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ASSESSING MANAGEMENT OPTIONS FOR WASTEWATER TREATMENT WORKS IN THE CONTEXT OF LIFE CYCLE ASSESSMENT

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ABSTRACT

This paper presents the preliminary results of a Life Cycle Assessment (LCA) study comparing different wastewater treatment works, operated by Thames Water Utilities Ltd. in the UK. Fifteen works have been studied, representing a range of size and type of treatment works. Five management regimes for centralising sludge treatment and disposal were analyzed in the context of LCA to provide guidance on choosing the best practicable environmental option (BPEO).

Consideration of Global warming potential indicates that the four proposed management regimes with centralisation of sludge for treatment and disposal, as adopted by Thames Water Utilities Ltd., is an environmental improvement upon the current practice. One of these options, that of complete centralisation and composting of sludge prior to disposal, exerts the least environmental impact with respect to Global warming potential. This suggests that the adoption of composting at Crawley is environmentally preferable to increasing the digestion facility at this works. © 1998 IAWQ. Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Life cycle assessment; management; sludge disposal; wastewater treatment.

INTRODUCTION

The UK privatised water companies are facing the challenge of reviewing their practices in terms of environmental performance. The last decade has seen a general increase of environmental awareness, so much so that the environment is now recognised as one of the major considerations in any proposed work such as project design or process optimisation. In addition, customers are becoming increasingly critical of the service received and demand greater environmental responsibility from the industry.

Figure 1. The water service utilities of England and Wales.

This paper considers the management of 15 wastewater treatment works within a particular Figure 1. The Water Service Utilities of geographical region, under the management of Thames England and Wales. Water Utilities Ltd. (Figure 1). This includes a spectrum of large works, treating up to 11 x 10^9 tonnes wastewater per year, to small works, treating 8 x 10^6 tonnes wastewater per year (Table 1). Under the current management regime raw sludge is disposed to land from eleven of the works; this practice is being phased out where practical to minimise potential or perceived health risks. The sludge arising from smaller works is either transported directly to land by tanker for disposal; or to a larger works from where it is then disposed directly to land. Various alterations to this method of operation have been proposed, and as part of the decision making process the environmental impacts of the options are currently being assessed. This paper presents the preliminary results of the ongoing environmental assessment of the works under the current and proposed management regimes.

Current management regime

The method and amount of wastewater treated differs between the Thames Water sites (Table 1). The current management regime involves direct land disposal of sludge by sub-soil injection from nine works. The sludge arising from the remaining works is either transported directly to land by tanker for disposal, or to a larger works from where it is then disposed to land (Figure 2).

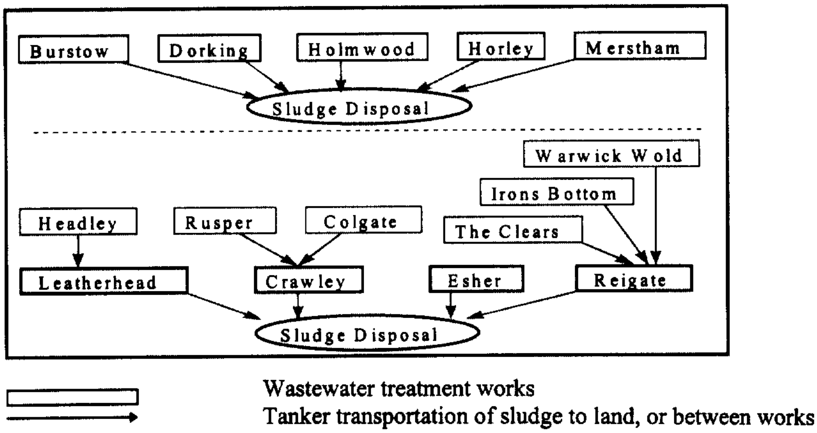

Figure 2. Diagrammatic representation of the current management regime.

Table 1. The fifteen wastewater treatment works considered

Wastewater treatment works	Method of treatment	Tonnes of raw wastewater treated per annum (x10^6)	Type of sludge disposed to land, disposal route & mean distance travelled (km)
Esher	0,1,AS+PF	11244	Raw sludge direct to land - 32
Crawley	0,1,AS	10739	Digested cake direct to land - 18
Leatherhead	0,AS	4114	De-watered sludge direct to land - 26
Horley	0,AS,3	2824	Raw sludge direct to land - 21
Dorking	0,1,AS,3	2106	Digested sludge direct to land - 22
Reigate	0,1,PF	1639	Digested, thickened sludge direct to land - 19
Burstow	0,1,PF,3	1060	Raw sludge direct to land - 30
Merstham	0,1,PF	784	Raw sludge direct to land - 22
Holmwood	0,1,PF	615	Raw sludge direct to land - 20
Rusper	1,PF	38	Raw sludge to land via Crawley - 44
Headley	1,RBC	26	Raw sludge to land via Leatherhead - 46
The Clears	0,1,PF	16	Raw sludge to land via Reigate - 47
Colgate	1,PF	14	Raw sludge to land via Crawley - 44
Irons Bottom	1,PF	11	Raw sludge to land via Reigate - 37
Warwick Wold	1,PF	8	Raw sludge to land via Reigate - 49

Key:			
0	preliminary treatment	AS	secondary treatment by activated sludge
1	primary treatment	PF	secondary treatment by percolating filters
3	tertiary treatment	RBC	secondary treatment by rotating biological contactors

Proposed management regimes

It is the policy of Thames Water to centralise, where possible, sludge treatment and disposal. A proposal to upgrade the method of treatment at Crawley presented an opportunity to improve the sludge management of the surrounding works. Various options were considered for the Crawley Sludge Centre, including:

Option 1	maintain current operations (Table 1 and Figure 2)
Option 2	Increase digestion facilities at Crawley and tanker the sludge from all works, except Esher, Leatherhead and Headley which remain unaltered, to Crawley for further treatment and disposal.
Option 3	The same as Option 2, but composting is adopted rather than increasing the digestion facility at Crawley (Figure 3).
Option 4	Increase digestion at Crawley and tanker the sludge from all works to Crawley for further treatment and disposal (Figure 4).
Option 5	The same as Option 4, but composting is adopted rather than increasing the digestion facility at Crawley.

In economic terms there is little difference between Options 2 to 5. For example, the CAPEX (Capital Expenditure) constituted approximately 15% of the NPV (net present value over 20 years) for each Option. The CAPEX for Options 2 and 3, and 4 and 5 was estimated to differ by £300K, insignificant compared to NPVs of £37 and £44million for each respective pair of Options. This demonstrates that CAPEX does not always give a definitive indication of the preferred option when planning capital schemes. Accounting for additional factors such as environmental impacts could more fully inform the decision making process. The purpose of this work is to quantify the environmental impacts of the proposed management regimes and to determine if quantitative consideration of these impacts alters the feasibility of the regimes proposed, enabling a clearer decision to be made.

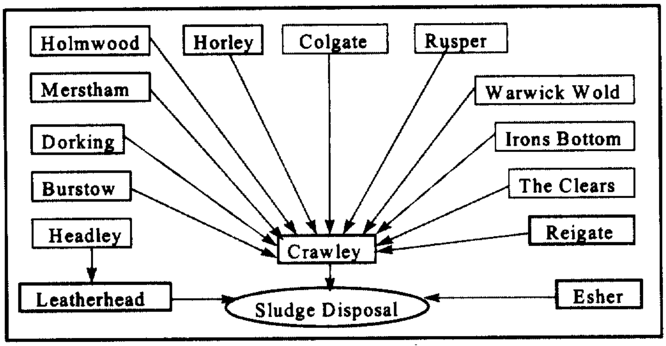

Figure 3. Diagrammatic representation of a proposed management regime: Option 3, with composting at Crawley.

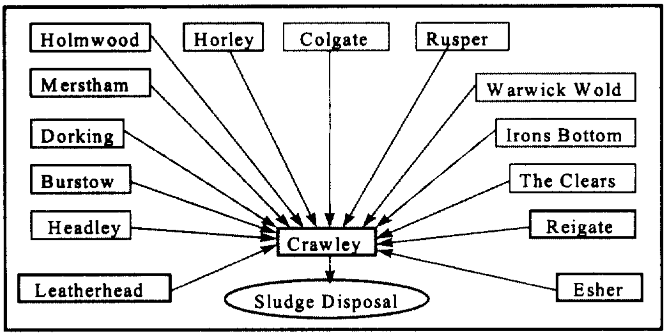

Figure 4. Diagrammatic representation of a proposed management regime: Option 4, with increased digestion at Crawley.

METHODOLOGY

Life cycle assessment

Life Cycle Assessment (LCA) is a tool for evaluating the environmental performance of a product, process or service, starting from raw material extraction, through manufacture to use and final disposal. This is known as a "cradle-to-grave" approach (Figure 5). This approach enables identification of the major environmental impacts throughout the life cycle of a product and the assessment of the possibilities for effecting improvements.

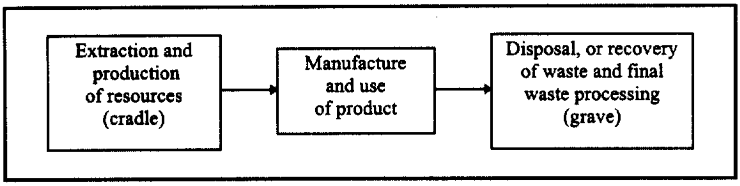

Figure 5. Process tree diagram indicating the stages considered in an LCA of a product system with no recycling.

LCA was first defined in the way we know it today at the Vermont Conference of the Society of Environmental Toxicology and Chemistry (SETAC) in 1990 (SETAC, 1991). The concept is holistic, promoting analysis, quantification and understanding of all the environmental impacts associated with an activity. The provision of such information aids decision making and helps in the formulation of environmental strategy and policy, as such LCA has been accepted into the mainstream of environmental thought and management (Markovic, 1994; Tshudy, 1994; Chen, 1995; Baumann, 1996; ENDS, 1996; Ollerenshaw, 1996).

The LCA methodology comprises four main stages: Goal Definition & Scoping, Inventory Analysis, Impact Assessment and Improvement Assessment (SETAC, 1993). Goal Definition and Scoping defines the purpose of the study, the system to be studied, the functional unit and issues relating to data quality. The functional unit forms the basis upon which systems can be compared as it relates to the service(s) provided by the product, process or activity under analysis. Inventory Analysis quantifies the environmental burdens, (i.e. material and energy use, emissions and solid wastes) associated with the provision of the functional unit. Impact Assessment aims to assess the environmental impacts of the burdens identified in the Inventory Analysis, providing manageable and meaningful data. Improvement Assessment identifies and evaluates options for reducing the environmental impacts of the system under study.

Application of LCA within the Water Industry to date has been limited. Emmerson *et al.* (1995) reported on the LCA of small-scale wastewater treatment processes comparing activated sludge and biological filter plants. They concluded that LCA has potential for environmental assessment within a water utility, and recommended further work. Nichols (1997) presented results of a study applying LCA to a variety of sludge disposal methods, the aim being to inform future decisions on sludge disposal strategy.

LCA of wastewater treatment works and associated sludge disposal

To quantify the environmental impacts associated with the various management regimes, and thus provide a basis for comparing the results, the functional unit was taken to be **9.4x10^{8} kg of raw wastewater treated with subsequent sludge disposal**. This is equivalent to the average mass of raw wastewater treated at Esher per month. Sludge disposal is modelled as sub-soil injection and allowance was made for the avoided burdens arising from the fertiliser value of the sludge. The system boundary is shown in Figure 6.

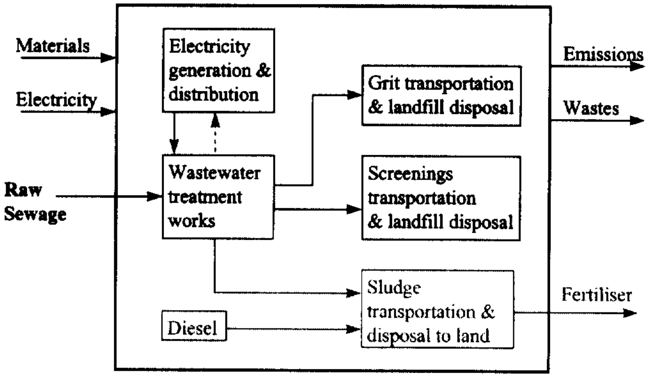

Figure 6. Flow diagram and system boundary indicating the process stages modelled for each works.

Where appropriate, the process stages indicated in Figure 6 were modelled for each works. For example, electricity is only fed back into the grid from Crawley via a Combined Heat and Power plant; there is no electricity use at Colgate; grit and screenings disposal is site specific and only occurs at Holmwood and larger works (Table 1). The treatment of wastewater at each site and subsequent transport of sludge (either directly to land, or via a larger works) was modelled for each of the five options. The application of compost to land (Options 3 and 5) was not modelled, but the sub-soil injection of sludge was (Options 1, 2 and 4). The production of polyethylene packaging for the distribution of compost was included in the study (Options 3 and 5).

The impacts arising from each works, under each management option, were summed to indicate the total environmental impacts associated with each management regime. The Impact Assessment of the burdens quantified at each works was carried out using the normalised problem orientated approach (SETAC, 1993). The environmental impacts considered include Global warming potential, acidification and eutrophication. Global warming potential is a measure of the potential contribution of different gases to the greenhouse effect, it is calculated using carbon dioxide (CO_2) as a reference gas. Acidification is a measure of the phenomena known as acid rain which is caused by gaseous pollutants, it is calculated on the basis of hydrogen ions which can be produced per mole of sulphur dioxide (SO_2). Eutrophication is a measure of an increase in biomass due to the addition of nutrients to water or soil, it is calculated with reference to the capacity of phosphate (PO_4^{3-}) to form biomass.

RESULTS AND DISCUSSION

Current management regime

Considering Burstow, a medium sized works (Table 1), it is clear that firstly the wastewater treatment process, and secondly the sludge disposal, contribute significantly to environmental impacts such as acidification and eutrophication (Figure 7). Therefore these stages of the life cycle would present the greatest opportunity for improving environmental performance.

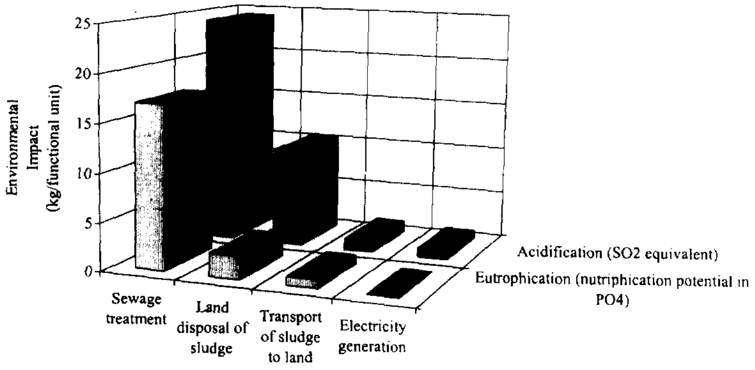

Figure 7. Environmental impacts arising from Burstow wastewater treatment works under the current management regime.

Colgate, a small works (Table 1), differs from Burstow, with the burdens arising from sludge disposal making a greater contribution to acidification and eutrophication than the wastewater treatment process itself (Figure 8). Compared to Burstow treatment at Colgate is inefficient (Table 2), this is indicated by the greater mass of sludge disposed per functional unit of raw wastewater treated.

Table 2. The mass of sludge disposed per functional unit of wastewater treated

Wastewater Treatment Works	Burstow	Colgate
Annual raw wastewater treated (kg)	$1{,}000 \times 10^6$	14×10^6
Annual mass of sludge disposed of (kg)	4.6×10^6	0.2×10^6
Mass of sludge disposed per functional unit (kg)	4×10^6	15×10^6

These results suggest that the burdens associated with sludge disposal are significant, especially when a significant mass of sludge is disposed from small works such as Colgate. Therefore it can be concluded that a reduction in the mass, and associated volume, of sludge disposed to land could result in significant environmental improvements of the system studied.

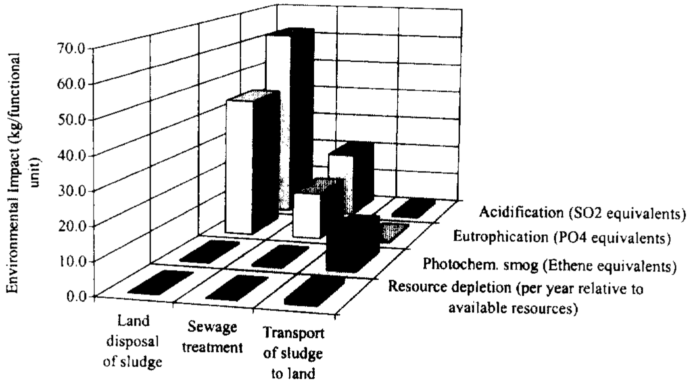

Figure 8. Environmental impacts arising from Colgate wastewater treatment works under the current management regime.

Proposed management regimes

Consideration of the environmental impact exerted by the proposed options upon Global warming potential is taken as an indication of the possible, total environmental impacts of the options. Future analysis will quantify environmental impacts such as fossil reserve depletion, acidification and eutrophication.

The results show that the proposed management regimes, compared to the current regime, significantly reduce the Global warming potential (Figure 9). The addition of a polyelectrolyte in options 2 to 5 significantly reduces the volume of sludge requiring disposal as the percentage dry solids increases by a factor of five from 4% to 22%. This significantly reduces the burdens arising from sludge transport and disposal to land, further reducing the Global warming potential (Figure 9).

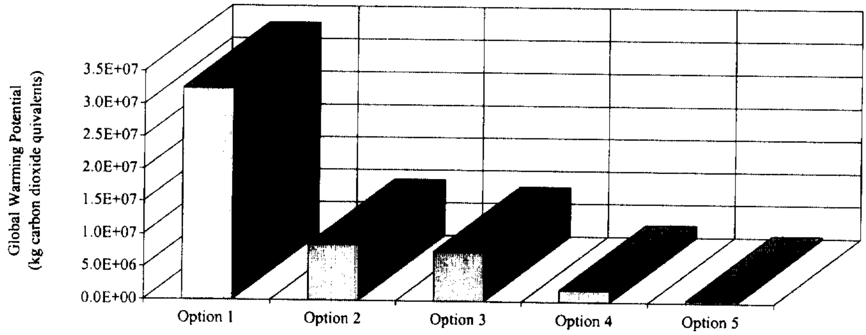

Figure 9. Total Global warming potential of the current and proposed management regimes.

The results clearly show that complete centralisation of sludge for further de-watering at Crawley, prior to disposal, provides the greatest reduction in Global warming potential (comparing Options 2 and 3, with 4 and 5). The results also indicate that by adopting composting (Options 3 and 5), as opposed to increasing the digestion facility (Options 2 and 4) at Crawley, a further reduction of Global warming potential is possible. This may be explained by the significant burdens arising from sludge disposal via sub-soil injection (Figure 10). Figure 10 shows the contribution to Global warming potential made by the individual life cycle stages within the composting and digestion systems, represented by Options 3 and 2 respectively. Figure 10 also indicates that environmental improvements may be made to the composting system if an alternative packaging material for compost distribution were to be chosen. However, it should be remembered that the quality of composted sludge is not guaranteed and that this may affect the marketability of the product.

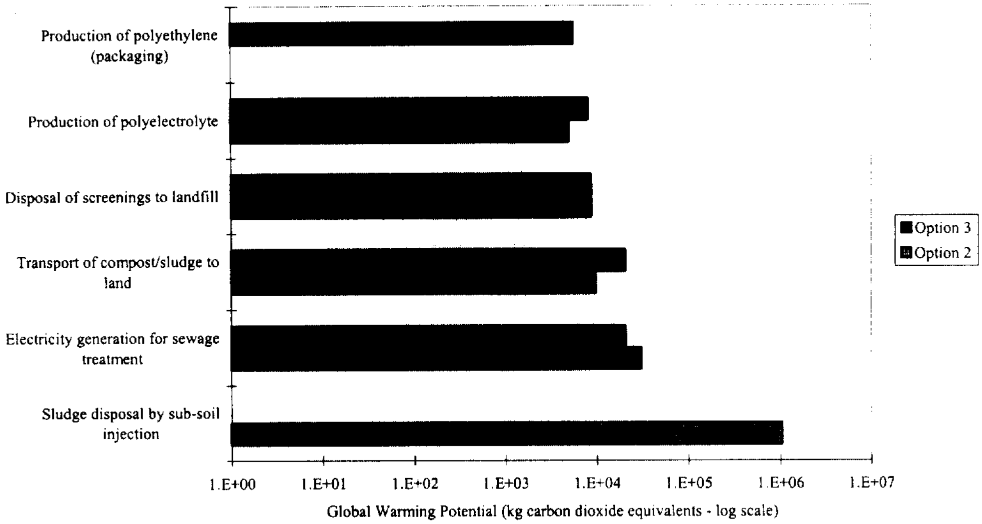

Figure 10. Significant life cycle stages that contribute to the cumulative global warming potential of options 2 and 3.

CONCLUSIONS

Preliminary results suggest that the environmental impacts associated with sludge disposal can be reduced by de-watering the sludge at the wastewater treatment works. Option 5 has the lowest Global warming potential. Consideration of this impact alone indicates that the proposed management regimes represent a significant environmental improvement upon the current management regime. Moreover, the adoption of composting, as opposed to increasing the digestion facility at Crawley, has a lower environmental impact. These results demonstrate that centralisation of sludge for treatment and disposal, as adopted by Thames Water Utilities Ltd., is an environmental improvement upon the current practice.

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