SEWAGE SLUDGE DISPOSAL:
CURRENT AND FUTURE OPTIONS

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ABSTRACT

Sewage sludge is an inevitable product of all conventional sewage treatment processes. Disposal of sludge in an economic and environmentally-acceptable manner is becoming generally more difficult. Sludge quantities are rising and disposal options decreasing. Disposal will increasingly require positive and careful management. There are four basic destinations for sludge - agriculture, other types of land, the sea or minor outlets. Treatment methods are available for the production of nine basic types of end-product to suit particular disposal requirements. The new EC Directive will regulate sludge to agriculture and will require that all sludge to farmland is treated unless it is immediately buried under the soil.

Sludge to agriculture (grassland or arable) is subject to soil metal limits and to the need to minimise the risk of disease transmission. Sludge to landfill is subject to increasing constraints, particularly on physical stability. Sludge to sea is still practised by the UK but is closely controlled by Government licence and a requirement for monitoring. Minor outlets such as oil production, protein extraction etc are only at the experimental level. A computer program (WISDOM) provides a means of evaluating the short/long-term viability of alternative treatment and disposal options to identify the most economic and environmentally-acceptable strategy on an objective basis.

KEYWORDS

Sewage sludge, production, treatment, disposal, characterisation, agricultural use, landfill, marine disposal, minor uses.

INTRODUCTION

With our present knowledge, there seems little prospect of developing a cost-effective sewage-treatment process which does not transfer a significant proportion of the pollutant load into a concentrated wet solids sidestream requiring off-site disposal. For the foreseeable future, therefore, sewage works will continue to function as "sludge factories" with unceasing and unstoppable output. Sewage sludge will also remain a product whose quality is not strictly controllable, which may have no secure long-term outlet and which, usually, entails processing, transport and disposal costs of up to half the total cost of operating the sewage works. Sewage sludge is thus often regarded as the 'major problem' of water pollution control technology.

The Member States of the European Community (EC) currently operate over 30,000 "sewage-sludge factories" yielding a total of some 5.5 million dry tonnes of solids per year (Bowden, 1987). With the further major water pollution control schemes in prospect, EC sludge production is expected to rise by at least one third over the next
10 years. In the UK, where over 85% of the population is already served by sewage works, sludge production is just over 1 million tonnes dry solids per year and will continue to rise gradually. UK sludge treatment and disposal costs are now of the order of £250 million per year.

The disposal of sewage sludge always requires very positive and careful management but the ease, or difficulty, with which disposal is actually achieved, and the associated costs will obviously depend very much on circumstances. Both local and national geographical, agronomic, economic and ‘political’ factors will have some influence. The general trend in recent years in most developed countries has been for the disposal of sewage sludge to become more, rather than less difficult; and in some areas it is becoming very difficult indeed! The problem applies particularly to the more densely populated areas; for example, in the Netherlands where the agricultural outlet for sludge is becoming increasingly restricted and is competing with increasing quantities of animal manures (de Bekker and van den Berg, 1987). In Switzerland, agricultural use of sludge has decreased markedly during the last few years owing to stricter requirements. Landfill represents another option but restrictions on this outlet are increasing (Lichensteiger et al., 1987). Sea disposal is not an option for most countries.

All EC States will be subject in 1989 to a new community Directive designed to protect the agricultural environment from adverse effects of sludge utilisation on land (Council of the European Communities, 1986). This will impose further restrictions on sludge ‘producers’ though the general effect will be to promote better control of sludge quality and use to help ensure that the agricultural outlet is both safe and beneficial.

In recent years, sewage sludge has become an ‘international topic’ with numerous conferences and, in the case of the EC, interstate co-ordinated research and scientific committees focussing on various common problems (Commission of the European Communities, 1983). This activity reflects the growing realisation that while world sludge production is on a relentless growth curve, environmental quality requirements for sludge are becoming increasingly stringent, disposal outlets are decreasing and yet economic pressures still require low-cost solutions to sludge disposal problems.

THE CURRENT STATE OF KNOWLEDGE

Research and development relating to the treatment and disposal of sewage sludge has increased markedly in the last 10 - 20 years. UK expenditure on R & D in this area has been running at approximately £2 million per year. There has been a great increase in knowledge about production rates, methods of characterisation, handling and processing techniques, about the potential benefits and risks of sludge utilisation in agriculture and the behaviour of sludge in other disposal environments. But sludges differ widely in their characteristics. No two works produce an identical product, so there is no general solution for every situation.

Quantities

There is now fairly good agreement on rates of production of different types of sludge so predictions can be reasonably accurate for design purposes (Poulanne, 1984). Using conventional sewage-treatment technology, it is difficult to achieve any substantial reduction in production rates. However, the search for a method to significantly reduce production will continue. The ‘wet oxidation of sludge solids’ is one possibility and has been examined in a number of studies (Fisher, 1971). This process represents an almost ‘sludgeless’ method of sewage treatment but practical considerations and costs rule it out, except in very special circumstances.

In the UK, a process known as ‘LOSILUJ’ is under investigation (Hoyland and Ronald, 1984). It is essentially biological filtration of sewage but differs from traditional filtration in that the primary sedimentation stage is replaced by fine screens so that most of the sewage suspended solids pass into the filter to be partially destroyed by biological action. The filter has high-voidage media. Compared with traditional treatment, LOSILUJ produces solids at about 40% of the lower rate for conventional treatment. The overall effect is to reduce operating costs by approximately 20%. However, the prospects of employing more than a few of these plants in the next few years are limited so they will have a minor effect on national sludge production.
Sewage sludge disposal

Sewage sludge disposal

Sludge quality

The quality of raw sludge is only partly under the control of sewage works management. Using trade waste control, the concentrations of potentially toxic components can be reduced to acceptable levels and great improvements in this direction have been seen in the UK and other countries in recent years. Domestic sludges represent the least contaminated type but some heavy metals, detergents and other organic residues are always present. The pathogen content of raw sludge is determined basically by the health of the local contributing population and cannot be initially controlled. However, techniques of disinfection are now available for use and a great deal more is known about the effectiveness of conventional processes in destroying pathogens.

Economic considerations rule out the use of special processes at sewage works to remove chemical contaminants from sludge although the practicality of extracting heavy metals has been demonstrated. The contaminants would still require disposal somewhere.

One of the potential problems with regard to the quality of sludge is its content of rag and other 'litter' material. This can present a problem when sludge is spread on land or in the marine environment. In recent years, advances have been made in the fine-screening of sewage and successful methods of sludge screening are now also available. The practice of fine-screening is a growing one and its beneficial effects are likely to become more widely appreciated when seen in the context of improved ease of treatment and disposal (Holladay, 1986).

Characterising sludges

Sludges vary considerably in their characteristics. A total of 27 different parameters for sludge characterisation, and methods of determining them, have now been developed, (Commission of the European Communities, 1983). These range from conventional total solids, and volatile solids determinations to measurements of consolidation characteristics and filtration characteristics requiring specialised equipment. In designing a treatment plant, it is important, where possible, to characterise the sludge as closely as possible in order to be able to design the optimum sizes and sequence of treatment processes. In the absence of a sludge (ie. a 'greenfield' site) then it may be appropriate to assume "modal" characteristics which represent typical sludges. However, the variability of sludge behaviour is such that even this assumption presents some risk.

SLUDGE PROCESSING IN RELATION TO DISPOSAL ROUTE

It may be argued that selection of the 'best disposal route' for sludge from a particular works should start by identifying the most secure and environmentally acceptable final destination for the sludge and this, in turn, will dictate the type of treatment required before disposal. In theory, at least, the sludge processing requirements might even determine the type of sewage treatment process employed. For example, a high-rate activated sludge process is not ideal where dewatering to a high-solids cake is required. This reverse sequence of selection procedures rarely occurs in practice and, indeed, sludge disposal is still often a secondary consideration in sewage works design. Disposal has often been done on an 'ad hoc' basis with each work's management determining a local sludge disposal solution. However, in recent years, in the UK, sludge disposal strategies for much larger areas (eg river basins) have been evolved.

The options potentially available for sludge disposal in the UK are indicated in Fig. 1. These are basically (i) agriculture (including horticulture), (ii) other on-land outlets, (iii) the marine environment, and, (iv) specialised outlets such as building materials, feedstuffs, fuels etc. Referring to Fig 1, the degree of usage of outlet in the UK decreases from left to right. The actual percentages are shown against 'destination'.

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It is seen that a given final destination may be reached only by complying with certain constraints, which may be more or less restrictive depending on the actual destination. The agricultural outlet is by far the most popular for inland works, mainly because it is the most convenient and least expensive. Gregory (1986) has shown, for example, that the cost of three options in one Water Authority are:

<table>
<thead>
<tr>
<th>Option</th>
<th>£/tonne DS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge digestion and tankering to farm</td>
<td>47</td>
</tr>
<tr>
<td>Plate pressing/tip</td>
<td>62</td>
</tr>
<tr>
<td>Incineration</td>
<td>80</td>
</tr>
</tbody>
</table>

By comparison, the cost of sea dispersal could range from £30 - £200 per tonne DS but it is obviously appropriate only for works sited on or near estuaries and coasts and only then if officially licensed.

The long-term future of sea dispersal is under considerable pressure but there is no reason why agricultural use should not continue providing it is carried out in accordance with scientifically-based guidelines and regulations.

**Treatment requirements for disposal outlets**

It is technically feasible, by employing appropriate treatment processes, to produce at least nine different types of sludge end-product for final disposal (Fig. 2). This total excludes the more exotic end products such as oil, protein and building materials (Frost and Campbell, 1986) which require special, and expensive, processing techniques.

The most basic end product - raw sludge (thickened or unthickened) - can still represent the most economic type for disposal provided a suitable outlet is available. Raw sludge is becoming less and less acceptable environmentally but even under the new EC Directive it can still be used in agriculture provided it is immediately injected or ploughed into the soil (i.e. in situ treatment). Raw sludge may also go to sea but there is a need to ensure that it does not cause visual pollution from grease and floating solids.

For most situations, however, sludge needs first to be treated. In the EC Directive, "treated sludge" is defined as "sludge which has undergone biological, chemical or heat treatment, long term storage or any other appropriate process so as significantly
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to reduce its fermentability and the health hazards resulting from its use. This is clearly a rather loose definition of treatment, but the general intention is clear, that is to process sludge so as to reduce its nuisance value from odour and to reduce significantly the number of pathogens present. Individual EC states will provide closer definitions of the treatment actually required within their borders in order to meet the requirements of the Directive. In the UK, a Code of Practice will indicate a range of treatment processes which will be deemed to satisfy the definition of "treated" as given in the Directive.

The requirements for treatment before landfilling or land reclamation will depend on the particular site and the site owner's requirements. The general trend for landfill is to require sludge cake which is physically stable and this may require dewatering to a solids content of well above 30%, so appropriate dewatering systems have to be used.

For marine disposal, the conditions of the Government licence will specify maximum quantities and maximum amounts of specific pollutants that may be disposed of at sea but there may be no definite requirement for treatment. However, it is often in the best interests of the producer to, for example, thicken the sludge prior to disposal to reduce volume and to stabilise, by say digestion, to minimise the quantity of sludge solids for disposal and to control local odour nuisance.

DEVELOPMENTS IN SLUDGE PROCESSING

The range of unit operations and processes which may be used to modify the quantity and character of raw sludge before disposal are summarised in Fig 2. (Bruce et al, 1984.) Essentially, there are 6 which can be employed, either alone or in combination.

(a) Screening to remove gross solids
(b) Thickening to reduce liquid volume
(c) Positive disinfection to destroy pathogens
(d) Stabilisation to improve odour and reduce pathogens
(e) Dewatering to form a solid cake
(f) Thermal destruction of organics (incineration) to minimise the mass of solids for disposal

Specialised treatment/conversion processes such as pyrolysis, protein extraction etc, are not included since they are used only in rare circumstances, and not at all in the UK as yet.

FIG 2. Flow-chart of sludge processing options for production of suitable end-products for utilisation or disposal.
Screening

Screening of raw sludge to remove coarser material is becoming more important since it is seen as clearly advantageous in reducing down-stream processing problems (e.g. blockages of pumps and pipelines, scum formation etc) and in avoiding visual contamination of the disposal area with 'litter'. Several new screening devices have become available in recent years (Holladay, 1986) but further developments and evaluation work are still proceeding. The alternative option of fine screening of the sewage flow is also becoming more widely applied and this obviates the need for separate sludge screening.

Thickening

Economic assessments show that the installation of sludge thickening often represents a considerable cost benefit, especially where the sludge is finally transported in liquid form to its disposal outlet. The use of thickening in the UK has, in the past, been relatively limited. But now there is a surge of interest in gravity thickening and considerable numbers of new thickeners are being installed or planned. This has largely come about as a result of a much better fundamental understanding of the physical mechanism of consolidation thickening (Hoyland, Dee and Day, 1988). Laboratory characterisation tests can now be carried out to quantify the thickening characteristics of the sludge from a given works. Tests are important because sludges vary widely in their consolidation behaviour. The results of the tests are used in a computer model to derive the optimum physical dimensions of a full-scale thickener for a given load. There have also been advances in the mechanical design of full-scale picket-fence thickeners. Performance of such units has been shown to be extremely good (Hudson et al. 1987).

Disinfection

A requirement for the positive disinfection of sludge in order to ensure complete destruction of pathogens is unusual. In the UK, there is no general need but in Switzerland and FR Germany there is a requirement for 'hygienisation' of sewage sludge before use on pastureland. Several techniques are available for disinfection, and most of these are based on the heating of the sludge to a relatively high temperature for a short period of time (e.g. 70°C for 30 mins - pasteurisation). The range of options for disinfection are reviewed elsewhere (Bruce and Fisher, 1984).

In the UK, the process of 'submerged combustion' has been used successfully to heat raw sludge for pasteurisation before anaerobic digestion. The pasteurisation plant uses digester gas as the fuel and is self-sufficient in energy. The degree of destruction of pathogens was very high (Hudson et al. 1987). If such a process can be demonstrated to be cost-effective, it could come into wider use since it gives added security to agriculture disposal.

Stabilisation

Sewage sludge can be stabilised in various ways, all with the major object of rendering the sludge less offensive particularly with regard to odour. Most stabilisation processes are also effective in reducing pathogen numbers. Anaerobic mesophilic digestion is still by far the most common method of stabilisation. Apart from its effectiveness in odour control, it is also efficient for pathogen destruction so long as a suitable storage period is provided after the primary digestion stage. Energy recovery from digester gas is also an advantage in some cases.

A development of major importance in recent years in the UK, although not to any extent elsewhere, has been the use of pre-fabricated steel tanks for digesters, particularly at smaller works. There has also been a strong trend towards feeding thickened sludges to digesters and this, together with lower design retention periods (usually in the range 12 - 15 days) has resulted in a general 'intensification' of the anaerobic digestion process and an overall improvement in the economics.

However, perhaps the most important innovation in recent years has been the practical implementation of autothermic thermophilic aerobic digestion. With operating temperatures of 55°C and above and retention periods of 7 - 10 days it provides a
process for both stabilisation and disinfection in one stage. The simplicity of the process compared to anaerobic digestion gives it a particular advantage at smaller works (Bruce and Oliver, 1988).

**Dewatering to solid state**

Dewatering to a solid remains a technique of major importance though in the UK in recent years there has been some trend towards disposal in liquid form, and maintaining dewatering plant for emergency use only. Some new dewatering systems can produce very high cake-solids. One of the major cost factors in dewatering is the need to use chemical flocculants to condition the sludge. Recent developments in the UK offer a much more efficient method of addition of polyelectrolyte to sludge by means of an on-line mixing device just ahead of the dewatering machine (Hoyland and Ovens, 1987). An automatic system for filter press cake-quality control has also been developed and the two systems together have been shown to reduce dewatering costs by at least one-third.

**Incineration**

There has been much development to improve the technology of incineration, particularly in Europe, and modern plant appears now to be more attractive in terms of both capital and operating costs than older plants. Techniques are now available to control gaseous emissions to meet stringent environmental standards. The UK has only 4 sludge incinerators in operation at present but 2 new incinerators are planned in Yorkshire and incineration will become a major disposal route within that area (Lowe 1987).

**ENVIRONMENTAL QUALITY REQUIREMENTS FOR DISPOSAL OUTLETS**

**Utilisation on land**

This disposal outlet allows recycling of the plant nutrients and organic matter in the sludge. It has to be spread relatively thinly and, therefore, it is not left to accumulate at one site where it might represent a potential pollution threat. The importance of agriculture as a disposal outlet in Europe has been reported by Bowden, (1987). Overall, approximately 37% of total production goes to agriculture.

**Grassland**

This is the main form of agriculture to the north and west of the UK, in Ireland and in upland regions of Europe. For sludge utilisation, grassland has the advantage that it is likely to be accessible throughout the year.

It has the disadvantage that there is a risk of disease transmission to grazing animals due to the possible presence in the sludge of pathogens such as Salmonella or beef tapeworm eggs (Taenia saginata). If sludge is spread on the surface of grassland, it is necessary first to treat it by a process which significantly reduces numbers of pathogens so as to avoid disease transmission. In the UK this is currently achieved by a combination of sludge treatment and disposal practice as set out in Table 1.

The EC Directive will not permit the application of untreated, sludge to grassland unless injection is used to bury the sludge beneath the soil surface. Where soil conditions and operator skill result in successful injection there is the dual advantage of avoiding both pathogen risk and odour nuisance. This can otherwise be a major source of complaints from the public in built up areas. Grassland is best suited to receive dressings of liquid digested sludge because digestion gives adequate control of pathogens and the sludge contains sufficient plant-available ammoniacal nitrogen to sustain rapid growth of grass. Dewatered sludge, unless applied thinly and evenly, can leave persistent lumps of sludge on the surface of the grass which may cause sward damage or adversely affect grazing animals if ingested.

As with other land utilisation outlets, sludge applied to grassland is subject to soil metal limits. Those currently recommended for the UK are set out in Table 2. These
will alter in June 1989 with implementation of the EC Directive metal limits (Table 3) together with updated UK limits currently being formulated into the new UK Code of Practice.

Grazing animals may inadvertently ingest sludge adhering to herbage or on the soil surface. For this reason sludges applied to grassland are subject to special limits on their lead and fluoride content. The limits for molybdenum are also set to protect the health of ruminant animals since an excess of this element in the diet may interfere with trace element metabolism and cause induced copper deficiency.

### Table 1 Summary of Recommendations to Control Pathogen Problems (DoE/NWC, 1981)

<table>
<thead>
<tr>
<th>Sludge</th>
<th>General arable inc. forestry, land reclamation, conservation crops</th>
<th>Seed potatoes and export nursery stock</th>
<th>Grazed crops</th>
<th>Salad crops consumed raw</th>
<th>Park flower beds</th>
<th>Orchards turf</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Liquid raw</td>
<td>/</td>
<td>x</td>
<td>C</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2. Liquid raw stored 2 weeks</td>
<td>/</td>
<td>x</td>
<td>C</td>
<td>x</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>3. Cold anaerobic digested</td>
<td>/</td>
<td>x</td>
<td>AB</td>
<td>E</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>4. Lagooned 2 years</td>
<td>/</td>
<td>x</td>
<td>AB</td>
<td>E</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>5. Mesophilic anaerobic</td>
<td>/</td>
<td>AB</td>
<td>E</td>
<td>/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Heat processed</td>
<td>/</td>
<td>AB</td>
<td>E</td>
<td>/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Non-limed cake</td>
<td>/</td>
<td>C</td>
<td>x</td>
<td>x</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>8. Non-limed cake stored</td>
<td>/</td>
<td>AB</td>
<td>E</td>
<td>/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Limed, cake or stabilized</td>
<td>/</td>
<td>C</td>
<td>E</td>
<td>/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Full treatment biological (inc. aerobic digested and extended aeration of whole sewage)</td>
<td>/</td>
<td>C</td>
<td>E</td>
<td>/</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>11. Partial treatment biological</td>
<td>/</td>
<td>x</td>
<td>C</td>
<td>x</td>
<td>x</td>
<td>D</td>
</tr>
</tbody>
</table>

/ Acceptable.  
X Unacceptable.  
A 3 weeks grazing interval, but 5 weeks for cattle which produce milk which is consumed unpasteurised.  
B Where <40% organic matter is destroyed in digestion or storage period less than that recommended, the grazing interval should be increased accordingly from 3 weeks to 6 months for pigs and cattle.  
C Grazing interval for pigs, cattle, 6 months, other animals as A.  
D No fruit or turf harvested for 3 months after application.  
E None to be sown until 12 months after application.  
F Only mesophilic digested and heat treated sludges to be used in gardens and allotments - this practice to be phased out.

Food chain contamination resulting from the use of sludge on grassland is likely to be minimal because heavy metals do not accumulate in either meat or dairy products for human consumption. The exception to this is cadmium which can accumulate in offal (liver and kidney). However, this is unlikely to be a problem where the EC soil limits are observed especially since farm animals for meat production are short-lived. Certain lipophilic persistent organic contaminants eg organochlorine insecticide residues (Lindsay, 1983) can accumulate in fatty tissues and be excreted in milk following direct ingestion of contaminated sludge. Suitable controls on trade effluents from industrial premises which make, use or handle these compounds usually restrict their levels in sludge to negligible concentrations. Therefore, specific limits for organics in relation to sludge utilisation are not considered necessary at
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In the USA, there is a limit of 10 ppm for PCBs in sludge used on land (US EPA, 1979) although the concentrations usually found are one to two orders of magnitude lower.

Table 2 Recommended Limits for Potentially Toxic Elements (DoE/NRC, 1981)

<table>
<thead>
<tr>
<th>Metal</th>
<th>Receiving situation</th>
<th>Limit of addition kg/ha</th>
<th>Arable soil limit mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>All</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Cadmium</td>
<td>All, Gardens, etc</td>
<td>5</td>
<td>3.5</td>
</tr>
<tr>
<td>Chromium</td>
<td>All</td>
<td>20**</td>
<td>1000</td>
</tr>
<tr>
<td>Copper</td>
<td>Arable land pH &gt;7</td>
<td>560</td>
<td>280*</td>
</tr>
<tr>
<td></td>
<td>Permanent pasture</td>
<td>560</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arable pH &lt;7</td>
<td>280</td>
<td>140*</td>
</tr>
<tr>
<td>Mercury</td>
<td>All</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>All</td>
<td>4***</td>
<td>4</td>
</tr>
<tr>
<td>Nickel</td>
<td>Arable land pH &gt;7</td>
<td>140</td>
<td>70*</td>
</tr>
<tr>
<td></td>
<td>Permanent pasture</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arable pH &lt;7</td>
<td>70</td>
<td>35*</td>
</tr>
<tr>
<td>Lead</td>
<td>All</td>
<td>1000</td>
<td>550</td>
</tr>
<tr>
<td></td>
<td>Pasture land</td>
<td>2000**</td>
<td></td>
</tr>
<tr>
<td>Selenium</td>
<td>All</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Zinc</td>
<td>Arable land pH &gt;7</td>
<td>1120</td>
<td>560*</td>
</tr>
<tr>
<td>equivalent</td>
<td>Permanent pasture</td>
<td>1120</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Arable land pH &lt;7</td>
<td>560</td>
<td>280*</td>
</tr>
<tr>
<td>Boron</td>
<td>Arable land</td>
<td>5-3.5****</td>
<td>3.25</td>
</tr>
<tr>
<td></td>
<td>Pasture land</td>
<td>7-4.5****</td>
<td></td>
</tr>
<tr>
<td>Fluorine</td>
<td>All</td>
<td>600</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Pasture land</td>
<td>3500**</td>
<td></td>
</tr>
</tbody>
</table>

+ Except for boron, the metals should be added over at least 30 years; no more than one-fifth in one application.
* EDTA extractable.
** mg/kg^-1^ sludge.
*** When >0.15 kg/ha/y monitor herbage, when this >2 mg/kg dry weight, seek advice.
**** kg/ha/y (hot water soluble).

Table 3 Limit Values for Metals (CRC, 1986)

<table>
<thead>
<tr>
<th>Metal</th>
<th>Soil (mg/kg ds)</th>
<th>Sludge (mg/kg ds)</th>
<th>Annual amounts (kg/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>1-3</td>
<td>20-40</td>
<td>0.15</td>
</tr>
<tr>
<td>Copper</td>
<td>50-140</td>
<td>1000-1750</td>
<td>12</td>
</tr>
<tr>
<td>Nickel</td>
<td>30-75</td>
<td>300-400</td>
<td>3</td>
</tr>
<tr>
<td>Zinc</td>
<td>150-300</td>
<td>2500-4000</td>
<td>30</td>
</tr>
<tr>
<td>Lead</td>
<td>50-300</td>
<td>750-1200</td>
<td>15</td>
</tr>
<tr>
<td>Mercury</td>
<td>1-1.5</td>
<td>16-25</td>
<td>0.1</td>
</tr>
</tbody>
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Surface applications of sludge to permanent grassland lead to accumulation of metals in the upper 7.5 cm of the soil profile (Davis, Carlton-Smith, Stark and Campbell 1988). Because the sludge is not cultivated down the profile it is held in a smaller volume of soil. The maximum metal limit will be reached by the application of only about 30% of the sludge required to reach this level in a cultivated, arable soil profile. Whether or not it is appropriate to work to soil metal limits in the upper 7.5 cm of permanent grassland is currently being researched. This does represent a potential future restriction on the quantity of sludge that can be applied to permanent grassland. The reasons why permanent grassland remains unploughed relate mainly to soil conditions, topography and accessibility and these factors may also make it unsuitable for sludge. In particular, steep slopes make spreading difficult.
and prone to run-off problems. Permanent grassland soils tend to be acid (pH value 5.0-6.0) and this will probably require working to lower soil metal limits (for zinc, nickel and copper) because of increased metal mobility and hence potential toxicity. This is a further restriction on the amount of sludge that can be applied to these soils.

Arable land This is land used to grow a rotation principally of cereal and forage crops. Sludge utilisation on arable land is a well established outlet throughout the world. There is therefore a reliable base of operational experience and research results on which to develop environmentally-acceptable practices suitable for particular agricultural conditions.

In the UK, arable land receives about 25% of sludge production. It is not as sensitive as grassland to problems of disease transmission, except when used on land growing crops eaten raw but problems can be avoided by appropriate sludge treatment and disposal practice, (Table 1).

The long-term effects of sludge in relation to soil quality and crop production also require examination. There has been concern that contaminants in sludge applied to the land may become more environmentally active and potentially toxic many years after application have ceased. An increase in environmental activity might be linked to long-term changes in soil properties such as a reduction in organic matter or an increase in acidity. Evidence from one historically sludge-treated site suggests that metals from sludge may ultimately reduce soil microbial biomass and nitrogen-fixing capability (MoGrath and Brookes 1986). Research is in progress to find out if these investigations could lead to a further tightening of soil metal limits where sludge is used.

Dedicated land This is farmland set aside on a sacrificial basis for sludge disposal. The sites concerned are often old sewage farms surrounding the sewage treatment works, which have been used for the disposal of sewage and sludge over many years. Although these sites represent only a minor outlet for UK sludge they are of strategic importance locally and provide a very low-cost disposal outlet. Cultivation of forage crops or small-grain crops for animal feed is a low-risk option for historically-contaminated soils in which metal levels may already exceed the maximum
Sewage sludge disposal

permissible concentrations. The EC Directive permits the continued use of dedicated land already in use in 1986 provided it is used to grow crops exclusively for animal consumption with no resulting hazard to either human health or the environment. Strict management along these lines (Rundle, Calcroft and Holt 1982) can permit productive farming to continue on sacrificial land which might otherwise be condemned to permanent dereliction. Apart from low cost, the advantage of using dedicated land is that any polluting potential is contained, and contamination problems can be minimised by using suitable farming practices. The disadvantage is that the high concentrations of contaminants in the soil will severely restrict use of the land for other purposes. Drainage water from these sites will be high in nutrients, especially nitrate, following repeated heavy applications.

Horticultural land and gardens Use of sludge in gardens and for horticultural crops represents a comparatively high-risk outlet in terms of effects of metals and potential for pathogen transmission because there is likely to be little control over how the sludge is used. It will probably remain a minor outlet suitable only for sterilised or composted sludge of very low metal content.

Reclamation and green areas Extraction of coal, minerals, clay, sand and gravel and other earth moving activities leaves behind barren land which is unproductive and unsightly if it is left bare of vegetation. The substrate is likely to be poorly structured and devoid of organic matter and plant nutrients. A heavy once-only application of sludge of perhaps 100 tonne dry solids/hectare can be an effective method of restoring fertility to the soil surface (Hall, et al 1986). This will enable vegetation to establish thereby improving the appearance of the site and helping to prevent erosion but account must be taken of the proposed use of the restored land. With good management there should be no difficulties where the land is to be used for low grade agricultural purposes or for landscaping. If housing is proposed, then the fact that some of the restored land will become gardens that may be used for vegetable growing has to be considered. In environmental terms, the use of sewage sludge in land reclamation is an attractive option representing positive recycling with little risk of problems due to pathogens or contaminants. The main difficulty in using sludge for land reclamation is that of finding sufficient accessible sites on a continuous basis. This may require on-site storage of sludge before use and the co-operation of those responsible for restoration of the site. Often, dewatered sludge is required but repeated applications of liquid sludge can be made and will be more effective if incorporated into the soil profile, for instance by subsurface injection.

Green areas such as amenity grassland, parks and golf courses represent a minor outlet in the UK but may be of strategic use when other land is inaccessible.

Forestry The problem with this outlet is again logistical since forest land is usually remote from the conurbations producing sludge. Experience in the UK (Bayes, Davis and Taylor, 1987) and USA (USA EPA, 1984) suggests that sludge can be utilised satisfactorily in commercial coniferous forests either to prepare the ground before planting (dewatered sludge) or to fertilise growing trees (liquid sludge). In these circumstances, there should be no problems due to pathogen transmission or food chain contamination. Environmental concerns relate to the possibility of run-off since forest land is often on steep slopes in water catchment areas, and to the acid soils which may cause metal mobility. According to the USA EPA (1984) forest soils are well suited to sludge application, having high rates of infiltration (which reduce run-off and ponding), large amounts of organic material (which immobilise metals from the sludge), and perennial root systems (which allow year round application in mild climates).

Landfill

Disposal to sanitary landfills is used for more than 40% of sludge in Europe and about 20% of sludge in the USA and Canada. Despite the importance of this outlet, it has received comparatively little research attention and it is not usually subject to specific disposal guidelines apart from those for landfill management in relation to groundwater protection. Heavily-contaminated industrial sludge might, of course, be
classified as hazardous waste to be handled accordingly. Provided that workers on-site are suitably equipped, pathogen transmission from landfilling should not be a problem. There is no clear pattern regarding sludge treatment for landfilling. However, stabilised sludge may be attractive to the landfill manager as an 'end-of-day' or final cover material before restoration.

The main prerequisite for sludge going to landfill is dewatering to provide physical stability. The addition of liquid sludge to a landfill in any significant quantity will inevitably increase the volume of leachate which is generated and requiring to be treated or dealt with in some way which avoids pollution of ground or surface water. The other advantage of using dewatered sludge is that it provides some physical stability which is essential for the movement of vehicles on the site. Landfills receiving sludge are usually co-disposal sites where the sludge is mixed with domestic refuse. In order to incorporate sludge as 10-20% of the overall fill the sludge will need to be dewatered to a dry solids content of at least 25% and preferably more. In the FRG it is considered necessary for sludge going to landfill to have a dry solids content of at least 35% (Brunner and Lichtensteiger, 1987). One reason for this is that the plant for moving, handling and compacting waste on landfills tends to be designed for use with urban refuse. If specialist plant was available there might be scope to incorporate alternative types of sludge. Given a choice, landfill managers prefer sludge conditioned with lime rather than polyelectrolytes. Lime-treated cake is odour-free, easier to handle and has better physical stability. In large landfills where gas recovery is possible, gas yield may be improved by using sludge either as a source of degradable organic matter or, in the case of anaerobically-digested sludge, as an inoculum of methanogenic bacteria. Trials recently reported in the USA showed that the addition of 10-30% by volume of digested sludge to municipal solid waste induced rapid anaerobic biological stabilisation substantially more quickly than when no sludge was added. Also the addition of sludge reduced the COD load of the leachate (Farrell, Dotson, Stamm and Walsh, 1987).

Incineration

This is an option mainly for sludge from works remote from farmland suitable for utilisation or landfill sites and where road haulage to such sites would cause traffic nuisance. The location of incinerators may be subject to planning difficulties associated with public concern about the possible emission of mercury and cadmium and organic contaminants. However, more effective dewatering of sludge, efficient heat recovery from the combustion process and reliable control of the flue gas emissions has lead to renewed interest in incineration for urban sewage treatment works which may be producing comparatively contaminated sludges.

Sea Dispersal

This is an outlet for coastal and estuarial sewage works accounting for about 5% of sludge in Europe, predominantly from the UK and Ireland where it is an important disposal route. In the USA about 4% only of sludge is dispersed at sea (Webber et al 1986) but it is strategically important for the cities involved. The Oslo and London conventions (1972) call for control by general permits of materials such as sewage sludge which contain only traces of Annex 1 substances (eg mercury, cadmium and organochlorine compounds) and Annex 2 substances (eg lead, zinc, copper and arsenic). Marine disposal of sludge from the UK is carried out under licence from the Ministry of Agriculture, Fisheries and Food (or Department of Agriculture and Fisheries for Scotland) issued under the Food and Environment Protection Act, 1985. Account is taken of the quantity of sludge and the location and suitability of the disposal ground where the sediment quality and the diversity and abundance of the benthic fauna are usually monitored.

The UK disposal grounds range from accumulating to dispersing. At the former, currents are weak and sedimentation is rapid so that sludge solids accumulate on the sea bed with associated effects on the benthos although these effects are likely to be confined to a relatively small area. At dispersive sites, the sludge is widely dispersed before settling out with less intense effects on the benthos. The effects may be difficult to evaluate, especially if contaminants from other sources are present in the same general area. Sensitive environmental tests have been developed to quantify the environmental impact of sea disposal of sludge (eg Whitelaw and Andrews 1987) and the effect of nutrients derived from sludge is a further
consideration (Rheinallt 1988). Sludge for sea disposal may or may not be treated by such processes as anaerobic digestion and it may be thickened but it is never dewatered. Discharge by pipeline, as opposed to disposal from sea-going vessels, accounts for about 2% of sludge in Europe (Bowden 1987). Successful trials in South Africa have led to the City of Durban using sea disposal of sludge through pipelines as an alternative to land disposal and incineration (McGlashan and Macleod 1986).

Novel uses and other minor outlets

Various novel uses are discussed by Webber et al (1986) and Frost and Campbell (1986) including vermicomposting use as an animal feed supplement, lipid extraction, protein extraction, vitamin B12 extraction, metal recovery, overseas shipment, brick manufacture and thermal conversion to liquid and solid fuels. None of these are likely to be more than of local importance at least in the short-term and all require an ‘entrepreneurial’ spirit on the part of the sludge producer to promote an unusual outlet for his product.

SUMMARY ASSESSMENT OF DISPOSAL OPTIONS

The need to dispose of sludge economically and safely will be a continuing requirement into the future. Therefore, effective sludge disposal means finding the best value for money consistent with safeguarding the environment and maintaining long-term security of the operation. Selection of the best practicable environmental option involves consideration of social as well as economic and technical factors. The general public is becoming increasingly well-informed on environmental matters and environmental quality is a political issue. Whilst keeping within economic constraints, operators will have to ensure that sludge is disposed of in an environmentally acceptable way and that the public perceives that this is so.

Disposal methods which involve agricultural land have the advantage that the sludge is being put to positive use through the recycling of its content of plant nutrients to improve soil conditions for plant growth. Most countries have established guidelines or regulations for sludge utilisation on land and sufficient research has been undertaken to ensure that procedures designed to avoid contamination problems and pathogen transmission have a sound scientific basis. Long term effects of contaminants in the soil remain a matter for some anxiety but this can be allayed by research into effects on soil quality and a determined effort to reduce contaminant levels in sludge. The latter will also serve to lengthen the period of time over which land can receive sludge and hence secure the agricultural outlet as an economic option in the long term.

Grassland is a more sensitive outlet than arable land where good quality sludge is required in terms of both low metal levels and treatment to remove the risk of pathogen transmission. Subsurface injection of sludge is a desirable option, where soil conditions permit, for removing both the risk of pathogen transmission and the problem of odour nuisance which can be associated with surface spreading. Application of sludge by high profile rain guns is unpopular and can only be practised in remote areas. Utilisation on land depends on the goodwill of farmers and they will no longer take sludge unless their requirements are met. These include applying sludge in accordance with crop requirements for nutrients, which will also avoid leaching of excess nitrate, and avoiding soil structural damage. Land utilisation is vulnerable in the sense that news of problems will travel quickly amongst farmers and may dissuade them from taking sludge. It is also dependent on suitable weather for spreading, although facilities for on-farm storage of sludge can minimise this problem.

Horticultural land is a sensitive and rather impractical outlet which is unlikely to become of importance on more than a local basis. Forest land is an acceptable outlet but will always be subject to economic restrictions due to transport costs. Inclusion of forest land where feasible can add to the flexibility of a disposal strategy based principally on agricultural utilisation. The same is true of utilisation in land reclamation. The problems here are logistical, as described earlier, and also institutional since several agencies will have to collaborate to make reclamation a feasible outlet for sludge. It is nevertheless an attractive option with scope for further exploitation. A case can be made for the use of dedicated land for sludge
disposal on both environmental and economic grounds where spare land is available. However, the EC Directive will not permit expansion of this outlet beyond those sites already in use in 1986. Composting is a utilisation option practised on a growing scale in the USA and parts of Europe since the mid 1970s. Whilst doubts remain about its suitability for large operations it has proved successful in some larger cities of the USA (Kuchenrither et al. 1987) following increasingly tight regulatory control of conventional sludge disposal methods such as incineration, sea disposal and landfilling. In these circumstances it is an option which needs serious consideration.

Landfilling of sludge is likely to continue to be a major option for sludge disposal both in Europe and elsewhere. There is a shortage of suitable sites and costs of site operation are likely to increase due to requirements for groundwater protection such as lining and monitoring and provision for adequate leachate treatment. Normally, landfilling involves codisposal of the sludge with domestic refuse. If the sludge component is to exceed more than about 20% by volume of the codisposal mixture it may be required to undergo more costly treatment to improve physical stability by dewatering perhaps to at least 40% dry solids or even chemical stabilisation processes (Tittlebaum et al. 1985). Thus landfilling will remain an important disposal outlet for sludge but a route subject to increasing costs in the future.

Incineration is an option traditionally associated with high capital and operating costs, planning consent difficulties and potential problems due to gaseous emissions and ash disposal. Technological advance in sludge pretreatment, heat recovery from the process and efficient stack emission control may lead to an increase in the use of incineration in the future, particularly as costs now seem more attractive. It is a possible option for coastal and estuarial cities now using sea dispersal if faced with the need to find an alternative outlet in the future.

Sea dispersal is an outlet subject to strong political pressure at present. Some municipal authorities in the USA have been under pressure for many years to stop it. They will now have to submit detailed studies of land-based sludge disposal alternatives for scrutiny by the EPA if sea disposal permits are to continue (Sludge Newsletter, 13 (2) 20 January 1988). The problem is that land-based alternatives (such as incineration or landfilling) are likely to be unpopular with local communities because of the 'not in my backyard' syndrome. The outcome of the North Sea Ministerial Conference (November 1987) seems likely to prevent any increase in sea disposal of sludge by the UK and require restrictions on contaminants in sludge to present levels. There is also concern about nutrient inputs to sensitive areas of the North Sea. In the UK, both those responsible for the sea disposal operations (Hanbury, Green and Andrews, 1987) and those involved in the licensing of sites (Topping 1987) have made the case that it can be the best practicable environmental option for sludge disposal from coastal and estuarial towns compared with land-based alternatives. Holdgate and McIntosh (1986) have observed that public opinion needs to be guided towards recognising that the best practicable environmental option for waste disposal should be checked in order to make sure that substitute policies are not even less acceptable environmentally than disposal at sea. They go on to suggest that a methodology for conducting BP EO analysis, relating scientific impacts and economic costs, together with public perceptions of risks and with appropriate allowances for uncertainty, should be developed as a matter of urgency.

The WRc has since devised a computer model - WISDOM - (Powlesland 1987) which simulates sludge treatment and disposal operations at works within a given region. WISDOM was developed in a recent study with Yorkshire Water. WISDOM requires data on sludge production, disposal outlet availability and the capital and operating costs associated with the disposal operation. By taking account of existing and likely future constraints on the treatment and disposal operation, WISDOM provides a valuable means of testing the short and long-term viability of alternative treatment and disposal options to identify the most economic and environmentally acceptable strategy on an objective basis. It seems likely that sludge disposal management will, in the future, come increasingly to depend on the assistance of such computer-based techniques.
REFERENCES


