MANAGEMENT, USE, AND DISPOSAL OF SEWAGE SLUDGE

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Summary

Sewage sludge is a by-product of urban wastewater treatment. Sludge production in Europe and the USA has increased dramatically with the implementation of environmental programs to improve the quality of discharges from wastewater treatment plant. Environmental legislation has also banned the disposal of sludge by sea dispersal requiring all the sludge from sewage treatment to be disposed of on land. The amount of sludge generated in the EU is expected to increase by 50% to about 10 million t ds y^{-1} by 2005 compared to 1992 and approximately 7 million t ds y^{-1} are currently produced in the USA. Germany, UK, France, and Italy contribute the largest amounts of sludge equivalent to 70% of total EU production and Spain is also forecast to become a major sludge producer in future.

Mesophilic anaerobic digestion is the most popular sludge stabilization process and 50% of sludge produced in the EU is treated by this method. Thermophilic aerobic digestion is also widely employed and about 20% of sludge in the EU is stabilized aerobically. Thermal drying is probably the most significant recent development in sludge treatment technology in terms of: (1) producing bio solids that achieve Class A pathogen reduction requirements for unrestricted use, (2) maximizing bulk reduction, and (3) the formulation of sludge products for use in agriculture and horticulture. Nevertheless, the quantity of sludge treated by thermal drying remains relatively small. Agricultural re-use is the main outlet for sludge and is currently expanding as sludge production increases. This represents the only outlet where a significant benefit is gained from the valuable nutrient and organic matter resources contained in sludge for crop production. Incineration is also expanding and may become more important for

sludge disposal than landfill, which is expected to decline with the implementation of new regulations on land filling organic waste. Forecasts suggest that the distribution of sludge amongst the various outlets in the EU by 2005 will be: re-use 54%, incineration 24%, and landfill 19%. The greatest uncertainty about the future trends in sludge management lies in the prospects for recycling sewage sludge in agriculture due to political and environmental concerns about this practice and tightening legislation. This is strategically the most important outlet for sludge and is the most environmentally sustainable from the point of view of recycling resources. However, the future of agricultural re-use will depend on adopting pragmatic controls that facilitate land application and protect the environment based on sound scientific principles and risk assessment. It will also crucially depend on counter-acting prejudicial perceptions about sludge and gaining consumer confidence that land application is a safe and acceptable practice that, on balance, represents the best overall approach to sludge management. As the availability of outlets for sludge diminish, the ability to provide secure, cost-effective and environmentally acceptable approaches to sludge management becomes ever more challenging. This emphasizes the importance of maintaining the land application route to allow beneficial re-use of sludge otherwise the only remaining viable alternative will be the construction of more sludge incinerators in urban areas and for ash disposal to landfill.

1. Introduction

Sewage sludge is an inevitable by-product of urban wastewater treatment. It is a mixture of solids and water produced during the treatment of wastewater. In the USA, "bio-solids" is the preferred term to describe treated sewage sludge that is suitable for beneficial re-use and this is becoming widely accepted as a more appropriate and less prejudicial description for sludge. Wastewater treatment processes purify combined discharges from domestic and industrial sources by a series of physical, biological and chemical processes to remove and stabilize the degradable materials present in raw wastewater. A simple schematic representation of the main stages of sewage treatment is shown in Figure 1. These involve prescreening to remove grit, plastic and other debris; primary sedimentation of the settle able solids, followed by secondary aerobic biological treatment of the settled sewage, or primary effluent, by aerated reactors (activated sludge process) or biological filters (percolating filter). Biological sludge from these aerobic stages, and sludge from tertiary treatment, that may be required to further purify the effluent including nutrient removal processes (nitrogen and/or phosphorus), are co-settled with the primary sludge.

Effluent treated to the appropriate standard required by environmental legislation, which is defined by the Urban Waste Water Treatment Directive (91/271/EEC) (UWWTD) in the case of EU member countries, is discharged to the nearest surface water. However, the residual sewage sludge requires further careful management and a number of options are available for its treatment, disposal or beneficial re-use that need consideration in relation to cost, practicability, potential environmental impacts as well as public perceptions.

Sewage sludge contains agronomically significant amounts of nitrogen and phosphorus and has value as an effective fertilizer replacement for these important nutrients. Sludge application to soil also conserves organic matter and together these attributes provide a case for encouraging the beneficial re-use of sludge as a resource in agriculture, forestry or land reclamation in preference to its disposal. The presence of a range of potentially toxic elements (PTEs) and organic contaminants in urban wastewater also requires vigilant trade effluent control and quality standards to protect the environment when sludge is re-used beneficially on land. Excreted human pathogenic organisms also transfer to the sludge during wastewater treatment and the risk of spreading disease is controlled by appropriate sludge treatment processes and by carefully managing the use of sludge on land.

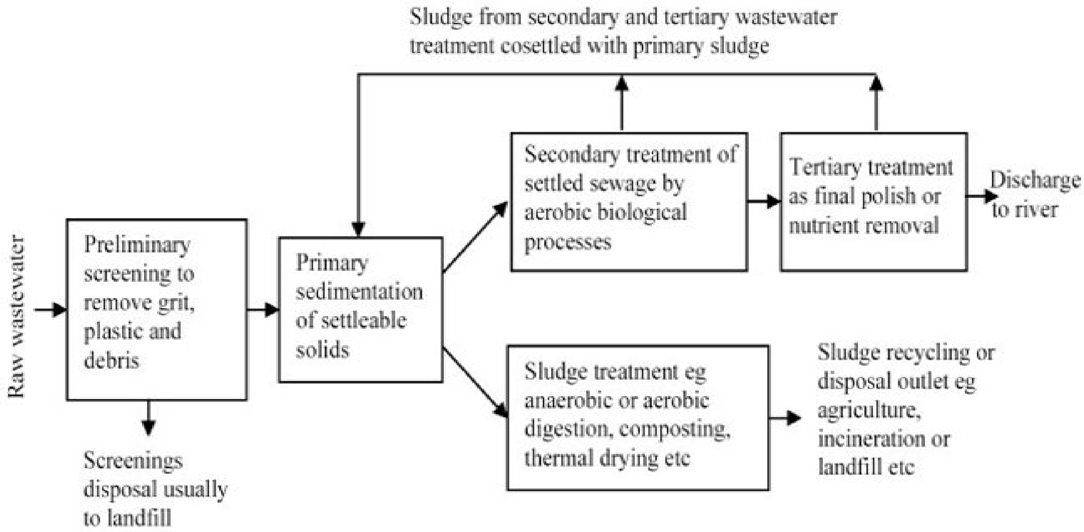

Figure 1. Schematic representation of a sewage treatment works showing the principal process stages and outputs.

Environmental legislation within the EU is reducing the availability of the traditional disposal outlets for sludge. For example, the UWWTD ended sea dispersal in 1998 and the disposal of sludge in landfills is no longer regarded as a sustainable option and will be restricted by the recent Landfill Directive (1999/31/EC). Incineration is not favored in many countries and is often considered negatively by the general public. Agricultural use of sludge is regulated specifically by the Council Directive of 12 June 1986: *On the Protection of the Environment, and in Particular of the Soil, When Sewage Sludge is Used in Agriculture (86/278/EEC)*, which unified environmental standards for recycling sludge on farmland across the EU. However, for a variety of reasons, some European countries have introduced more stringent environmental legislation, particularly with respect to the limit values for PTEs in sludge and soil. Any revision of Directive 86/278/EEC is likely to follow this lead, but there is a danger that the new standards may be unnecessarily restrictive and will limit opportunities for using sludge in agriculture. The recent food hygiene crises have also focused attention on the safety and potential risks to human health from land spreading sludge, despite the fact that these outbreaks have been unrelated to agricultural re-use. These issues, together with a frequently negative media, have tended to undermine confidence in recycling sludge and the long-term future, and operational security of this outlet must also be in question.

In the USA, a more proactive and positive approach towards beneficial re-use on land is apparent than in many European countries and the 1993 US EPA: *Part 503–Standards for the Use or Disposal of Sewage Sludge* is designed to facilitate and encourage recycling as far as possible. Furthermore, in contrast to the apparently *ad hoc* development of regulations and Directives influencing sludge management practices in the EU, the Part 503 provides a cohesive framework of controls encompassing all aspects of sludge re-use and disposal including land filling, and incineration.

Despite these pressures, the Water Industry is charged with delivering cost-effective solutions to sludge management problems and to invest in appropriate treatment technologies so that sludge can be used or disposed of in a safe, cost-effective, and sustainable manner. This challenge not only faces industrialized nations, but is increasingly important in developing countries because the construction and operation of basic wastewater collection, and treatment facilities to improve the environment and public health goes hand-in-hand with increased sludge production.

This paper examines the techniques available for selecting the optimum methods of sludge treatment and management depending on local conditions and circumstances. Recent information on sludge production and quality in different countries is reviewed and the methods available for sludge treatment, disposal or re-use are compared. The potential environmental consequences of the main routes for sludge management are considered, and future trends and developments are discussed.

2. Best Practicable Environmental Option

Step		Comment	
1	**Objectives and constraints** ↓	Identify what is to be achieved by the study and the constraints	
2	**Collect data on disposal operation** ↓	Provides feedback on current operation; constraints identified and quantified	
3	**Generate treatment and disposal options** ↓	Different treatment and disposal options are generated for sewage treatment works in the study area	
4	**Screen treatment and disposal options** ↓	'Coarse screen' the options generated in Step 3 to identify options for further evaluation	
5	**Evaluate treatment and disposal options** ↓	Consider -	Environmental impacts Economic aspects Operational security
6	**Identify preferred option** ↓	Select the BPEO	
7	**Review the preferred option** ↓	Detailed review of the BPEO to establish the feasibility of the selected option	
8	**Presentation on the evaluation** ↓	Prepare a succinct report on the data collection methods, generation of options and evaluation procedures	
9	**Implement and monitor option**	Implement BPEO and monitor environmental and economic impact	

Figure 2. Key steps in the development of sludge BPEO.

An objective assessment of the complex and interacting factors that govern sludge treatment and disposal scenarios is performed by undertaking a Best Practicable Environmental Option (BPEO) study. Key stages in the development of a BPEO for sludge are shown in Figure 2. The objective of the BPEO approach is to achieve reductions in environmental pollution and damage and improvements in the quality of the environment as a whole. Emphasis is placed on the selection of a route for sludge treatment and disposal that will minimize the overall potentially adverse environmental impacts, on a case-by-case basis, with costs occupying a secondary role. However, a reasonable balance between benefits and costs should be identified and the financial implications of adopting the BPEO should not be disproportionate. A fundamental principle of the BPEO is that impacts on all environmental media (air, water, soil) or compartments are considered, although this often requires objective judgments on the potential significance and extent of different environmental impacts.

Treatment processes	**Transfer options**	**Management options**
Digestion: Thermophilic aerobic Mesophilic anaerobic – Use of gas for CHP – Gas refining and export as fuel – Other uses	Road vehicle Rail Pipeline	Agriculture: – Surface spreading – Soil injection Specialist products – Domestic market – Horticulture
Disinfection – Pasteurisation – Lime addition		Forestry Sacrificial/dedicated land
Composting		Construction materials
Thickening – Gravity – Mechanical		
Mechanical dewatering		
Thermal drying		
Incineration		

Table 1. Available methods for the treatment, disposal or re-use of sewage sludge.

The generation of options (Step 3 in developing the sludge BPEO, Figure 2) examines all the possible treatment, transport and disposal re-use options available (Table 1) and these are screened to identify the option that has the minimum environment impact, but does not incur excessive cost (Figure 3). Agricultural use is the BPEO in most circumstances, and this will require the selection of an appropriate treatment process for sludge that is intended for re-use in agriculture based on an evaluation of the environmental benefits and costs of different treatment options for particular STWs. Incineration is often the BPEO when the availability of agricultural land is limited, as is the case for STWs in large urban conurbations, or when sludge quality prohibits its use on land. Incineration is the BPEO under these circumstances because the environmental impacts and costs of transporting sludge to farmland are a major constraint to implementing a recycling option and polluted sludge is unsuitable for re-use. However, local circumstances differ and, when available, land reclamation can be a suitable BPEO for sludge, although this has to be balanced against the security and availability of this outlet for sludge, which may be limited in the longer term.

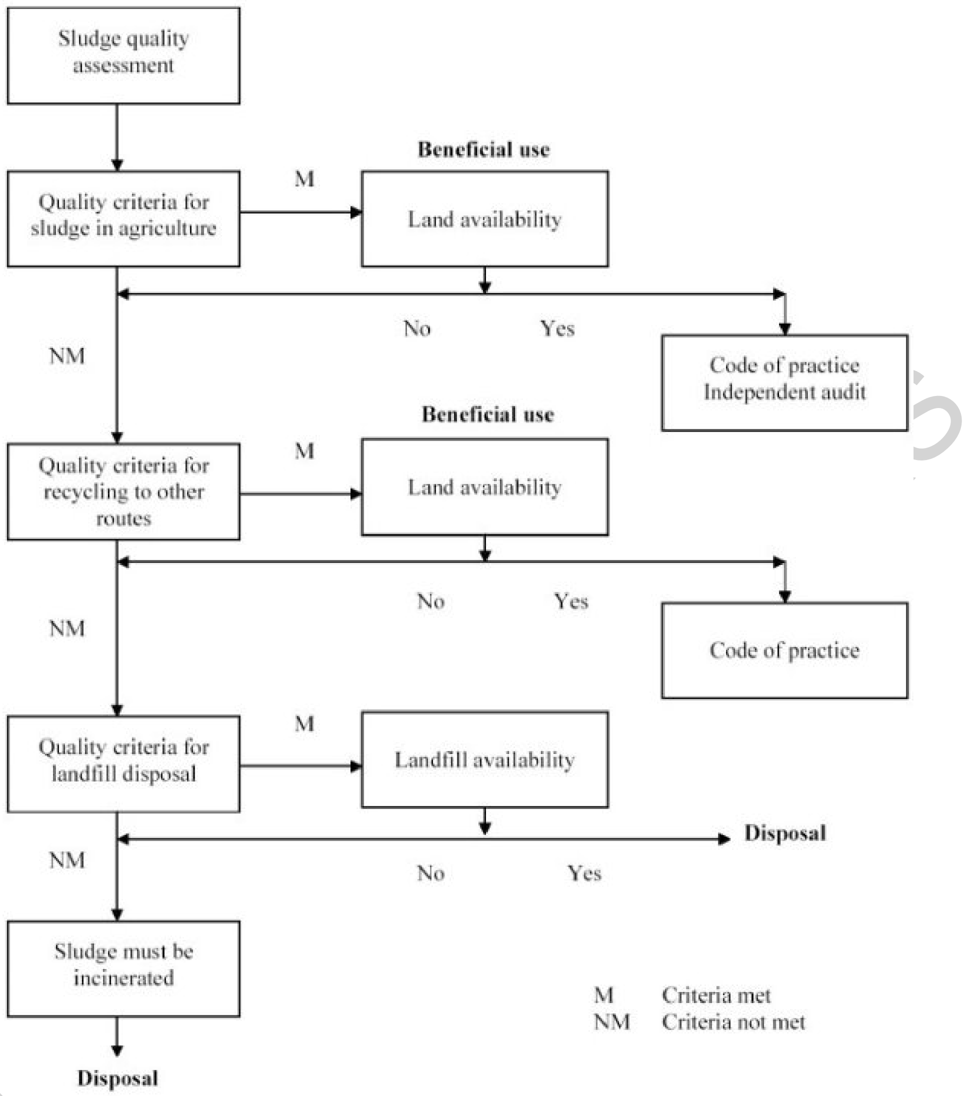

Figure 3. Simplified flow-chart for identifying sludge disposal or recycling routes.

3. Hazard Assessment Critical Control Point and Sludge Management Audits

Agricultural re-use of sludge is often the BPEO from a technical, quantitative assessment of the available treatment and management options. However, this is a voluntary route for sludge and is dependent on many external factors not under the control of the Water Undertaker. It is reliant on good will between the farmer and sludge producer. This relationship is dependent on the provision of a high quality of service by the sludge producer in terms of sludge treatment and land application practices. However, farming methods are increasingly subject to codification and assurance schemes required by major food retailers, and the use of sludge for crop production has come under scrutiny. The British Retail Consortium and UK Water Industry agreed a series of measures, known as the Safe Sludge Matrix, to improve confidence within the food industry in the agricultural use of sludge. These measures included banning the use of untreated sludge, that carried the largest potential risk of disease transmission from enteric pathogens (although no link has been proven), and classifying the acceptable uses of treated and advanced treated sludges (Section 5). UK legislation and the 1996 DoE (now DETR) *Code of Practice for the Agricultural Use of Sewage Sludge* will be revised in the light of these developments. A revision of the EU Directive on agricultural use of sludge (86/278EEC) will also up date the requirements for effective treatment processes and the acceptable uses of sludge on farmland.

Industrial effluent control and screening
Proven treatment processes for stabilisation, odour minimization, and pathogen destruction
Appropriate use on land (rates of application, nutrient additions, crop types, waiting periods, and sowing and harvesting constraints)
Monitoring protocols and quality assurance systems for treatment processes and field application operations
Standard analytical methods for PTEs, organic contaminants and microorganisms
Management systems
Communication (customer, regulator, public and stakeholders including landowners and retailers)
Training and staff competence
Record keeping
Reporting
Independent audit control
Indemnity insurance

Table 2. Focal points for quality assurance in sludge recycling operations.

The introduction of independent auditing to visibly demonstrate quality assurance in sludge treatment and land application operations will form an important feature of revised legislation on agricultural use of sludge; the UK Water Industry has already agreed to demonstrate compliance with the requirements of the Safe Sludge Matrix. Some examples of critical focal points for quality assurance in sludge recycling operations are listed in Table 2. A transparent audit process and quality assurance are regarded as important steps in building consumer confidence and gaining acceptance for recycling sludge on agricultural land. Sludge audit schemes are being introduced, but the most rigorous of these have been developed based on the principles of Hazard Assessment Critical Control Point (HACCP). This involves identifying hazards during a production and treatment system and introducing stringent process controls at critical points to prevent unacceptable risk from passing through the process (see Figure 4). A process flow diagram is constructed and the potential hazards are listed that may be expected to occur at each step. A decision tree (see Figure 4) is used to determine whether a process step is a Critical Control Point (CCP) for each identified hazard. The CCP is a step in the process at which control can be applied and is essential to prevent or eliminate a hazard or reduce it to an acceptable level. Originally designed as a mechanism to protect food safety, HACCP procedures are transferable to the assessment of technical and managerial processes involved in treating and recycling sewage sludge on farmland to identify CCPs that protect the environment when sludge is used in agriculture. Thus, CCPs are identified that prevent or reduce the contamination of sludge with PTEs, organic contaminants, microbial pathogens, and that minimize odor, and nuisance etc. Using these examples, source control is the CCP for chemical contaminants; sludge treatment conditions (e.g. time, temperature, pH) and land use (e.g. crop types, waiting periods, application methods) provide CCPs for pathogens and also minimize potential odor nuisance. An example of this approach to quality assuring sludge re-use operations is the Bio-solids and Other Organics Sludge Treatments (BOOST) audit and insurability system, which applies the principles of HACCP to sludge treatment and recycling and provides independent accreditation that Good Practice standards are being consistently achieved.

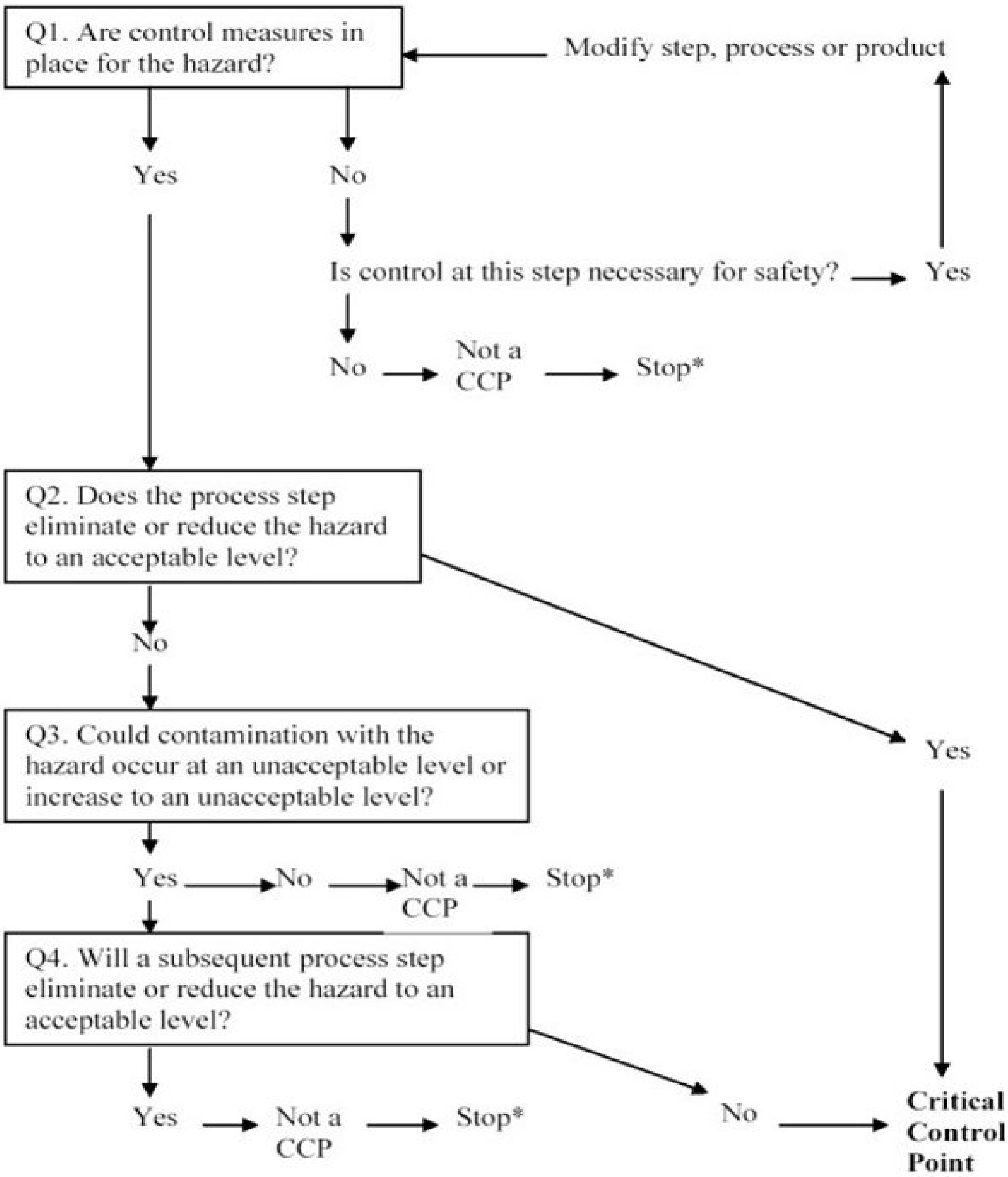

Figure 4. A Critical Control Point decision tree.

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Biographical Sketch

Dr Stephen Smith is a lecturer in Environmental Engineering in the Department of Civil and Environmental Engineering at Imperial College, London and he is the Director of the Centre for Environmental Engineering and Waste Management. Dr Smith is a specialist in sludge management issues and is recognized in particular for his expertise and research on the environmental effects of recycling sewage sludge in agriculture and on the agronomic value of sludge. Dr Smith has written more than 100 reports and scientific papers on the subject of the agricultural utilization of sewage sludge for the UK Government and Water Industry, and this experience culminated in the publication of a text-book on the subject. He has also worked overseas on sludge management problems and was the principal environmental scientist assigned to develop the sewage sludge disposal strategy for Cairo.