentially harmful elements in sewage sludges
Thames WA & Oxford University	Sludge soil interaction
Water Research Centre & North West WA	Agricultural significance of molybdenum in sewage sludges used on pasture
Water Research Centre	The use of indicator crops to assess heavy metal status of sludge-treated soils
Water Research Centre	Phytotoxicity experiments using sludges prepared from metal-enriched sewage
Water Research Centre	Uptake of fluoride by ryegrass
Water Research Centre	Effects of cadmium in sludges used in agriculture
Water Research Centre	Evaluation of the use of sludge from spiked sewage
Edinburgh School of Agriculture	Long term effect of sewage sludge on trace-element composition of agricultural soil
Macaulay Institute of Soil Research	Metals in plants and soils
Grassland Research Institute	Uptake and distribution of heavy metals in forage plants

Toxic chemicals (continued)

Organisation	Area of investigation
Department of Agricultural Science, Oxford University	Mineralisation of sewage sludges
Plymouth Polytechnic & South West WA	Profile dispersion characteristics on heavy metals in soils
School of St Helen & St Katherine	Uptake and distribution of toxic heavy metals in crops

Manurial value

Organisation	Area of investigation
MAFF (ADAS) Wye & Reading and Thames WA	Dried, pelleted sewage sludge as a fertilizer
MAFF (ADAS) Bristol & Wessex WA	Sewage sludge injection into grassland
Severn Trent WA	Use of sewage sludge in land reclamation
Severn Trent WA & Keele University	Comparison of manurial effects of different sewage sludges
Welsh WA	Disposal of untreated sludge to sand dunes
Wessex WA	Manurial value of digested sludge to grassland
Yorkshire WA	Utilisation of sewage sludge
Water Research Centre	Utilisation of sewage sludge on agricultural land
Water Research Centre	Effects of sewage sludge on growth of ryegrass on reclaimed land
Water Research Centre	Effects of time of application of liquid digested sludge on growth of cereals
Water Research Centre & South West WA	Manurial value of septic tank sludge
Water Research Centre	Effects of digested sewage sludge and waterworks sludge on reclaimed land

Manurial value (continued)

Organisation	Area of investigation
Water Research Centre & University of Leeds	Utilisation of liquid digested sludge
Water Research Centre & West of Scotland Agricultural College	Utilisation of liquid digested sludge in SW Scotland
Portsmouth Polytechnic	Rapid aerobic composting of sewage sludge mixed with refuse

Other aspects

Organisation	Area of investigation
Anglian WA	Evaluation of subsurface injection of sewage sludge
Anglian WA	Sludge to land trials
Anglian WA	Rheology of sludges
Thames WA	Chicken feed from primary sewage sludge
Thames WA	Pelletisation of sewage sludge
Thames WA	Evaluation of lipid and protein extraction processes
Thames WA	Lime stabilisation of sewage sludge
Welsh WA & University College, Cardiff	Extraction and purification of protein from sewage sludges
Wessex WA	Disposal of digested sewage sludge to forestry land
MAFF (ADAS) Trawsgoed	Leaching of nutrients and heavy metals following sludge application to soil
Water Research Centre	Economic and operational research models for sludge disposal
Water Research Centre	Measurement and control of odours
Water Research Centre	Effect of the disposal of sewage sludge on groundwater quality
University of Leeds	Composting sewage sludge and domestic refuse

APPENDIX D

EXAMPLE CALCULATION FOR THE MAXIMUM PERMISSIBLE ADDITION OF SEWAGE SLUDGE TO NON-CALCAREOUS ARABLE SOILS OVER 30 YEARS OR MORE

Example for cadmium

Sludge cadmium content	= 29 mg/kg dry solids (assumed)
Uncontaminated soil background concentration	= 1 mg/l (Table 8)
Maximum permissible addition of cadmium	= 5 kg/ha (Table 8)

Example A

Background concentration of cadmium in soil = 1.5 mg/l

Cadmium excess over uncontaminated concentration = 0.5 mg/l

= 0.5 x 2 kg/ha (para 6.20)

Maximum permissible addition of cadmium = (5–1) kg/ha

Maximum permissible addition of sludge = $\dfrac{(4 \times 1000}{29}$

= 138 t ds/ha over 30 years

or = 4.6 t ds/ha each year

Example B

Background concentration of cadmium in soil = 0.5 mg/l

Cadmium short-fall below uncontaminated concentration = 0.5 mg/l

= 0.5 x 2 kg/ha

Maximum permissible addition of cadmium = (5 + 1) kg/ha

Maximum permissible addition of sludge = $\dfrac{(6 \times 1000}{29}$

= 207 t ds/ha over 30 years

or = 6.9 t ds/ha each year

Subject to the needs of crops in relation to the manurial value of the sludge, up to 1/5 of the maximum permissible long term amount of cadmium may be applied in any one year, providing no more cadmium is added to this site until 6 years later. This could be added in the following applications of sludge:

Example A $\dfrac{138}{5}$ = 27.6 t ds/ha

Example B $\dfrac{207}{5}$ = 41.6 t ds/ha

If in a particular situation the acceptable nitrogen application limits the addition of sludge to say only 10 t ds/ha in a year, which is less than the 1/5 maximum application based on cadmium, this addition may be repeated in:

$$\frac{10}{4.6} = 2.2 \text{ years (Example A)}$$

$$\frac{10}{6.9} = 1.5 \text{ years (Example B)}$$

Similar checks should be made for the other elements in Table 8 and the sludge application rate selected to comply with the most limiting criterion.

APPENDIX E

REFERENCES

1. Agricultural Development and Advisory Service (ADAS). Permissible levels of toxic metals in sewage used on agricultural land. Advisory Paper No. 10. 1971.

2. Andersson A and Nilsson K O. Influence of lime and soil pH on cadmium availability to plants. Ambio 3, 198–200. 1974.

3. Bagchi S. Differential toxicity of Cadmium in rice varieties. Acta Agron. Acad. Scient. Hung. 25, 175–180. 1976.

4. Berrow M L and Webber J. Trace elements in sewage sludges. J. Sci. Fd. Agric. 23, 93–100. 1972.

5. Bolton J. Liming effects on the toxicity to perennial rye grass of a sewage sludge contaminated with zinc, nickel, copper and chromium. Environ. Pollut. 9, 295–304. 1975.

6. Brit. Hydromechanics Research Association. Sewage Sludge Pumping Project. Reports Nos. 1 to 6. 1978–1979.

7. Bunting A H. Experiments on organic manures (1942–49). J. Agri. Sci. Camb. 60, 121–144. 1963.

8. Chaney R L. Crop and food chain effects of toxic elements in sludges and effluents. Proc. Jt. Conf. Recycling municipal sludges and effluents on land. US EPA, Illinois, 129–141. July 1975.

9. Chaney R L et al. Heavy metal relationships during land utilisation of sewage sludge in the North East as a waste management alternative. Proc. 8th. Waste Man. Conf., Cornell Univ., Rochester NY. April 1976.

10. Coker E G. The value of liquid digested sewage sludge. J Agri. Sci. Camb., 91–107. 1966.

11. Coker E G. Utilisation of sludge in agriculture. 4th Public Health Eng. Conf. Univ. Loughborough, 1971.

12. Crewe W and Owen R R. A review of literature on tapeworms in sewage sludge. Liverpool Sc. Trop. Med. report for DOE. Dec. 1977.

13. Crewe W and Owen R R. Tapeworms in sewage sludge — research project: Liverpool Sc. Trop. Med. report for DOE. Sept. 1978.

14. Cunningham T D et al. Phytotoxicity and uptake of metals added to soils as inorganic salts or in sludge. J. Environ. Qual. 4, 455–460. 1975.

15. Davies G R. Pot experiments testing zinc, copper and nickel salts on the growth and composition of crops. ADAS Conf. Inorg. Poll. and Agric. 1977.

16. Davis R D. Uptake of copper, nickel and zinc by crops growing in contaminated soils. J. Sci. Food and Agric. 30, 937–947. 1979.

17. DOE/NWC. Report of the Working Party on the Disposal of Sewage Sludge to Land. STC Report No. 5. 1977.

18. DOE/NWC. Sewage Sludge Data and Reviews of Disposal to Sea. STC Report No. 8. 1978.

19. DOE/NWC. Report on the Economics of Sewage Sludge Disposal. STC Report No. 19. 1980.

20. DOE: Water Engineering. Research seminar on pathogens in sewage sludge. Technical Note No. 7. 1977.

21. DOE: Water Engineering. Research seminar on manurial value of sewage sludge. Technical Note No. 9. 1977.

22. DOE: Water Engineering. Research seminar on the effects of metal contaminants in sewage sludge. Technical Note No. 11. 1978.

23. DOE: Water Engineering. Inventory of UK research on land disposal of sewage sludge. Technical Note No. 12. 1978.

24. Dowdy R H and Larson W E. The availability of sludge-borne metals to various vegetable crops. J. Environ. Qual. 4, 278–282. 1975.

25. Doyle P J, Lester J N and Perry R. Survey of literature and experience on the disposal of sewage sludge on land. Report from Imp. Coll. Sci. and Tech. for DOE. 1978.

26. Furr A K et al. Multi-element and chlorinated hydrocarbon analysis of municipal sewage sludges of American cities. Environ. Sci. Technol. 10, 683–687. 1976.

27. Furr A K et al. Study of guinea pigs fed Swiss chard grown on a municipal sludge-amended soil. Arch. Environ. Health 31, 87–91. 1976.

28. Garner H V. Comparisons of farmyard manure, sewage sludge and other organic manures. J. Agri. Sci. Camb. 67, 267–280. 1966.

29. Hagiri F. Plant uptake of cadmium as influenced by cation exchange capacity, organic matter, zinc and soil temperature. J. Environ. Qual. 3, 180–183. 1974.

30. Institute for Research on Animal Diseases. Susceptibility of cattle to salmonellae in sewage sludge. Research project report for DOE. 1977.

31. John M K. Cadmium uptake by 8 food crops as influenced by various soil levels of cadmium. Environ. Poll. 4, 7–15. 1973.

32. John M K. Differential effects of cadmium on lettuce varieties. Environ. Poll. 10, 163–172. 1976.

33. John M K. Varietal response to lead by lettuce. Water, Air, Soil Poll. 8, 133–144. 1977.

34. Johnston A E, Mattingly G E G and Poulton P R. Effect of phosphate residues on soil P values and crop yields. Rothamsted Exp. Stn. report for 1975, 2, 5–35. 1976.

35. Jones P W et al. The occurrence and significance to animal health of salmonellas in sewage and sewage sludges. J. Hyg. Camb. 84, 47–62. 1980.

36. Jones R L et al. Cadmium content of soybeans grown in sewage sludge-amended soil. J. Environ. Qual. 2, 351–353. 1973.

37. Klein L A et al. Source of metals in New York City wastewater. J. Wtr. Poll. Con. 46, 12, 2653–2662. 1974.

38. Lahann R W. Molybdenum hazard in land disposal of sewage sludge. Water, Air, Soil Poll. 6, 3–8. 1976.

39. Larkin E P et al. Persistence of virus on sewage-irrigated vegetables. J. Environ. Eng. Div., ASCE 102, 29–35. 1976.

40. Latterell J J et al. Sludge-borne metal uptake by soybeans as a function of soil cation exchange capacity. Comm. Soil Sci. and Plant Anal. 7, 465–476.

41. Lawrence J and Tosine H M. Polychlorinated biphenyl concentrations in sewage and some sludges of some waste treatment plants in southern Ontario. Bull. Environ. Con. and Toxicol. 17, 49–56. 1977.

42. Marks M J, Williams J H and Chumbley C J. Field experiments testing the effects of metal-contaminated sewage sludges on some vegetable crops. ADAS Conf. Inorg. Poll. and Agric. 1977.

43. Newton W I et al. Observations on the effects of various sewage treatment processes upon eggs of Taenia saginata. Amer. J. Hyg. 49, 166–175. 1949.

44. Page A L. Fate and effects of trace elements in sewage sludge when applied to agricultural lands. US EPA 670/2–74–005. 1974.

45. Page A L, Bingham F T and Helson C. Cadmium absorption and growth of various plant species as influenced by solution Cadmium concentration. J. Environ. Qual. 1, 288–291. 1972.

46. Royal Commission on Environmental Pollution. 7th. Report. Agriculture and Pollution. Cmnd. 7644. HMSO. September 1979.

47. Silverman P H and Guiver K. Survival of eggs of Taenia saginata after mesophilic anaerobic digestion. J. Inst. Wat. Poll. Con., 345–346. 1960.

48. Simon E. Cadmium tolerance in populations of Agrostis tenuis and Festuca ovina. Nature, Land. 265, 328–330. 1977.

49. Sommers L E et al. Variable nature of the chemical composition of sewage sludges. J. Environ. Qual. 5, 303–306. 1976.

50. Southey J F and Glendinning K R. The effect of mesophilic digestion of sludge on potato root eelworm cysts. J. Inst. Sew. Purif. 65, 186. 1966.

51. Webber J. Effects of toxic metals in sewage on crops. Wat. Poll. Con. 71, 404–413. 1972.

52. Webber J. Effects of zinc and cadmium added in different proportions on the growth and composition of lettuce. Proc. Conf. on utilisation of sewage sludge on land. ADAS Conf. Inorg. Poll. and Agric. 1977.

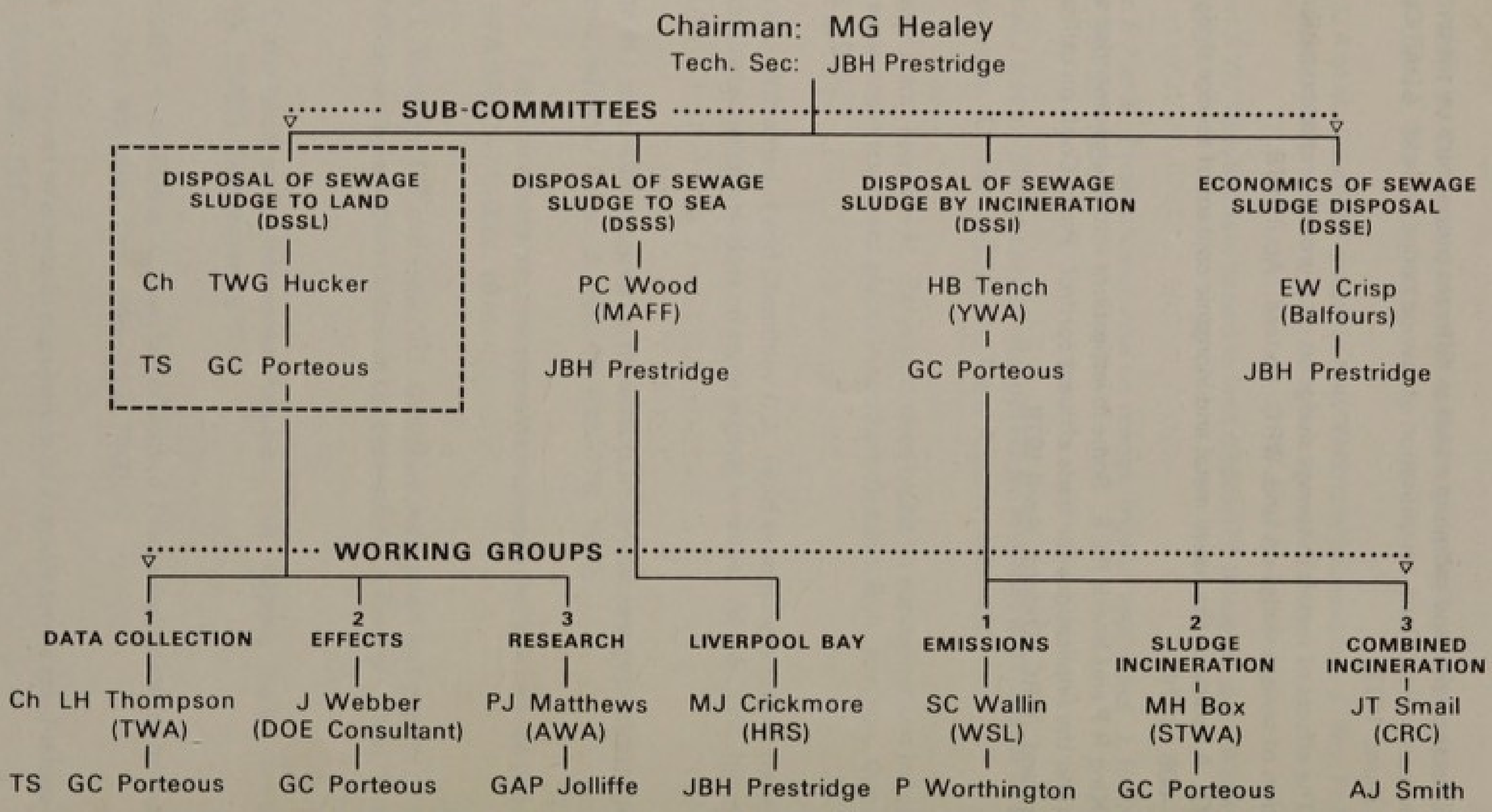
53. Webber J. The effects of metals in sewage sludge on crop growth and composition. Proc. Conf. on utilisation of sewage sludge on land, WRC. Oxford. April 1978.

54. Williams R O. A survey of the heavy metal and inorganic content of sewage sludges. Wat. Poll. Con., 607–608. 1974.

55. Wood L B, King R P and Norris P E E. Some investigations into sludge-amended soils and associated crops and the implications for trade effluent control. Proc. Conf. on utilisation of sewage sludge on land. WRC. Oxford. April 1978.

STRUCTURE OF THE STANDING COMMITTEE ON THE DISPOSAL OF SEWAGE SLUDGE

MARCH 1981



(The research activities of DSSS,DSSI and DSSE are dealt with at sub-committee level.)

APPENDIX G

SHORT INDEX

The main paragraphs relevant to subjects discussed in the report under the sections on sludge characteristics, disposal practice, effects, optimisation and recommendations are listed below for convenient reference.

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