SEWAGE SLUDGE DISPOSAL: OPERATIONAL AND ENVIRONMENTAL ISSUES

A Review of Current Knowledge

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SEWAGE SLUDGE DISPOSAL
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Review of Current Knowledge (ROCK)

Review of Current Knowledge

Introduction

This ROCK is primarily concerned with sludge from treating municipal and domestic wastewater but some of the principles will also apply to sludges from wastewaters from industrial processes. The objective of treating these wastewaters is to separate the water from its pollutants including nutrients, particulates and dissolved organic matter to an extent that the water is fit for release back to the environment, or for reuse. Most of these wastewater treatment processes use natural biological systems to convert carbonaceous matter into settleable biomass and CO_2, ammonia into nitrate or nitrogen gas and phosphate into organic biomass. The surplus biomass grown during these biological treatment steps, together with the particulate matter that has been separated from the wastewater by primary sedimentation is called "sewage sludge". This is something of a misnomer because 25-40% of the dry matter content is biomass that was grown in the treatment facility; it is one reason why the term "biosolids" was coined in the last decade of the 20^{th} century. In the text that follows the term biosolids will be used for all types of wastewater sludge.

The production of residual biosolids, requiring separate management from the main liquid stream, is an unavoidable consequence of all current methods of sewage treatment. For fundamental reasons, there is no prospect of this situation changing in the foreseeable future. Biosolids production will therefore continue to be a characteristic feature of water pollution control technology; and the more sewage that is treated, the greater will be the quantity of biosolids produced. It follows that the amount of sewage produced is a broad measure of society's achievement in protecting the water environment from pollution. This is well demonstrated by the significant increase in UK biosolids production resulting from the many new works being installed to treat the sewage that used to be discharged to estuaries and coastal waters in order to meet the requirements of the EC Urban Wastewater Treatment Directive(1).

Biosolids should therefore be regarded in a positive light, particularly as some of its constituents have a value that can be recovered and used. Examples are when it is recycled to agriculture as an organic fertiliser and soil conditioner or used to restore disturbed land e.g. after quarrying or landfilling. In treated form, it is also used for amenity areas or in gardens. In the UK, biosolids products have been sold, or made available without charge, to gardeners since the 1940s. While supply lapsed in the 1980s it was reintroduced in the 1990s, albeit still to a limited extent.

Championship golf course constructed on former landfill with soil built using biosolids

The use of biosolids on land is not generally in the public's mind because water utilities normally carry out the practice in a well-managed and unobtrusive manner. Only occasionally are there local problems when it is done in a way that generates odour or excessive truck traffic. However, from time to time, there are concerns that there might be a wider public antipathy to the practice because of the basic origin of biosolids and an innate and emotive perception of it.

Apart from the relatively few cases where it can be retained permanently within the curtilage of a treatment works, there must be some residual material (which would include incinerator ash), to be deposited eventually, somewhere in the environment external to the works. In earlier years (up to the beginning of the 1970s) biosolids were not regulated closely and local practices varied considerably. Some practices resulted in contamination of agricultural soils (some of which have provided opportunity to research more “extreme” conditions[(2)] than could occur with current practice) or the creation of permanent biosolids dumps or lagoons close to the treatment works. However, over the last twenty-five years or so, the management of biosolids has developed into a scientific, closely-controlled operation. It has become subject to an increasing number of regulatory constraints designed to safeguard the environment and the health of humans, animals and crops.

As will be discussed later, both the benefits and the potential environmental impact of using biosolids on land have been extensively researched. Most developed countries have enacted legislation designed to regulate biosolids use to protect health and the environment.

Why is sewage sludge produced?

Raw sewage comprises a complex mixture of organic and mineral matter suspended or dissolved in water and is potentially highly polluting if it were released into water because degradation of the organic matter would strip oxygen from the water and the nutrients would stimulate plant growth (including algae – microscopic plants). Fish cannot survive in the absence of dissolved oxygen in the water. For example, this was the condition of the metropolitan River Thames up to the middle of the 20^{th} century, it was dead. But as a result of installing wastewater treatment it was restored to health such that by the end of the 20th century it was the healthiest it had been for 300 years and acknowledged as the cleanest metropolitan river in the world. A similar situation exists in most of the UK's urban rivers. Treatment at sewage works to remove these pollutants may involve several processing stages including initial physical screening to remove coarse solids. All of the subsequent stages, (primary, secondary or tertiary) involve the conversion to and/or separation of suspended solids from the liquid stream by settlement and the formation of a watery sludge. Whilst the treated liquid effluent flows out to the receiving waters, all of the biosolids produced must be retained initially on the works for separate processing and then finally disposed, or used, externally to the works.

Calculations show that, using conventional treatment methods, most of the organic and inorganic polluting matter entering a works in the original sewage ends up in the biosolids. A relatively small proportion only of the carbon in the original sewage organic matter is converted to carbon dioxide by biological oxidation during secondary treatment; a small fraction is also discharged as residual suspended and soluble carbon in the final effluent.

Wastewater treatment used to be designed basically to remove suspended solids and biological oxygen demand (BOD). However, concern to prevent eutrophication of receiving waters has meant that additional (tertiary) treatment has been required at many works to remove nitrogen and/or phosphate. For a review of eutrophication, see the ROCK on eutrophication of fresh waters[(3)]. These tertiary treatments increase the amount of biosolids generated.

From time to time, claims are made for 'low-biosolids' or even 'biosolids-less' sewage treatment processes. These may be based on a chemical oxidation process or on biological treatment involving extended aeration of the biosolids. Although such processes may reduce the total mass of biosolids (dry weight), some recalcitrant organic matter will remain. This, together with the mineral solids, which comprise up to 25% by dry weight of typical biosolids, means that some residual material is inevitable.

Review of Current Knowledge

How much biosolids are produced?

The quantity of biosolids produced by a particular sewage works is usually not easy to measure with great accuracy but, in recent years, studies have shown that biosolids production rates per head of population for different types of treatment are reasonably predictable. Table 1 shows the typical values (and normal ranges) of production for different types of sludge.The actual per capita output is dependent both on the degree of treatment provided (primary, secondary or tertiary), the proportion and composition of any industrial wastes, and the method of secondary treatment. The activated sludge process typically produces up to 50% more secondary biosolids than biological filters. Activated sludge is also the more difficult to treat because (unless it is pre-treated to rupture the cells) it resists digestion and is more difficult to dewater.

Table 1. Typical quantities (and ranges of values) of raw sludge produced per annum per head of population served by a sewage works

Treatment Stage	Annual quantity of dry solids (kgDS/head/year) Typical value and range
Primary	19 (16 - 21)
Secondary	11 (8 - 13)*
Tertiary	2** (1 - 3)
Total	**32** **(25 - 37)**

* Quantity of secondary solids varies with type of treatment process

** Quantity may be significantly greater where phosphorus removal by chemical means is practised

Review of Current Knowledge

Surveys of national and regional biosolids production have been carried out in the UK from time to time. The most recent survey was published in 1999[4] for the years 1996/97 and this showed that the total annual quantity of biosolids produced in the UK in that period was close to 1.1 million tonnes dry solids (tDS). Predictions for the year 2005/2006, by which date all new sewage treatment works installed in response to the Urban Wastewater Treatment Directive will be operational, indicated an eventual annual UK biosolids production of about 1.5 million tDS. This figure is in reasonably close agreement with that predicted from Table 1 assuming a total UK population of about 58 million, and adjusting for the proportion of biosolids destroyed by anaerobic digestion at some works.

Unless the normal UK dietary intake changes significantly, or major changes occur in quantities of industrial discharges to sewers, it is reasonable to conclude that national annual production of biosolids will remain at about 1.5 million tDS for the foreseeable future.

What do biosolids contain - and when do they become 'biosolids'?

Sludges, as formed initially, are complex and highly variable mixtures of organic and inorganic substances in the form of an aqueous slurry. Primary sludge comprises a high proportion of human faecal material and thus untreated primary sludge will contain a variety of human pathogens and/or parasites depending on the incidence of infection in the contributory population. Depending on the origins of the original sewage, primary sludge might also contain animal and plant pathogens and parasites. Sludges from secondary biological treatment are less likely to contain human or animal pathogens in as large numbers as primary sludges but they cannot be regarded as 'pathogen-free'.

In its raw untreated form, biosolids quickly becomes malodorous and therefore a material to which most people have a strong aversion. Until recently, a significant quantity of UK biosolids was used on farmland in this (untreated) form but it was injected beneath the soil's surface or ploughed in to prevent odour nuisance and to make a barrier to disease vectors. This practice stopped from the end of 2001. Treatment to reduce the offensiveness of biosolids (e.g. by anaerobic digestion or other forms of stabilisation) produces materials that are more acceptable for use on land. It is now becoming the practice to call such treated material 'biosolids', with the intention that the term will present an improved 'image', help the public acceptance of its use in agriculture and differentiate it in the minds of those who work with it.

Biosolids may contain hazardous chemical constituents derived from both domestic and industrial sources. The environmental and health risks presented by their presence in biosolids have been researched extensively. In the USA, the federal rules for the use or disposal of biosolids(5) are based on a 14 pathway risk assessment(6) that was subjected to international peer review during its preparation. The USA, EU(7) and UK(8) have selected the same suite of inorganic 'potentially toxic elements' (PTEs) to monitor and control. The first line of control is to regulate discharges from non-domestic premises; this has been very effective as can be seen from Table 2. There is significant domestic contribution of some elements, notably copper from plumbing and zinc from cosmetics and galvanising. However, these elements are also essential trace elements for crop nutrition.

In recent years, there has been growing attention to potentially harmful trace organic compounds (e.g. PCBs, dioxins and PAHs). Some of the compounds of interest are potentially endocrine disrupters; this matter is reviewed in the ROCK on endocrine disrupters(9). Some European countries have adopted standards for organic contaminants in sewage biosolids intended for agricultural use but there is no consistent approach to the selection of contaminants or to numerical limits(10).

Review of Current Knowledge

Some constituents of biosolids are potentially beneficial. Nitrogen and phosphorus are major plant nutrients; typically they are both present in concentrations sufficient to render biosolids useful for agriculture with a similar fertiliser value to animal manures and slurries (Appendix 1). There is less of the other major crop nutrient, potassium (K), than in animal slurries but there is enough to replace crop offtake from soils with adequate amounts of available K. Biosolids contain agronomically useful amounts of the secondary plant nutrients calcium, magnesium and sulphur; the last has become particularly important because atmospheric deposition, which used to provide an adequate supply, has decreased as a result of controls on atmospheric emissions. Biosolids also provide a broad spectrum of trace elements essential for plant growth.

The organic matter in biosolids is usually about 60% of the dry solids content and their addition to land increases the humus content and water-retaining capacity of the soil, improves soil structure and feeds soil microbial biomass. These are very important benefits. They render soil less susceptible to erosion and increase water infiltration capacity, both useful in the context of increasing frequency of extreme weather resulting from climate change. The EU's soil protection strategy recognises the importance of conserving soil organic matter[(11)].

The major component of all biosolids, as initially formed, is water (95-99% by weight). Volume reduction by dewatering is an important operational objective in most cases in order to reduce subsequent handling and transport costs. The solids are strongly hydrophilic in nature, which means that conditioning chemicals and use of special dewatering equipment are needed. Biosolids are also 'non-Newtonian' in their flow behaviour, which means that, even in liquid form, they can be much more difficult to pump than water. Some thickened or dewatered biosolids exhibit thixotropic behaviour, i.e. they can be fluidised if subjected to mechanical vibration.

Table 2 Improvements in the quality of biosolids used in agriculture over the last 14 years (Ref. 4)
(Values are median values for all UK biosolids)

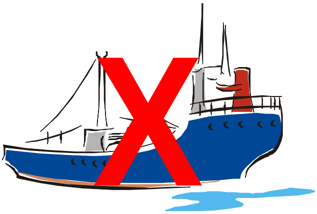
Potentially toxic element (mg/kg DS)	1982/83	1990/91	1996/97
Cadmium	9	3.2	1.6
Mercury	3	3.2	1.5
Zinc	1205	889	559
Copper	625	473	373
Nickel	59	37	20
Lead	418	217	99
Chromium	124	86	25

Note 1: Weighted average concentrations (DS basis) for all UK biosolids are somewhat greater (see Ref 4)
Note 2: It is difficult to compare the data from different countries because different methods of sampling, analysis and data extraction are used across the EU

Review of Current Knowledge

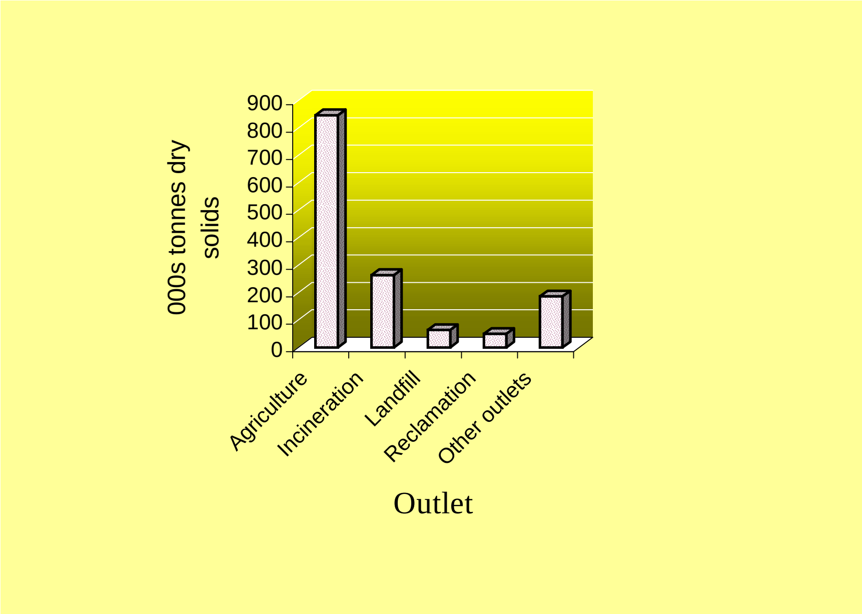
Basic Options for Biosolids Utilisation or Disposal

With the cessation of sea disposal at the end of 1998, all outlets for UK biosolids must now be located on land. The 'export' of biosolids to countries short of organic fertilisers, whilst it has been considered, has not been a real option. Apart from the possibility of relatively minor use for building aggregates and other derived products, virtually all biosolids will therefore eventually be deposited on the land. As shown in Figure 1[4] by far the main outlet for UK biosolids in 2000 and onwards was predicted in 1997 to remain use in agriculture (846,000 tDS/y—60%). The remaining 40% or so of biosolids was expected to be either incinerated (263,000 tDS/y—20%), deposited directly in landfill (63,000 tDS/y—4%), used in land reclamation schemes (49,000 tDS/y—3%), or used in 'other outlets' (186,000 tDS/y—13%). The term 'other outlets' represents a variety of possible beneficial uses including compost for horticultural use and energy recovery through gasification and aggregate production. Gasification has been experimented with for many years but it has yet to become a practicable reality for biosolids. Similarly mixing cake with clay and then firing granules so that the biosolids burn away leaving a porous aggregate has yet to be exploited commercially. There is one plant (in Perth, Australia) using pyrolysis to produce fuel oil from biosolids; it was the result of 18 years' development. The latest figures from Water UK[12] show that 70.7% of biosolids was recycled (agriculture plus reclamation) in 2000/01 – this exceeded the prediction made in 1997.



Although incineration is included as an outlet for biosolids, it is strictly a treatment process to destroy biosolids organic matter and reduce its mass and volume. Incineration still leaves a residue of mineral ash, representing up to 30% of the dry weight of the original biosolids, to which up to 20% water may have to be added to give it physical stability. For the foreseeable future, incinerator ash is expected to go mainly to landfill. Research is being undertaken to find a use for this material as a fine aggregate (sand) replacement in building products. However, ash from biosolids does not have unique advantages over sand and the rate of production, even from the largest incinerators, is very small compared with that of a sand quarry.

Fig. 1 Predictions of outlets for UK biosolids in 2000 made in 1997[(4)]



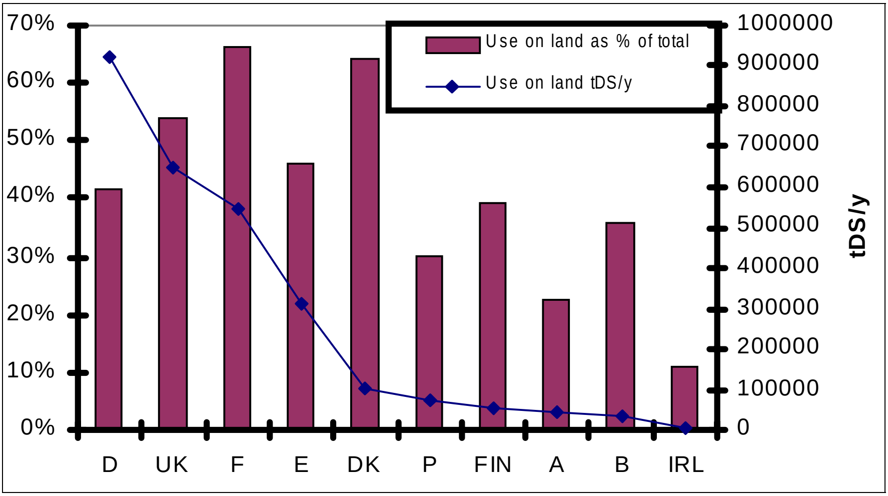
The quantities of biosolids going directly to landfill have remained fairly static over recent years. As an outlet for untreated biosolids, landfill is considered to be unsustainable in the longer term and to have a limited future. This is mainly because the recently adopted EC Landfill Directive[13] sets standards for the reduction of quantities of biodegradable waste disposed to landfill; these reductions are measured against the reference value of the quantity disposed in 1995. In the case of the UK (which has a 4-year derogation) this will mean that only 35% of the 1995 quantity will be permitted in 2020. The UK landfill tax is also a strong disincentive to use this outlet for biosolids.

Comparison with other EU Countries

The provisions of the community directives bind all EU Member States. Some have a bearing on biosolids production and management. In particular, the Urban Wastewater Treatment Directive has required the installation of a great many new sewage works throughout Europe. Member States estimated[14] that, as a result of the directive, EU biosolids production will increase by 17.5% between 1997 and 2005 to about 8.3 million tDS/y per annum by 2005. Germany will account for 33.5% of total EU production.

Biosolids use and disposal practices vary considerably within the EU, particularly with regard to the proportion used on land (see Figure 2). The overall picture (Appendix 2) shows that in 1997 a greater proportion of biosolids was disposed to landfill (36.8%) and a smaller proportion was used in agriculture (38.5%) than in the UK. However, Member States expected this balance to change in the future with beneficial use increasing to 55% by 2005 and landfill disposal decreasing to 18%. The policy of the European Commission is to encourage recycling and some Member States expect an increase in the agricultural use of biosolids. The Netherlands has been an exception; it has a very high human population density and an even higher density of farm animals. Therefore limits were set that make the use of biosolids in agriculture virtually impossible in order that the maximum amount of land is available for animal manure. In Germany, there has been intensive lobbying by the operators of incinerators and coal-fired power stations that can burn biosolids to end the agricultural use of biosolids but legislators have resisted these calls.

Fig. 2 Use of biosolids on land relative to total biosolids produced (data for 1995-7) [(14)]



The 5 Member States not included did not provide full reports to the EC

Use in agriculture

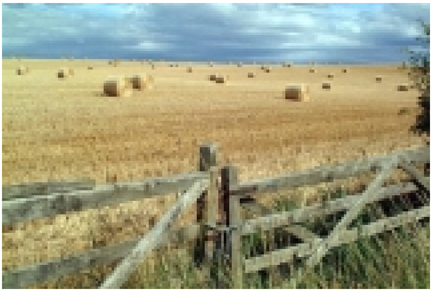
The agricultural use of biosolids has a long history in the UK, and it remains of vital importance for water utilities both now and in the future, although some companies actually depend on this outlet more than do others. A major reason for its popularity is that, by and large, the application of biosolids to farmland is more economic and convenient than other methods of use or disposal. Recycling biosolids to agriculture also fits the EC's and UK government's policies of 'reuse and recovery of wastes', where possible, with disposal (i.e. no recovery of value) only as the final option. In comparison with other outlets for biosolids, therefore, agricultural use (or use for land restoration) is usually considered as the 'best practicable environmental option'.

In 1996/7[(4)] biosolids were applied to nearly 80,000 ha of farmland in the UK. This represents only about 0.5% of the total agricultural land area in the country but since individual fields are only treated on a 5-yearly cycle (or longer) the gross area of land that benefits from biosolids is probably nearer to 3-5%. Some 60% of the land to which biosolids were applied was arable and 40% was pasture. Various methods of biosolids application were used, but the most common for both arable and pastureland was soil injection of liquid biosolids to plough depth; this was used for 58% of the area treated.

The picture in 2002 has changed considerably from the above due to cessation of biosolids disposal at sea (at the end of 1998), installation of more extensive wastewater treatment at coastal towns and voluntary changes of practice. A large proportion of the new biosolids is now used on [new] land to which biosolids has not been available in the past. Detailed quantitative data are not yet available. In terms of treatment,

dewatering has increased considerably. Lime stabilisation of raw cake has replaced much of the untreated liquid injection reported in the 1996/7 survey; the remainder is digested. A large proportion of digested biosolids is dewatered and applied as cake; this change happened partly to reduce costs and partly to increase operational flexibility. The 2001 outbreak of foot and mouth disease demonstrated that, if farmland is closed, it is much easier to store cake at the sewage treatment works than it is to store liquid biosolids.

There has been a great deal of research over the last 30 years to establish the fertiliser benefits of biosolids and to identify how it can be used without causing damage to the soil or to other parts of the environment[15]. From the farmer's point of view, use of biosolids can represent a substantial saving in mineral fertiliser costs. Estimates of savings vary according to circumstances. They depend on the type of biosolids applied, and the rate and time of application. It is misleading to consider the total content of N, P, K, Mg, S, etc. because a proportion will not be available to the crops. Therefore it is the 'fertiliser-replacement-value' that is appropriate. This is estimated from chemical analysis and models of availability constructed from field trials, which is exactly the same as the basis of advice for mineral fertiliser. For example digested cake applied at 50t/ha in November to February will have a fertiliser equivalent value of about £170/ha in the first year (at 1998 prices). If it were applied to a sandy soil in August it would be worth £150/ha, the difference being due to loss of nitrogen. The total 1st-year fertiliser-replacement-value of all the biosolids used in agriculture in the UK biosolids is about £10 million per annum. In addition there is the saving in crop protection chemicals, reduction in erosion, 2nd and 3rd year benefits, and the benefit of



increasing the efficiency of [mineral] nitrogen fertiliser. However, biosolids use in agriculture still accounts for only 1-2% of the total nitrogen input to farmland from chemical fertilisers and housed livestock manure; for phosphorus, the proportion is 2-3%.

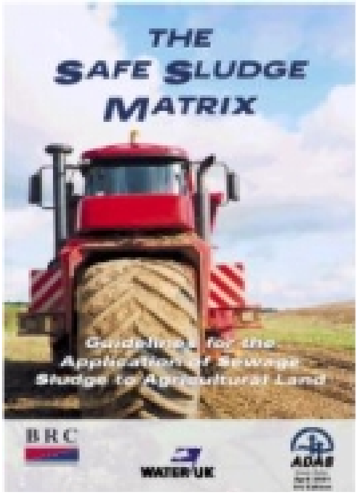
Regulations[8] on the use of biosolids in agriculture have been in force in the UK since 1989 and implement the provisions of an EC directive[7]. For several years before that, water utilities generally operated in accordance with 'guidelines' issued by a national government sponsored committee in 1975. To amplify the 1989 Regulations, a Code of Practice[16] on agricultural use of biosolids was introduced by the (then) Department of the Environment in 1989 (and revised in 1996) and has been used since as the main basis for day to day operational practice. The Code gives general guidance on agricultural use of biosolids, on effective methods of biosolids treatment to control pathogens and parasites, on limits for potentially toxic elements in soils, and on planting, grazing and harvesting constraints, record keeping and general environmental protection. Both the Regulations and the supporting Code of Practice are basically designed to encourage the use of biosolids in agriculture while preventing harmful effects to the soil, vegetation, animals and humans.

The use of the Regulations and Code of Practice have been very successful in preventing any significant adverse environmental impacts from the use of biosolids in agriculture including damage to the health of humans, animals or crops. It is also important to note that several official agencies have concluded that there is no documented evidence to link the controlled application of biosolids and the occurrence of disease in the general population through food or water contamination.

Nonetheless, the various recent health scares over Salmonella, Listeria, BSE and *E. coli* O157:H7 have heightened awareness of all possible routes for transmission of infection. This concern included that of food retailers who came to question whether practices for treating biosolids and using it on land based on experience in the 1980s were appropriate at the beginning of the 21st century.

The 'Safe Sludge Matrix'

The water industry, farmers, landowners, food industry and retailers discussed these concerns; this led to a working party from the British Retail Consortium (BRC) (representing the UK food processors and retailers) and Water UK (representing the UK water utilities). Discussions were mediated by ADAS. The result was an agreement on the sustainable use of biosolids that included a new code of practice including the so-called "safe sludge matrix"[17]. The matrix represents the new minimum standard for biosolids treatment in relation to agricultural use that is acceptable to the food industry. Its implementation is essential to the continued use of biosolids in agriculture. The matrix comprises a table of UK crops and the level of biosolids treatment considered appropriate for producing the crops on treated land **(Appendix 3).** These considerations led to the introduction of two classes of treatment, much like those of the USA's federal rule[5]. 'Conventional' treatment is acceptable where there is a second barrier, such as crop processing, ploughing in or die-off. 'Enhanced' treatment renders biosolids safe for unrestricted use because pathogens have been reduced to ambient numbers, i.e. the same as field soil. The first phase of the matrix was implemented from the end of 1998 and the second phase by the end of 2001. Water UK, the BRC, the UK Government and the Environment Agencies continue to evaluate new research information on use of biosolids in agriculture jointly. The Department of the



Environment, Food and Rural Affairs (DEFRA) is incorporating the matrix into revised biosolids regulations and a new edition of the Code of Practice for Agricultural Use of Sewage Sludge. This has been an interesting approach to regulation in that the stakeholders in the process have agreed the provisions that they deem necessary, based on science. Government has been party to the process, and the outcome will become law. The new regulations will not prescribe treatment conditions but will require that they are based on HACCP (Hazard Analysis and Critical Control Point) which is also the basis for food safety[(18)].

Government review of scientific basis for current controls

In 1996, in response to the recommendations of the Royal Commission on Environmental Pollution in its report Sustainable Use of Soil[(19)], the UK Government commissioned a comprehensive review by WRc of the scientific evidence underpinning the existing controls on the agricultural use of biosolids[(20)]. The review concluded (inter alia) that ‘the strategies adopted in the Code of Practice for controlling risks to health are, in principle, logical and sound’. However, the review also concluded that there is ‘a lack of definitive information on the survival of some of the more recently identified pathogens, for example *E. coli* O157:H7’. There is also recognition that ‘changing public concerns, the recognition of the precautionary principle and the need for sustainability, in the face of increasing pressures on agricultural land for recycling biosolids all require more attention be given to the measures for controlling risks to health of man, food, animals and crops’.

The review made recommendations to strengthen the microbiological safety relating to biosolids use in agriculture and to reduce the already small risks still further. The main recommendations include phasing out the use of untreated biosolids on land and the use of more stringent operating conditions for some of the treatment processes included in the Code of Practice. It also recommends that some additional processes involving thermal treatment should be introduced to the Code of Practice, and that only biosolids treated by thermal processes should be applied to the surface of grazing land.

House of Commons Committee Report

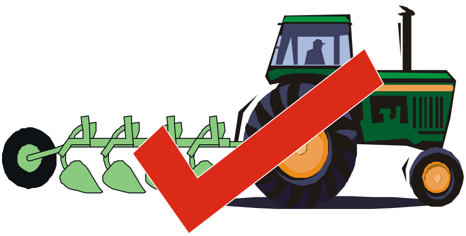
Another important development in promoting more stringent controls on biosolids was the report in 1998 of the House of Commons Environment, Transport and Regional Affairs Committee[(21)] which recommended (inter alia) that by the year 2002 all biosolids recycled to land should be subjected to treatment in the form of stabilisation and pasteurisation. In its response to the Committee's report, the Government announced in 1998[(22)] that it intended to make amendments to the statutory framework of controls and the associated Code of Practice as soon as possible. The most significant changes, which reflect the findings of the scientific review, are the phasing out of all use of untreated biosolids on agricultural land by the end of 2001 and more stringent requirements for the operation of biosolids treatment processes with the requirement that they be based on HACCP, which entails performance monitoring and auditing provisions. Another provision (already implemented by the water utilities by the end of 1998) is the banning of surface applications of conventionally treated biosolids to grass for grazing.

The government also announced two programmes of further research. One was into biological risk including the survivability of *E. coli* O157:H7 and other 'emerging' pathogens as well as researching into the efficacy of various biosolids treatment methods. This programme produced reports in 1999, 2000 and 2002[(23)]. The final part of the research was a risk assessment to point of harvest [and later to point of consumption] based on the findings of the other phases of the research. The other programme is a multi-site field trial into the chemical risks to soil fertility in particular and also crops. There are 9 sites in England, Scotland and Wales with different soil types and climates. Soil metal concentrations were increased to a range extending to 150% of the legal maximum over a period of 4 years. This involved large rates of addition, which were in excess of the legally permitted loading rate. Monitoring of the sites continues[(24)]; to date there is no evidence to suggest that the current UK limits need to be revised.

The future for Agricultural Use of Biosolids

In 1998[(22)], the Government confirmed its view that recovering value from biosolids through application to agricultural land is the best practicable environmental option in most circumstances. It also pointed out that agricultural use of biosolids brings savings of several million pounds in fertiliser costs and that the organic matter improves soil structure, its workability and water-holding capacity. The point was also made that agricultural use is the most economic option with consequent savings for water charge payers.

In 2002, the European Commission's DG Environment wrote "Research carried out in the past thirty years or so continues to demonstrate that a responsible and well-monitored use of biosolids - in compliance with the requirements of Directive 86/278/EEC - causes neither environmental damage nor endangers the food chain."



With the more stringent conditions to be applied to the treatment of biosolids before use in agriculture, the prospects for sustaining this vital outlet well into the 21st century are good. But the rapid developments in this area arising from 'external factors' such as the 'emerging' pathogens issue indicate that water utilities need to be proactive and to continuously improve the quality of biosolids operations and to maintain dialogue with other parties in the food production and distribution chain.

The subject of engaging with others involved in the food chain has been the subject of a scoping study for the Environment Agency[25]. Representatives of all sections of the chain agreed that a partnership is needed for the sustainable use of organic resources on land (biosolids, compost, manure, etc.) to build mutual trust, share information, identify gaps in knowledge and develop 'welcomed' practice by consensus. The idea was inspired by the National Biosolids Partnership in USA but this will be broader both in terms of the membership and the materials.

Energy from Biosolids

Biosolids represent a potentially exploitable 'non-fossil fuel' and a source of 'green' energy. The net (i.e. after deducting the heat required to evaporate the water) calorific value (CV) of biosolids is typically about 23 MJ/kgVS. VS is 'volatile solids', which is the combustible matter, it is measured by loss on ignition. The CV of brown coal is also about 23MJ/kgDS. If it is assumed that the total raw biosolids production in the UK is 1.5 million tDS/y and that the average proportion of combustible organic matter in biosolids is 75%, then the total primary energy contained in UK biosolids is 25,900TJ/y (equivalent to 7,190GWh/y). The total UK primary energy consumption is about 9.5 million TJ/y, so that the total primary energy in all UK biosolids produced in a year represents about 0.3% of national annual consumption, representing 1 day's energy consumption per year. The nitrogen-fertiliser value is destroyed and phosphate is converted to

Bradley incinerator, West Yorkshire

recalcitrant forms from which it cannot be extracted economically at present. This destruction of phosphate is regarded by many as a serious disadvantage because the world's economic reserves of P are estimated at only 100 years at current rates of extraction[(26)].

The above calculation represents a purely hypothetical situation because it would never be possible to recover the total energy from all UK biosolids. It demonstrates the relatively minor importance of biosolids as an energy source at the national level. In local situations, however, particularly at larger works employing new incineration plants with heat recovery, some relatively large useable energy yields can be obtained. Thus the Thames Water sewage treatment works at Beckton (East London)[(27)] can produce 8MW of electrical power from the heat recovered from the incineration plant treating biosolids from a population of about 2.5 million.

Anaerobic digestion (AD) represents a different way from incineration for extracting energy from biosolids. Bacteria convert some of the organic matter into methane-rich biogas (60% CH_4). AD can yield 1m^3 of biogas (CV= 22MJ/m^3) per kg organic and volatile solids destroyed. This gas yield is roughly equivalent to 0.3m^3 gas per kg total solids treated when AD is operated efficiently. It follows that if the total annual biosolids produced in the UK were to be digested, the gas yield would in theory be about 500 million m^3 gas per year which is equivalent to 11,000TJ/y or just over 0.1% of the national energy consumption per year. Significant amounts of energy are obtainable from biosolids AD plants. Thames Water generates a total of about 16MW of electrical energy from combined heat and power (CHP) plants running on digester gas at some 22 sewage works[(27)]. The heat is used to maintain digester temperature. At its large sewage works at Minworth, Birmingham, Severn Trent Water produces over 3MW of useable electrical energy, and 8MW of heat energy, from a digester gas CHP plant[(28)]. In Denmark, AD with CHP is part of the national renewable energy strategy and combinations of manure, biodegradable domestic waste and biosolids are co-digested at centralised sites[29]. This is an alternative to composting. The digested biosolids retains its value as a soil improver.

Fertiliser or Fuel ?

One of the current debates about the best way to exploit the value of biosolids relates to its use either as a fertiliser or as a fuel to generate energy. However, if biosolids are incinerated to yield usable energy, its value as a fertiliser is destroyed. Similarly, if the full fertiliser value of the biosolids is to be used, it cannot be incinerated.

The two basic options are, however, not completely mutually exclusive because it is common in practice to subject biosolids to AD and to produce useful amounts of methane-rich gas that can be used as an energy source. The digested biosolids retains its plant nutrients (N and P) and is a useful fertiliser, but the offensive odour is mitigated. The use of AD before agricultural use might therefore represent the optimum strategy for exploiting the value of biosolids and is also the best environmental option in many situations. The same is probably true for the wet organic fraction of municipal solid waste.

A strategy employed by some water utilities recently, in order to increase the flexibility of use of biosolids and enhance its value, is to dry it thermally to produce dry pellets or granules. The reduced quantity of product (1t dewatered cake yields about 0.23t granules) makes it more amenable for storage and cheaper to handle and transport; however, this is offset by the high cost of evaporating water. The main options for use of the dried biosolids are either as a fuel to generate energy or as an organic fertiliser. In some cases, a proportion of the product can be used for each purpose depending on circumstances including the time of year. Using modern drying methods, thermally dried biosolids are normally very acceptable in regard to odour and appearance. This provides an entry to the more sophisticated market of blended and supplemented fertilisers with a range of nutrient analyses; it has been exploited in the USA but not yet in the UK.

APPENDIX 1. Typical nutrient contents and fertiliser replacement values* of various types of biosolids and comparison with other forms of fertiliser

	Typical %DS	Nitrogen as N		Phosphate as P_2O_5		Potassium as K_2O		Magnesium as MgO		Sulphur as SO_3	
		Total % in DS	Avail-able kg/t fresh	Total % in DS	Avail-able kg/t fresh	Total % in DS	Avail-able kg/t fresh	Total % in DS	Avail-able kg/t fresh	Total % in DS	Avail-able kg/t fresh
Liquid digested	6	6	1	4.8	1	0.5	0.3	1.9	1	1.8	0.5
Digested cake	22	3.5	2	6.0	4.6	0.4	0.8	0.8	1.6	2.7	3
Farmyard manure	25	2.8	0.7	2.8	4.2	2	4.5	0.3	0.7	0.7	1.8
20:10:10 fertiliser	98	20	200	10	100	10	100	0	0	0	0

Data from DEFRA Fertiliser Recommendations RB 209 and TERRA ECO·SYSTEMS fertiliser model

* The fertiliser replacement values are for the first year after application, there will be [reducing] residual value in subsequent years.

APPENDIX 2. Recent and projected quantities and outlets for biosolids in EU Member States

Annual sludge production and % distribution between outlets in 1996 to 1998 depending on country							
Country	Sludge produced ktDS/year	Percentage of total production to each outlet					
		Agriculture	Incineration	Landfill	Restoration	Sea	Other
Luxembourg	8	70		30			
Denmark	151	62	22	12	4		
France	820	60	14	26			
Spain	685	46	7	24	23		
UK	1195	46	9	7	11	25	2
Germany	2227	40	11	48	1		
Belgium	85	38	14	48			
Sweden	230	36		34	20		10
Finland	136	31		38	31		
Austria	200	22	34	31			13
Italy	800	17	1	82			
Ireland	38	12		42		36	10
Portugal	245	11	29			3	57
Greece	59	10		90			
Netherlands	209	4	24	48			24
Million tDS	7.09	2.73	0.76	2.61	0.41	0.32	0.27
% of total		38.5	10.7	36.8	5.7	4.5	3.8

Predicted annual sludge production and % distribution between outlets in 2005						
Country	Sludge produced ktDS/year	Percentage of total production to each outlet				
		Agriculture	Incineration	Landfill	Surface water	Other
Luxembourg	14	65	27	8		
Denmark	200	63	25	12		
France	1172	66	34			
Spain	1988	54	8	32	6	
UK	1583	71	21	7		1
Germany	2787	50	30	18		2
Belgium	159	30	9	25		36
Sweden						
Finland	160	72		28		
Austria	195	35	34	29		2
Italy						
Ireland	113	75		25		
Portugal	359	30		60		10
Greece	99	8		92		
Netherlands	401	28	49	17		6
Million tDS	8.33	4.56	1.98	1.53	0.07	0.19
% of total		54.7	23.8	18.4	0.8	2.3

APPENDIX 3. The "Safe Sludge" Matrix (from Ref. 17)

CROP GROUP	UNTREATED SLUDGES	CONVENTIONALLY TREATED SLUDGES	ENHANCED TREATED SLUDGES
FRUIT	✗	✗	✓ (10 month harvest interval applies)
SALADS	✗	✗ (30 month harvest interval applies)	✓ (10 month harvest interval applies)
VEGETABLES	✗	✗ (12 month harvest interval applies)	✓ (10 month harvest interval applies)
HORTICULTURE	✗	✗	✓ (10 month harvest interval applies)
COMBINABLE & ANIMAL FEED CROPS	✗	✓	✓
GRASS & FORAGE - GRAZED	✗	✗ (Deep injection or ploughed down only) (3 week No Grazing and harvest interval applies)	✓ (3 week No Grazing and harvest interval applies)
GRASS & FORAGE - HARVESTED	✗	✓ (No grazing in season of application) (3 week No Grazing and harvest interval applies)	✓ (3 week No Grazing and harvest interval applies)

The types of treatment are described on page 18.

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Review of Current Knowledge