ACM/512

ADVISORY COMMITTEE ON THE MICROBIOLOGICAL SAFETY OF FOOD (ACMSF)

REPORT OF A MEETING OF THE *AD HOC* GROUP ON SEWAGE SLUDGE

Introduction

1. The agricultural disposal of sewage sludge is subject to controls emanating from Council Directive 86/278/EEC, implemented in Great Britain by the Sludge (Use in Agriculture) Regulations 1989, as amended. These Regulations are supported by the Department of the Environment Code of Practice for Agricultural Use of Sewage Sludge. The Royal Commission on Environmental Pollution, in its report on the sustainable use of soil, recommended that all sewage sludge applied to agricultural land should be treated by at least one of the methods listed in the Code of Practice and that the scientific basis for the specified periods laid down in the Code between use of sludge and planting or harvesting of crops and/or livestock grazing should be reviewed. MAFF, DH, the Department of the Environment, Transport and the Regions (DETR) and UK Water Industry Research (UKWIR) commissioned WRc plc (formerly the Water Research Centre) to carry out the review which, it was agreed, should be peer reviewed to ensure that the resultant report was both authoritative and independent. The ACMSF agreed to assist with the peer review of those aspects of the study relating to the microbiological risks to public health arising from possible exposure pathways in the food chain. An *Ad Hoc* Group was set up in 1997 to take on this task. Under the first phase of the exercise, the ACMSF provided detailed comments to the contractors during 1997 and 1998 to assist them with their reviews of the evidence underlying the 1989 code of practice and on the evidence since 1989 relevant to controls on the agricultural use of sewage sludge.

2. In 1998, further research was commissioned to characterise the risks associated with the agricultural use of sewage sludge. The stated objectives were to :-

- develop analytical procedures for determining human and animal pathogens in sewage sludge (a report on this work is awaited);
- study the fate of pathogens during the treatment of sewage sludge; and

- establish, by means of a risk assessment methodology, whether current sewage sludge recycling operations have an observable risk with respect to human and animal pathogens.

Current ACMSF involvement

3. The ACMSF was approached in October 2000 to undertake an independent peer review of the planned risk assessment. The Committee agreed to assist and a further *Ad Hoc* Group, comprising Dr Norman Simmons (Chairman), Mr David Clarke, Dr Tom Clayton and Dr Terry Roberts, met with water industry representatives on 13 February to consider 2 papers. Professor Banatvala, the other member of the Group, was, in the event, unable to attend this meeting. The water industry team comprised Alan Godfree from North West Water and Dr Paul Gale from WRc, supported by Dr Simon Pollard from the Environment Agency.

13 February meeting

4. Mr Godfree set the scene by introducing a short background paper (Annex A). During discussion of this paper, Mr Godfree confirmed that it was the intention to codify the Safe Sludge Matrix (Annex B) in regulations which would be supplemented by a stricter code of practice. Compliance would be enforced by DETR. Responsibility for non-compliance could, depending on the circumstances involved, rest with the supplier of sludge or the user. The water company supplying the material would be expected to supply material which had been properly treated, and to provide full information on use, application, etc. The user of the sludge would be responsible for taking proper account of such information and for compliance with the regulations and code of practice. The ACMSF Group stressed the need for strict compliance with the regulations and code of practice, and for effective enforcement.

5. Dr Gale then spoke to a preliminary report of a microbiological risk assessment in respect of pathogens in biosolids (Annex C). The aim was to establish whether current sewage sludge recycling operations were associated with an observable risk with respect to human and animal pathogens. Although the risk assessment was demonstrated for *Salmonella* and *Listeria monocytogenes* only, Dr Gale explained that it was also intended

to cover VTEC, *Campylobacter*, *Cryptosporidium*, *Giardia* and viruses. The Group wondered why, if the agricultural use of untreated sludges was to be banned completely, and it was proposed that treated sludges could either not be applied or could only be applied subject to strict conditions on harvesting etc, the risk assessment had not been restricted to the disposal of enhanced treated sludges only. It was explained that modelling the other options provided a safeguard against treatment failure and thus looked at a worst case scenario.

6. Points made by the *Ad Hoc* Group in discussion of the paper were that :-

- while the ACMSF had previously commented upon the (unproven) efficacy of the sewage treatments embodied in the existing code of practice, the fact of the matter was that the food industry had decided that these provided an insufficient level of protection. This had resulted in agreement between the UK water industry and UK food retailers on the Safe Sludge Matrix. The report of the risk assessment needed to reflect these developments and needed to concentrate on the efficacy of the improved arrangements;

- there was a considerable body of literature demonstrating the ability of *Salmonella* and other pathogens to survive for very long periods in agricultural environments. The importance of a proven method of resuscitation in the detection of low numbers of damaged pathogens should not be overlooked if survival was not to be under-estimated. The Group undertook to provide Dr Gale with appropriate references (subsequently supplied by Dr Roberts). Members were concerned that the data on which the model was based were insufficiently robust and that small uncertainties could result in large effects;

- animal access to treated sludges could present an enhance risk if VTEC was surviving for longer periods than anticipated;

- the risk assessment model was based on a fairly simple event tree based on the reduction in the bacterial loading of sewage sludge through treatment regimes and environmental decay, largely by dilution rather than loss of viability. No account was taken of other risk pathways (eg. unintended transfer of contaminated material to other fields, run off into watercourses, etc). The multiple hurdle approach (where it was difficult to ensure that each hurdle was effectively applied) contrasted with the approach adopted by the food industry of control via a single hurdle;

- the model assessed the overall risk to the whole of a defined population but, in practice risk was not evenly distributed. Whilst the model might therefore be mathematically valid, there was concern that it did not address actual events. It was precisely because of the peaks and troughs that the food industry incorporated a kill stage in its processes;

- the ACMSF would regard as unacceptable the presence of certain microorganisms on certain food crops (eg VTEC on salad crops);

- it was important not to overlook the dynamic nature of microbiological contamination;

- given the objective of assessing risk on a worst case basis, assessments needed to be made based on a range of soils, inocula, microorganisms, weather, etc. The effectiveness of the model depended on the robustness of the data at each hurdle, adjusted to reflect these variables;

- the ACMSF's view was that all sewage sludge intended for agricultural use should have been the subject of enhanced treatment, as defined in the Safe Sludge Matrix. The Committee welcomed the intention of embodying the Safe Sludge Matrix into new regulations governing the agricultural use of sewage sludge but every effort was needed to ensure that the matrix was complied with.

6. The water industry delegation were grateful for the *Ad Hoc* Group's comments and looked forward to receiving further ACMSF input as their work progressed.

Secretariat

February 2001

ANNEX A

ACMSF Review of Microbiological Risk Assessment into the Application of Sewage Sludge to Agricultural Land

Background Paper

Introduction

The objective of sewage treatment is to remove solids and to reduce its biochemical oxygen demand (BOD) before returning the treated wastewater to the environment. Sewage sludge, increasingly referred to as biosolids, is an inevitable product of wastewater treatment. Sludge is produced at various stages within the wastewater treatment process. Usually, these solids are combined and treated as a whole.

Sewage sludge contains valuable amounts of plant nutrients (nitrogen and phosphorus) and trace elements (Table 1). For this reason sludge has historically been applied to agricultural land as part of an integrated farm management plan. Other options for disposal include energy recovery and land reclamation activities. In Europe, the disposal of sewage sludge is subject to strict controls designed to protect soil quality whilst encouraging the use of sludge in agriculture. Codes of Practice, such as those published by the UK Department of the Environment (DoE, 1989, 1996) and MAFF (MAFF, 1998a,b), provide advice on practical aspects of utilising sewage sludge in agriculture.

TABLE 1 Nutrient content of sewage sludge (% dry weight)

Constituent	**Range**	**Typical**
Nitrogen	<0.1 – 17.6	3.0
Phosphorus	<0.1 – 14.3	1.5
Sulphur	0.6 –1.5	1.0
Potassium	0.02 – 2.6	0.3

Strict limits are set on the amounts of potentially toxic elements permitted in sludge which may be used in agriculture. Application rates are controlled to minimise the accumulation in the soil of toxic metals. Due to the low levels of metals in UK sludges, in practice application rates are governed by maximum nitrogen application rates (250 Kg/ha y^{-1} or 500 Kg/ha $2y^{-1}$) and to balance phosphorus addition with crop off-take.

Information on the amounts of sewage sludge produced and its disposal is collected by the European Commission. Annual sludge production in the EU is in the region of 5.1 Million tonnes dry solids (M tds) of which 48% is applied to land (CEC, 1999). Within the EU amounts of sludge produced vary considerably with Germany producing the largest amount of treated sludge followed by the UK and France (Figure 1). The proportion of treated sludge used in agriculture varies across the European Union with just over 10% of sludge production in Ireland being applied to land compared with 66% in France (Figure 2). Factors affecting the amount of sludge applied to agricultural land include topography, land use, climatic conditions, and the availability of alternative means of disposal. In the UK sludge production is increasing, principally as a result of the EU Directive on the treatment of urban wastewater (CEC, 1991).

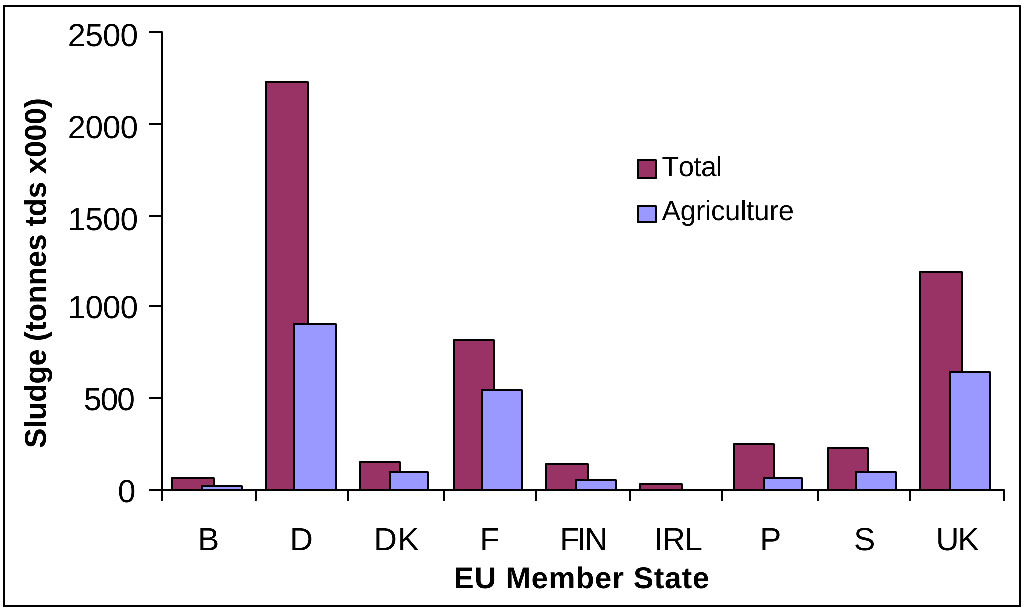


Figure 1 Sludge production within the European Union and amounts recycled to agricultural land

The cessation of sea disposal has resulted in a greater proportion of sludge being used in agriculture (Table 2) a trend which is projected to continue in the medium term (Figure 3).

TABLE 2 Sludge disposal outlets in the UK

Outlet	**Quantity (%) (tds y^{-1} $x10^3$)**	
	1990/91	**1996/97**
Agriculture	465 (42)	520 (47)

Dedicated site	25 (2)	39 (3)
Sea disposal	334 (30)	280 (25)
Incineration	77 (7)	91 (8)
Landfill	88 (8)	91 (8)
Land reclamation		64 (6)
Forestry		1 (<1)
Horticultural compost		13 (1)
Storage (on site)	50 (5)	15 (1)
Other	68 (6)*	1 (<1)
Total	1107 (100)	1115 (100)

* More general category of 'Beneficial' used which included activities classified separately in 1996/7 survey

Source WRc, 1998

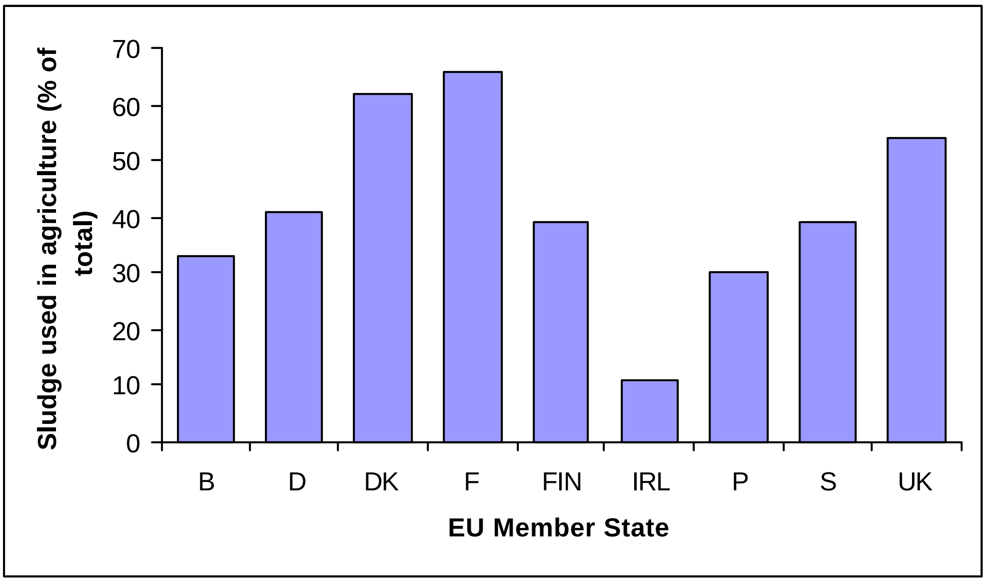


Figure 2 Proportion of EU sludge recycled to agricultural land

Regulations Governing the Use of Sludge in Agriculture

The controls on the application of sewage sludge to agricultural land within member states derive from Council Directive 86/278/EEC published in 1986 for implementation within three years (CEC, 1986). The principal rationale of the Directive was to minimise the accumulation in the soil of heavy metals or other potential toxic elements (PTE) with the objective of protecting soil fertility and public health. However, the Directive included measures for controlling transmissible disease by introducing constraints on the use of sludge.

In the UK, The Sludge (Use in Agriculture) Regulations 1989 directly implement the provisions of the Directive (Anon, 1989). This was accompanied by a Code of Practice (DoE, 1989, 1996) which provided practical guidance on how the requirements of the Directive could be met. It recognises that pathogens may be present in untreated sludges and that their numbers can be reduced significantly by appropriate treatment. Examples of effective treatment processes are given in the Code. At the time that the Code was prepared the pathogens of concern were considered to be salmonellas, *Taenia saginata* (human beef tapeworm), potato cyst nematodes (*Globodera pallida* and *Globodera rostochiensis*) and viruses.

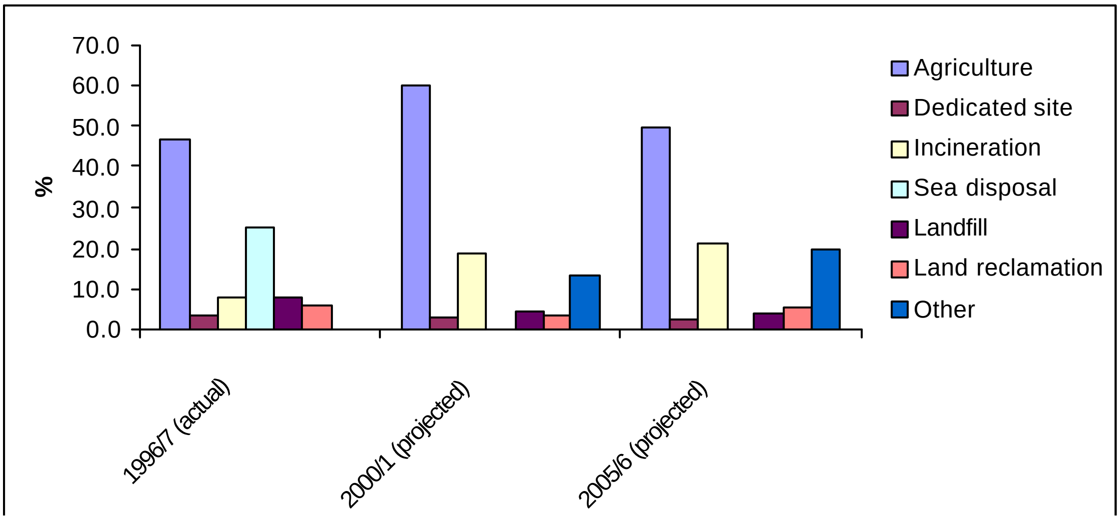
The guidance was based on the concept of multiple barriers to the prevention of transmission of pathogens when sludge was applied to agricultural land. The barriers are:

- Sludge treatment which will reduce pathogen content
- Restrictions on which crops may be grown on land to which sludge has been applied
- Minimum intervals before grazing or harvesting

Recent Developments

Against a background in the UK of concern over methods of food production the water industry, under the auspices of Water UK, and representatives of the food suppliers agreed a set of guidelines matching the level of sewage treatment with the crop under cultivation (Anon, 1998). Despite the current concerns surrounding the risks to food safety it is important to recognise that there have been no instances

documented in which disease transmission to man or animals has occurred where the provisions of the relevant UK Regulations and Codes of Practice



were followed (RCEP, 1996).

Figure 3 Sludge disposal routes in the UK

The Safe Sludge Matrix (Table 3a,b) forms the basis of the agreement and consists of a table of crop types, together with clear guidance on the minimum acceptable level of treatment for any sewage sludge (biosolids) based product which may be applied to that crop or rotation. The agreement was driven by the desire to ensure the highest possible standards of food safety and to provide a framework which gives the retailers and food industry confidence that sludge reuse on agricultural land is safe. The Matrix enables farmers and growers to continue to utilise the beneficial properties in sewage sludge as a valuable and cost effective source of nutrients and organic matter.

The main impact was the cessation of raw or untreated sewage sludge being used on agricultural land. As from the end of 1999, all untreated sludges have been banned from application to agricultural land used to grow food crops. Treated sludge[1] can only be applied to grazed grassland where it is deep injected into the soil. The regulations require that there will be no grazing or harvesting within 3 weeks of application. Where grassland is reseeded, sludge must be ploughed down or deep injected into the soil.

More stringent requirements apply where sludge is applied to land growing vegetable crops and in particular those crops that may be eaten raw (e.g. salad crops). Treated sludge can be applied to agricultural land which is used to grow vegetables provided that at least 12 months has elapsed between application and harvest of the following vegetable crop. Where the crop is a salad which might be eaten raw, the harvest interval must be at least 30 months. Where enhanced treated sludges[2] are used, a 10-month harvest interval applies.

The Department of the Environment, Transport and the Regions (DETR) have announced that they intend revising the Regulations and Code of Practice to

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[1] There are a range of different treatment processes used to reduce the fermentability and possible health hazards associated with sewage sludge. These rely on biological, chemical or heat treatment. The most common form of treatment is anaerobic digestion

[2] Enhanced treatment, originally referred to as "Advanced Treatment", is a term used to describe treatment processes which are capable of virtually eliminating any pathogens which may be present in the original sludge

take account of the Safe Sludge Matrix. It is envisaged that the revised regulations and code of practice will be introduced into parliament during 2001.

Research

During 1998 UK Water Industry Research Limited (UKWIR), the Environment Agency (EA) and the Department of the Environment, Transport and the Regions (DETR) jointly commissioned research to characterise the risks associated with the beneficial utilisation of sewage sludge in agriculture. Administration of the research work is performed by UKWIR.

The objective of the research work is to assure the safety of current recycling of treated sewage sludge and application techniques. Specifically:

1. To develop analytical procedures for determining human and animal pathogens in sewage sludge.

2. To study the fate of pathogens during the treatment of sewage sludge.

3. To establish, by means of a risk assessment methodology, whether current sewage sludge recycling operations have an observable risk with respect to human and animal pathogens.

Phase 1 has been completed and the report is in press. Phases 2 and 3 are on-going, the latter being the subject of independent peer review by ACMSF.

The objective of the microbiological risk assessment is to determine whether the application of sewage sludge to agricultural land carried out in accordance with the requirements of the revised Regulations and Code of Practice, and all other relevant guidance, poses a significant, incremental, pathogen risk to foodstuffs produced in/on such land i.e. the probability of any of the specified pathogens derived from treated sewage sludge being present on foodstuffs at the time of harvest or cropping. Figure 4 illustrates a conceptual model which identifies potential routes for the transfer of pathogens to foods intended for human consumption. The study boundary is marked.

It can be seen that there several pathways which are unrelated to the use of sewage sludge probably the most important of which is the application to land of organic wastes such as animal slurries and manures. The use of such materials in agriculture is less regulated than for sewage sludge and accounts for the majority of organic waste spread to land (Table 4).

Table 4 Estimates of the quantities of organic materials applied to land in the UK

Origin	Quantity (tonne x10^3 dw)
Farm animal	21 000
Sewage sludge	430
Paper industry	520
Food industry	600
Sugar industry	200
Others*	150

dw Dry weight

Source WRc, 1998

References

Anon (1989). The Sludge (Use in Agriculture) Regulations 1989. SI No. 1263 as amended by SI No. 880 (1990)

Anon (1998). The 'ADAS Matrix': the food and water industry in agreement. *Wastes Management*. December 1998, 28-29

DoE (1989). Code of Practice for Agricultural Use of Sewage Sludge (revised 1996)

CEC (1986). Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture

CEC (1991). Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment

CEC (1999). Report from the Commission to the Council and the European Parliament on the implementation of community waste legislation for the period 1995-1997. Commission of the European Communities, Brussels COM(1999) 752 final

MAFF (1998a). Code of good agricultural practice for the protection of water. MAFF Publications, London

MAFF (1998b). Code of good agricultural practice for the protection of soil. MAFF Publications, London

RCEP (1996). Royal Commission on Environmental Pollution Nineteenth Report, Sustainable use of Soil. Cm 3165. HMSO, London

WRc (1998). Review of the scientific evidence relating to the controls on the agricultural use of sewage sludge. WRc, Medmenham, UK

Table 3a The Safe Sludge Matrix

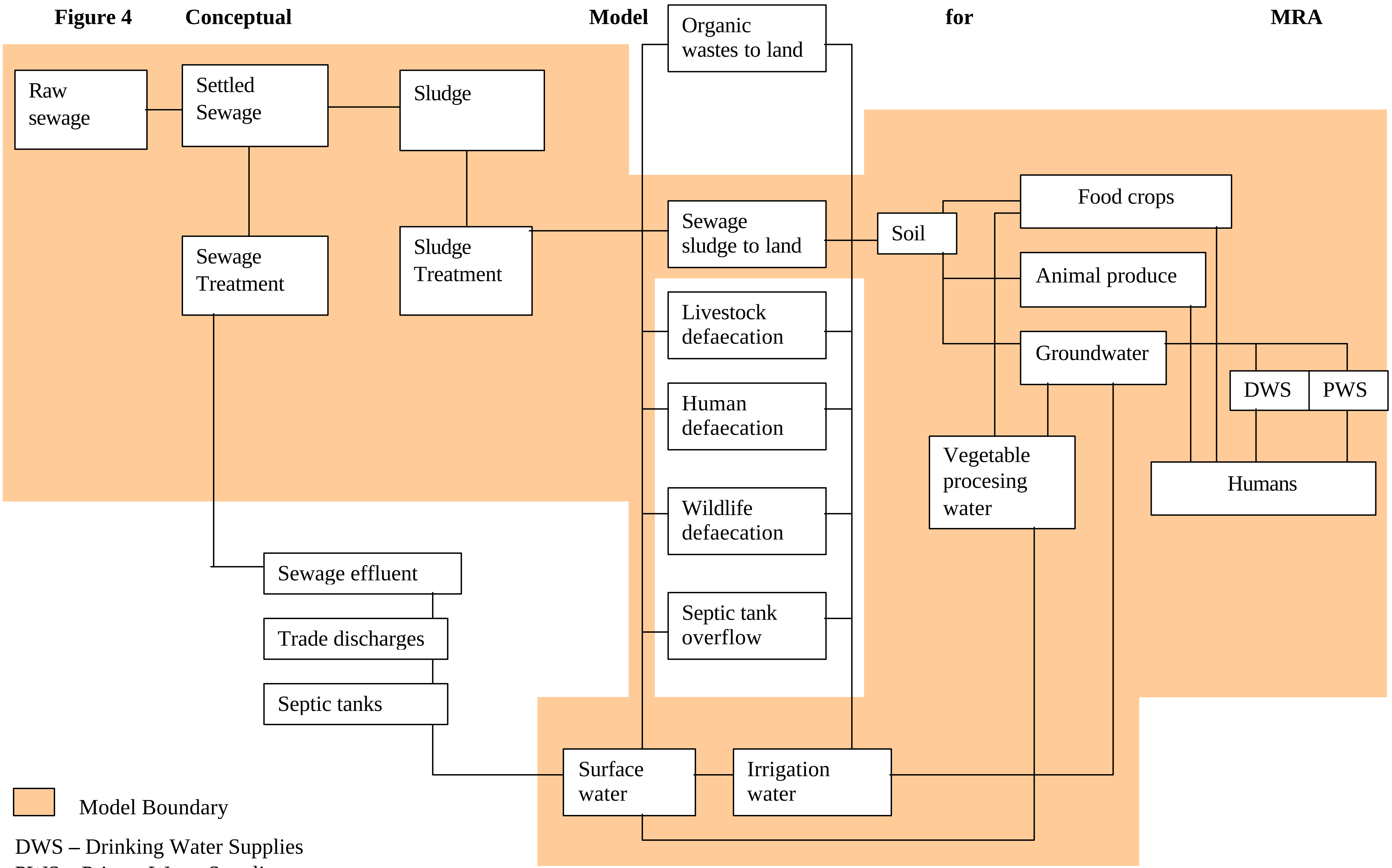
CROP GROUP	UNTREATED SLUDGES	TREATED SLUDGES	ENHANCED TREATED SLUDGES
FRUIT	✗	✗	✓‡
SALADS	✗	✗ (30 month harvest interval applies)	✓‡
VEGETABLES	✗	✗ (12 month harvest interval applies)	✓‡
HORTICULTURE	✗	✗	✓‡
COMBINABLE & ANIMAL FEED CROPS	✗	✓	✓
GRASS – GRAZING	✗	✗ † (Deep injected or ploughed down only)	✓†
GRASS – SILAGE	✗	✓†	✓†
MAIZE - SILAGE	✗	✓†	✓†

† 3 week no grazing and harvest interval applies
‡ 10 month harvest interval applies

Table 3b Cropping categories within the Safe Sludge Matrix

Fruit	Salad (e.g. ready to eat crops)	Vegetables	Horticulture	Combinable and animal feed crops	Grassland and maize	
					Silage	Grazing
Top fruit (apples, pears etc) Stone fruit (plums, cherries etc) Soft fruit (currants and berries) Vines Hops Nuts	Lettuce Radish Onions Beans (including runner, broad and dwarf French) Vining peas Mange tout Cabbage Cauliflower Calabrese/broccoli Courgettes Celery Red beet Carrots Herbs Asparagus Garlic Shallot Spinach Chicory Celeriac	Potatoes Leeks Sweetcorn Brussel sprouts Parsnips Swedes/turnips Marrows Pumpkins Squashes Rhubarb Artichokes	Soil based glasshouse and polythene tunnel production (including tomatoes, cucumbers, peppers, etc) Mushrooms Nursery stock and bulbs for export Basic nursery stock Seed potatoes for export Basic seed potatoes Basic seed production	Wheat Barley Oats Rye Triticale Field peas Field beans Linseed/flax Oilseed rape Hemp Sunflower Borage Sugar beet	Cut grass Cut maize Herbage Seeds	Grass Forage Swedes/turnips Fodder mangolds/ beet/kale Forage rye and triticale Turf production

Figure 4 Conceptual Model for MRA



DWS – Drinking Water Supplies
PWS – Private Water Supplies

ANNEX B

PATHOGENS IN BIOSOLIDS –

MICROBIOLOGICAL RISK ASSESSMENT

Report Ref. No. UKWIR USE ONLY

PRELIMINARY REPORT FOR CONSIDERATION BY AD HOC GROUP OF ADVISORY COMMITTEE ON THE MICROBIOLOGICAL SAFETY OF FOOD

UK WATER INDUSTRY RESEARCH LIMITED
Promoting Collaborative Research

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Project Title and Reference	**Pathogens in Biosolids and their significance in beneficial use programmes SL06**
Report Title	**Pathogens in Biosolids - Microbiological Risk Assessment**
Client	
Managing Company	**North West Water**
Collaborator	**WRc**
Contractor	
Sub-Contractor	
author of Report	**P Gale**
Principal Researcher	**P Gale, E B Pike & G Stanfield**
Report Type	**Final**
Period Covered	
Acknowledgements	

UK Water Industry Research Limited provides a framework for a common research programme to undertake projects which are considered to be fundamental to water operators on 'one voice' issues. Its contributors are the water and sewerage companies and the water supply companies of England and Wales, the Scottish Water Authorities and Northern Ireland's Water Service.

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Introduction

The objective of this report is to present the risk assessment approach for peer review by ACMSF. This report was written at week 16 of 26 of the contract time period. This risk assessment is demonstrated for Salmonella and *Listeria monocytogenes*. The objective of the risk assessment is to model the exposure of various crop types at the point of harvest. This is demonstrated here with respect to root crops.

Some background data used in the risk assessment

The following assumptions are made:-

- 1 litre of raw sewage give 0.005 litres raw sludge
- 1 litre of raw sludge weighs 1 kg
- Dry solid content of sludge is 2.7% (w/w)
- Up to 5 tonnes dry solids are applied per hectare of arable land.
- Sewage sludge is ploughed into a depth of 0.25 m.

Dilution of sewage sludge in soil

It is assumed that 5 tonnes dry solids sewage sludge is applied per hectare. This is ploughed in or injected to a depth of 0.25 m. The volume of soil into which the sludge is diluted is therefore 2,500 m^3. Assuming the dry weight of soil is 1.8 g/CM^3, this gives a w/w dilution of 5 tonnes sludge into 4,500 tonnes of soil. This is a 900-fold dilution.

Sludge Dilution in Soil

5 tonnes dry solids per ha

Volume = 100 x 100 x 0.25 = 2,500 m^3
Dry soil = 1.8 tonnes / m^3
Mass of soil = 4,500 tonnes
Dilution = 4,500 / 5 = 900-fold

Figure 1 Dilution of sewage sludge in soil. It is assumed the sludge is ploughed in or injected to a depth of 0.25 m

Amount of soil on root crops at point of harvest

WRc-NSF contacted Stewart Downing of DGM Growers, which process potatoes and root crops. He estimates that potatoes at point of harvest contain 2% (w/w) soil. This is based on the amount of soil recovered on grading and washing potatoes. He estimates the level of soil is less of beet crop
It is assumed therefore that there are 0.02 tonnes of soil per tonne of potato crop at point of harvest.

- **Levels of faecal contamination on crops grown in the field**

According to the median and 90 percentiles, leafy crops contain 2 – 10-fold lower levels of faecal contamination compared to root crops. In the absence of further data this could be used as a factor for risk assessment.

Table 1 Magnitude of faecal contamination observed on produce growing in the field (Geldreich and Bordner 1970). Faecal coliform (MPN/100 g)

Crop type	**No of samples**	**Median**	**90th Percentile**
Root	20	200	10,000
Leafy vegetable	34	20	5,000

Salmonella Risk Assessment

Salmonellae data

In Sections to , the steps and data used for the risk assessment are outlined.

- **Salmonella concentrations in raw and settled sewage**

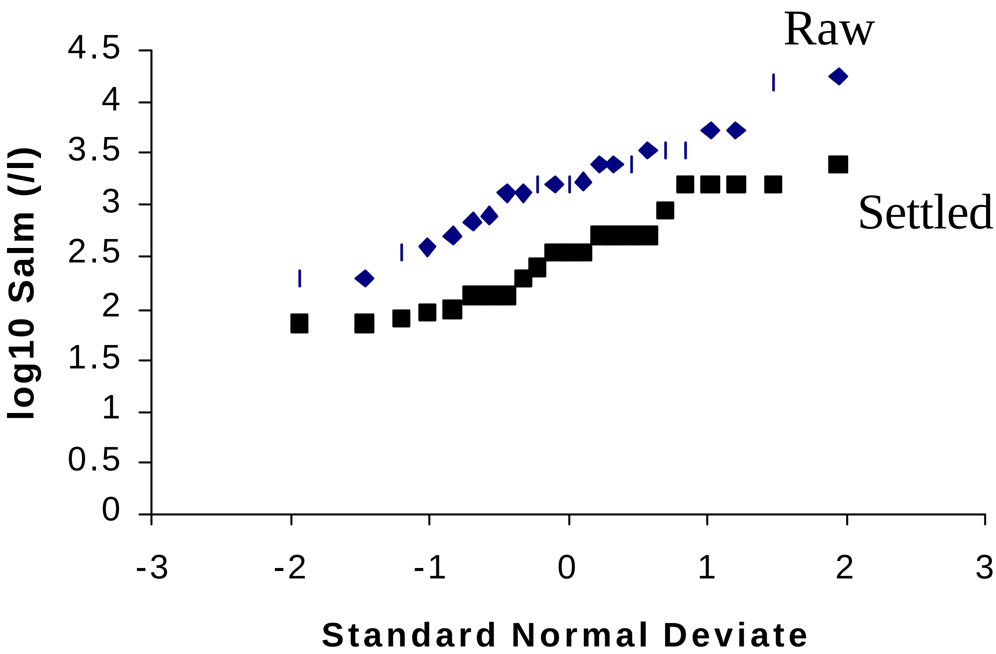

Figure 2 Salmonella concentrations in raw sewage and settled sewage from Guildford (Yaziz & Lloyd 1979)

Figure 2 compares log-Normal probability plots for salmonella densities reocrded in raw sewage and the settled sewage in the Guildford area (Faziz & Lloyd, 1979). The arithmetic mean Salmonella density in the raw sewage was 3,271 /litre and that in the settled sewage was 613 /litre. This suggests that

81% of the Salmonella settle during primary treatment and that 19% remain in the settled sewage.

- **Salmonellae concentrations in raw sewage sludge**

Figure 3 shows the event tree to model the concentrations of Salmonella partitioning into raw sludge. 81% of the salmonellas in raw sewage partition into the raw sludge during primary settlement. The 19% in the settled sewage go on to be treated by activated sludge treatment. This destroys some 90% of the salmonellas (Geldriech 1972). The sludges from activated sludge treatment are added to the raw sludges.

The event tree predicts some 2,713 Salmonella in the raw sludge per litre of raw sewage. Assuming that 1 litre of raw sewage gives 50-ml (0.5% v/v) of raw sludge then the arithmetic mean concentration of Salmonella in the raw sludge is 54,000 per 100-ml.

Fennel (1977) reported a range of 40 – 11,000 salmonellas per 100-ml and Jones (1977) reported values of 4,000 – 23,000 salmonellas per 100-ml of raw sludge.

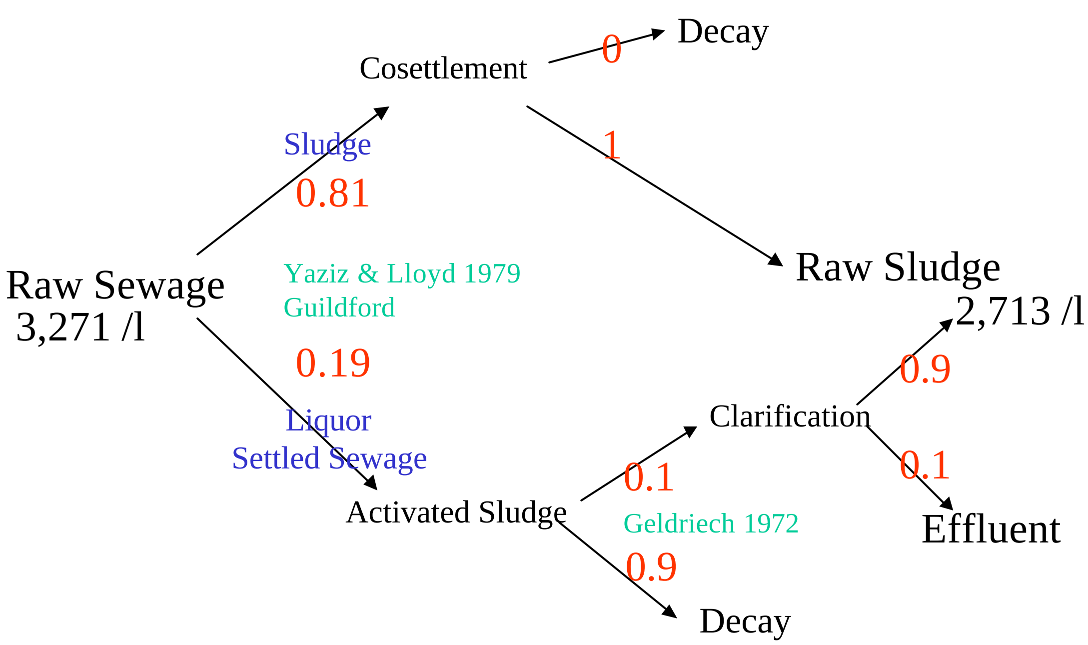

Figure 3 Event tree for partitioning of Salmonella into raw sewage sludge

- **Removal of Salmonella by sludge treatment**

Mathematical modelling and Monte Carlo simulations for removal of pathogens from water by drinking water treatment (Gale, 2000; Gale & Stanfield, 2000) show that it is the net pathogen removal by the process which is important for risk assessment. This is represented by the arithmetic mean removal ratio and not the median or geometric mean removal ratio. Problems with over-estimating the net removal, at least, for drinking water treatment processes are described by Gale (2000) and Gale & Stanfield (2000).

UKWIR have awarded a contract to Dr Nigel Horan at Leeds University to determine the net removal rates for seven pathogen types by sewage sludge treatment and advanced sewage sludge treatment. The objectives of that study are to provide pathogen removal ratios for use in the risk assessment described here. Those experiments are still ongoing. For the purpose of the risk assessment here it is assumed that sewage sludge treatment removes 2-logs of bacterial pathogen and advanced sewage sludge treatment removes 6-logs.

According to the risk assessment model, raw sewage contains an arithmetic mean of 54,000 salmonella per 100-ml raw sludge (Section). A 2-log removal by sludge treatment will give 540 salmonella per 100-ml of treated sludge.

Since 2.7% of the raw sludge is dry solids, it may be calculated that 54,000 salmonellas / l00-ml of (wet) raw is equivalent to salmonellas per tonne of dry solids.

Therefore, the salmonella loading in tonne dry solid treated sewage sludge is

540 x 10,000 x 1/0.027 = 2 x 10^8 salmonellas per tonne dry solid treated sewage sludge.

Since 5 tonnes dry solid treated sewage sludge are applied per hectare of soil, the total salmonella loading is 5 x 2 x 10^8 = 1 x 10^9 salmonellas per hectare.

- **Survival of Salmonellae in sewage sludge injected into soil**

Jones et al., (1982) reported that the T_{90} was not greater than 22 days on soil. The results give confidence in the 21 days grazing interval imposed by North West Water Authority at that time.

The die-off of Salmonellae on the surface of soil is affected by several factors such as moisture, temperature and sunlight. Andrews et al., (1983) reported a T_{90} for the winter period of 17 days; in the summer the T_{90} was 3.7 days.

Watkins & Sleath (1981) demonstrated a 2-log reduction for Salmonella in soil to which sewage sludge had been applied. The reduction over 8 weeks may well have been greater than 2-logs, but 0 readings were recorded at 6 weeks (Table 2). A conservative approach is adopted here in the risk assessment by assuming that only 2-log decay of Salmonella occurs.

A 2-log decay reduces the salmonella loading to 1 x 10^7 per hectare after 5 weeks.

Table 2 Survival of salmonellas in sewage sludge applied to land (Watkins & Sleath 1981)

Week No.	Salmonellas per 100 g soil
0	130
1	35
2	8
5	1
6	0
7	0
8	0

- **Salmonella concentrations predicted in the soil (assuming 2-log destruction by sludge treatment)**

The total mass of soil for dilution is calculated as 4,500 tonnes (Section 0). Therefore 1 x 10^7 salmonellas are diluted into 4,500 tonnes giving a concentration of 2,233 salmonellas per tonne of soil.

This is equivalent to 0.22 salmonellas per 100 g soil. Watkins & Sleath (1981) reported concentrations of between 0 and 1 salmonellas in soil at weeks 6 and 5, respectively, after application of sewage sludge (Table 2). The risk assessment is therefore in good agreement with published data.

- **Salmonella loadings on root crops at point of harvest (assuming 2-log destruction by sludge treatment)**

Since each tonne of potatoes contains 0.02 soil at point of harvest, the salmonella loading may be calculated as 2,233 x 0.02 = 44.6 Salmonellas per tonne of potatoes.

A prototype event tree for Risk Assessment for Salmonella on potato crops at point of harvest

The risk assessment approach to model the exposure of crop to Salmonella may be visualised as the event tree in Figure 4. Sludge treatment destroys 99% of the Salmonella allowing 1% remaining in the treated sludge. On application to the soil, 99% decay after 5 weeks leaving 1% remaining. Undoubtedly further decay will occur after 5 weeks, but the data of Watkins & Sleath (1981) recorded zeros, so the true decay rate is unknown without extrapolation. Dilution may be modelling as the probability of a tonne of potato crops colliding with a sludge particle. The dilution factor is 900. Therefore a potato has a 899/900 = 0.99888 probability of colliding with a soil particle. The probability of collision with a sludge particle is 1/900 = 0.00111.

Since each tonne of potatoes contains 0.02 tonnes of soil/sludge at point of harvest, 0.02 / 5 = 0.004 = 4% of the 5 tonnes dry solids of sludge applied to the hectare will be transmitted to the potato on collision with a sludge particle. 4.98 tonnes of the 5 tonnes of sludge applied = 0.996 = 99.6% will remain on the soil. This is illustrated as the final step of the event tree in Figure 4.

The event tree in Figure 4 follows on directly from that in Figure 3. The raw sludge in Figure 3 has 2,713 salmonellas per litre of raw sewage. Since 1 litre of raw sludge is produced from 200 litres of raw sewage, then 1 litre of raw sludge contains 2,713 x 200 = 542,600 Salmonellas. One tonne of raw sludge therefore contains 5.4×10^8 salmonellas. Of this raw sludge 2.7% is dry solids. Therefore 1 tonne of dry solids is compressed out of 37 tonnes of wet raw sludge. Therefore a tonne of dry solids raw sludge contains $5.4 \times 37 \times 10^8$ salmonellas = 2×10^{10} salmonellas. Applying 5 tonnes dry solids **raw** sludge per hectare is therefore equivalent to applying 1×10^{11} salmonellas per hectare.

The event tree in Figure 4 can now be followed through:-

$1 \times 10^{11} \times 0.01 \times 0.01 \times 0.0011 \times 0.004 = 44$ salmonellas per tonne of potatoes.

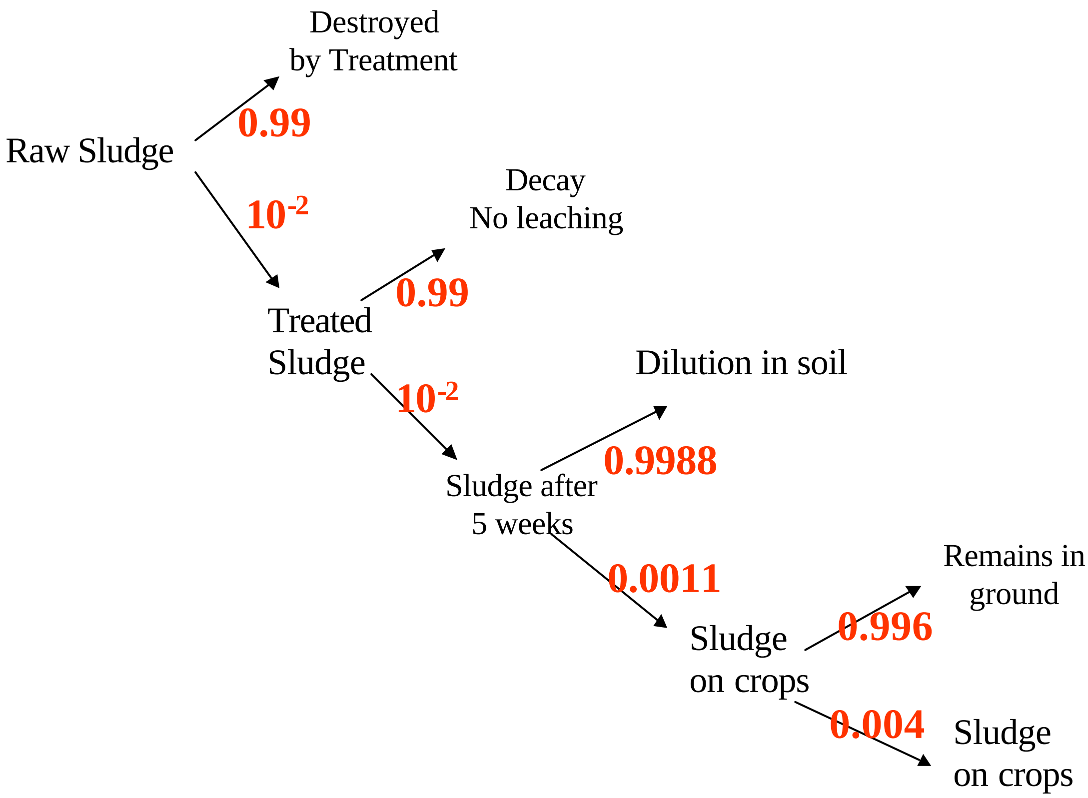

Figure 4 Prototype event tree for transmission of salmonella in raw sewage sludge to potatoes

The impact of sludge treatment on salmonella loadings on potatoes at point of harvest

Root crop exposures at point of harvest for different pathogen destruction rates during sludge treatment are presented in Table 3. It is apparent that with advanced treatment, the salmonella loadings are negligible. Even without treatment, loadings of 4,467 salmonellas per tonne of potato may not necessarily be of public health significance.

Table 3 Predicted root crop exposures to salmonella at point of harvest allowing for different rates of salmonella destruction during sludge treatment

Net removal by Sludge treatment (log of arithmetic mean)	Predicted numbers of salmonellas per tonne potato
0	4467
2	44.6

6	0.0044

Variation in Salmonella loadings in raw sewage

Levels of Salmonellas in raw sewage and sewage sludge will undoubtedly vary depending on season, loacation and time of sampling. This is shown for settled sewages in Figure 5. The data set used for the Salmonella risk assessment (Table 3) is the Guildford set in Figure 5. The arithmetic mean Listeria density in the settled sewage from Yorkshire is higher than that from the Guildford sewage treatment works.

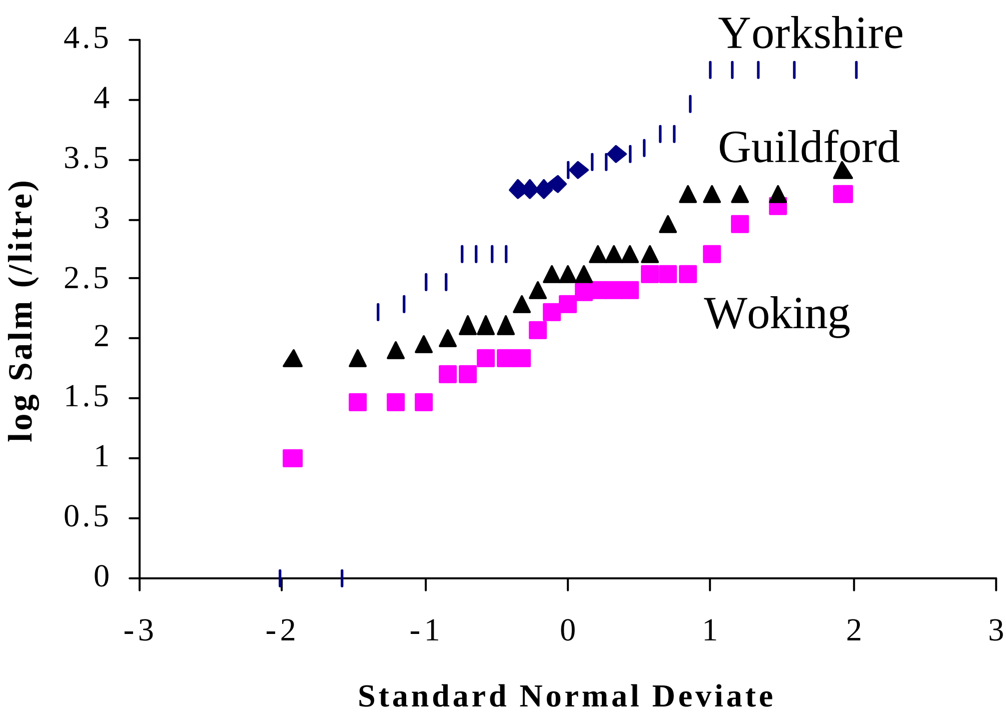

Figure 5 Salmonella densities in settled sewage from Guildford and Woking (Yaziz & Lloyd 1979) and Yorkshire (Watkins & Sleath, 1981).

Listeria monocytogenes risk assessment

Data for Listeria monocytogenes

Watkins & Sleath (1981) presented data for both salmonellae and *Listeria moncytogenes* in settled sewages and in soils to which sewage sludge had been applied. *Listeria moncytogenes* counts were often in excess of salmonellae counts.

- ***Listeria monocytogenes* concentrations in raw and settled sewage**

The distribution of Listeria monocytogenes counts in settled sewage from a number of sewage works in Yorkshire (Watkins & Sleath 1981) is presented in Figure 6.

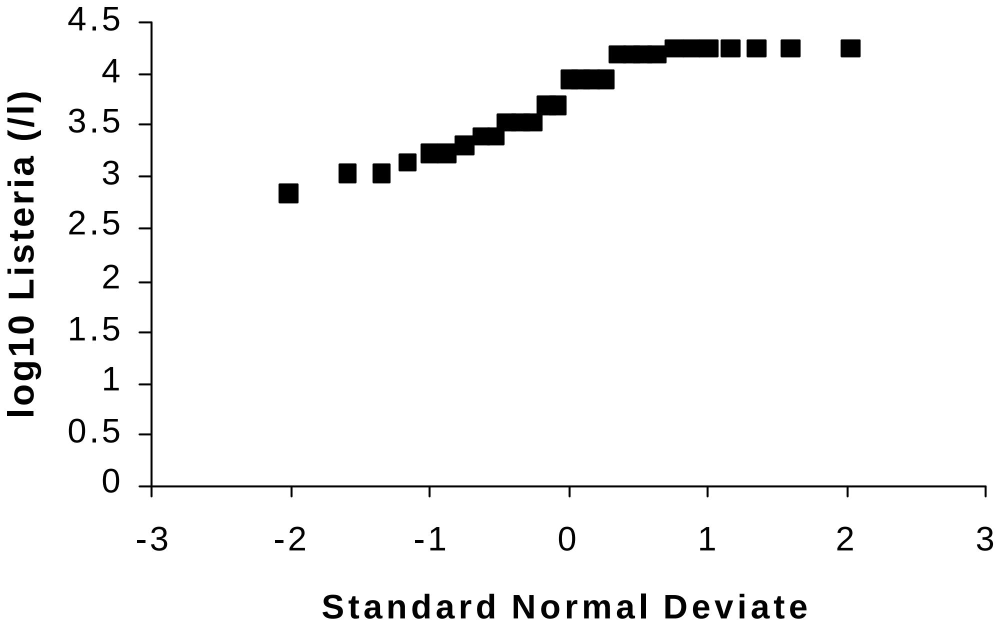

Figure 6 ***Listeria monocytogenes* counts in settled sewage from Yorkshire area (Watkins & Sleath 1981)**

Listeria counts were in general higher than the corresponding salmonella counts (Figure 5). Indeed, the arithmetic mean salmonella count was 4,875/l compared to 9,007/l for *Listeria monocytogenes*. It should be noted that these arithmetic means will be underestimated because some samples were recorded as >18,000 / l. This reflects all tubes turning positive in the MPN method.

Using this mean of 9,007 *Listeria monocytogenes* per litre, and assuming that Listeria settle in primery sewage treatment in a similar way to Salmonellas, the event tree in Figure 7 was used to calculate the partitioning of *Listeria* into the raw sludge. It should be noted that a 90% reduction of *Listeria* during the activated sludge treatment process was allowed for.

Figure 7 predicts 39,900 *Listeria monocytogenes* in the raw sludge per litre of raw sewage. Since 1 litre of (wet) sewage sludge is produced from 200 litres of raw sewage, the concentration of *Listeria monocytogenes* in wet raw sludge is 39,900 x 200 = 7.98×10^6 per litre raw sludge. Assuming 2.7% (w/w) dry solids, the *Listeria monocytogenes* loading in raw sludge is 2.95 x 10^{11} per tonne dry solids.

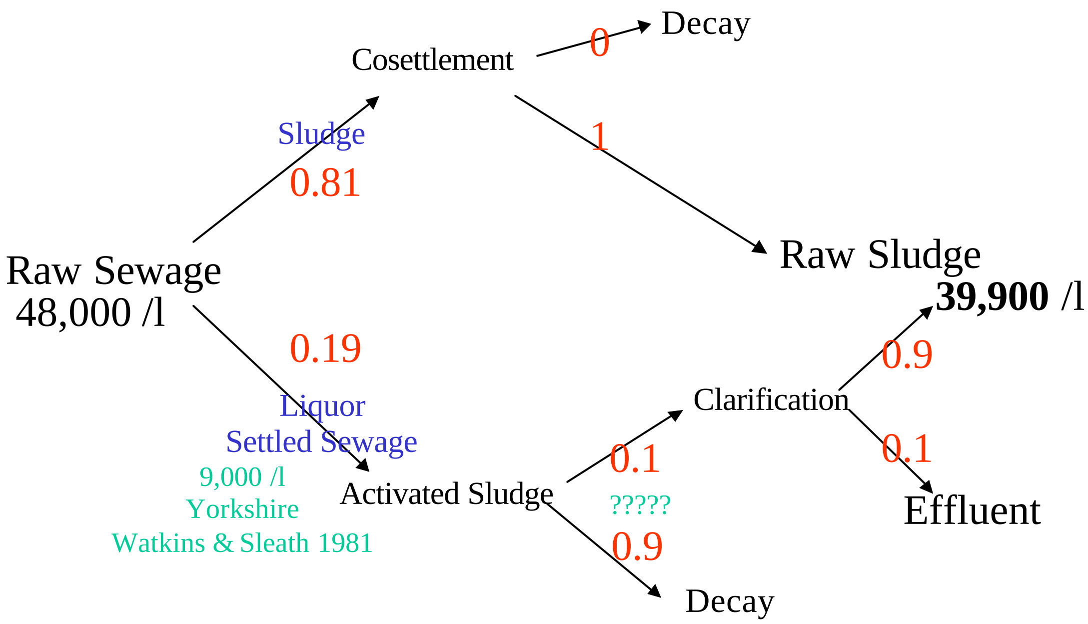

Figure 7 Event tree for partitioning of *Listeria monocytogenes* into raw sewage sludge.

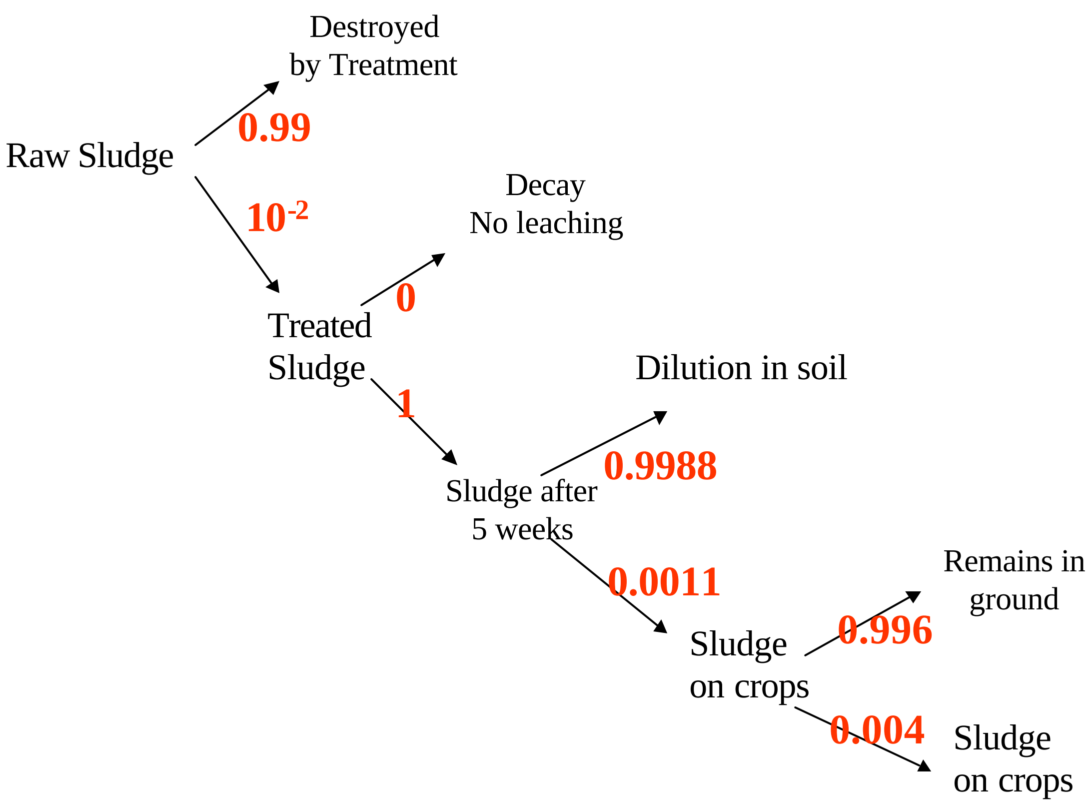

Figure 8 Prototype event tree for transmission of *Listeria moncytogenes* in raw sewage sludge to potatoes

A prototype event tree for transmission from raw sludge to potatoes is shown in Figure 8.

- **Survival of *Listeria monocytogenes* in sewage sludge applied to soil**

Results of Watkins and Sleath (1981) indicated that this organism survives longer than Salmonella spp. on land sprayed with sewage sludge. Indeed, *Listeria monocytogenes* showed little evidence of decay after eight weeks in sewage sludge applied to land (Table 4). In contrast, salmonellae counts decayed with a T_{90} of less than three weeks (Section).

Table 4 Survival of *Listeria monocytogenes* in sewage sludge applied to land (Watkins & Sleath 1981)

Week No.	*Listeria monocytogenes* per 100 g
0	170
1	350
2	225
5	>180
6	>180
7	>180
8	160

The risk assessment therefore allows for no decay of *Listeria monocytogenes* in the soil environment (Figure 8).

- **Predicted concentrations of *Listeria monocytogenes* in the soil (assuming 2-log destruction during sludge treatment)**

Assuming 5 tonnes dry solids of treated sewage sludge are applied per hectare, and allowing for no decay or leaching in the soil, then the predicted concentration of *Listeria monocytogenes* is 3.28 x 10^6 per tonne of soil. This is equivalent to 328 per 100 g of soil and is in good agreement with the 170 – 350 counts / 100 g of soil to which sewage sludge (Table 4) had been applied as reported by Watkins & Sleath (1981).

Listeria monocytogenes *loadings on root crops at point of harvest*

Applying 5 tonnes dry solids raw sludge per hectare gives 2.95 x 10^{11} x 5 = 1.476 x 10^{12} *Listeria* per hectare. Using the event tree in Figure 8, which allows for 2-log destruction by sludge treatment, the counts of *Listeria* per tonne of potato at point of harvest may be calculated as:-

1.476 x 10^{12} x 0.01 x 1 x 0.0011 x 0.004 = 65,000 per tonne root crop (Table 5).

Root crop exposures at point of harvest for different *Listeria* destruction rates during sludge treatment are presented in Table 5. It is apparent that with a 6-log removal by advanced treatment, the loadings would be low.

Table 5 Predicted root crop exposures to *Listeria monocytogenes* at point of harvest allowing for different rates of *Listeria* destruction during sludge treatment

Net removal by Sludge treatment (log of arithmetic mean)	**Predicted numbers of *Listeria monocytogenes* per tonne potato**
0	6,560,000
2	65,600
6	6.6

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ANNEX C

The Safe Sludge Matrix : Guidelines for the Application of Sewage Sludge to Agricultural Land

British Retail Consortium
Water UK
ADAS
Issue date : April 2000

The Safe Sludge Matrix, and the cropping categories and treatment processes described in the leaflet, are regularly reviewed as part of an on-going process and are subject to possible change and amendment. The contact for up-to-date information is :-

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