Application of Tracer Studies for Monitoring Leachate Recirculation in Landfills

Field-Trial Recommendations

Project Record
CWM 171A/98

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Research Contractor:

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This report recommends specific tracer studies for landfill sites where leachate recirculation trials are being planned or are actively in progress. The report includes outline details of each site, specific objectives of each tracer trial, outline programme requirements, estimated time-scale and likely limitations. Outline resource requirements are provided.

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R&D Project Record CWM 171A/98

FOREWORD

This report presents recommendations for the conduct of tracer trials at landfills where leachate recirculation studies are currently being undertaken.

A number of recent projects have demonstrated the advantages of leachate irrigation and recirculation associated with enhanced gas production and accelerated stabilisation of wastes. But, practical experience of meeting design criteria and demonstration of how well leachate percolates through waste masses is still not sufficiently understood to convince landfill operators that revised landfill management practices might work to their advantage. The completion of the recommended projects outlined in this report would go some way towards providing the necessary technical information required by landfill operators.

Another phase of this project has reviewed the technical experience of using tracers relevant to the landfill environment and has presented information on the selection and use of tracers for the investigation of the rate and flow of leachate through landfilled wastes.

The author acknowledges the support and assistance of Dr Louise de Rome in her role as Project Manager for this contract. The opinions expressed in this report are those of the author and do not necessarily represent those of the Environment Agency.

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EXECUTIVE SUMMARY

TECHNICAL BACKGROUND TO THE PROJECT

Research into the adoption of more sustainable approaches to landfill design, construction and operational practice has inevitably focused on the water management aspects of such installations. Over recent years a number of field-based pilot projects have demonstrated the advantages of leachate irrigation and recirculation. But, practical experience of meeting design criteria and demonstration of how well leachate percolates through waste masses is still not sufficient to convince landfill operators to adopt methods designed to accelerate waste stabilisation, either in a new design or at an appropriate existing site. One way of investigating the effectiveness of leachate percolation and migration in landfill is using tracer techniques, either through direct injection or using other non-invasive methodology.

The first phase of this project reviewed the technical experience of using tracers relevant to the landfill environment and presented information on the selection and use of tracers for the investigation of the rate and flow of leachate through landfilled wastes.

This report presents recommendations for the conduct of tracer trials at landfills where leachate recirculation studies are currently being undertaken.

PROJECT OBJECTIVES

In compiling this second report, for the study investigating the application of tracer studies for monitoring leachate recirculation in landfills, the following objectives have been observed:

- To assess landfill sites where recirculation trials are ongoing (maximum of six) to recommend specific methods to be used to determine how well leachate is being recirculated within the study area.

- To report the recommendations for each site indicating timescales, limitations of the methods, expected outcomes and if necessary suitable contractors to undertake the work.

OVERVIEW OF THE WORK CONDUCTED

A number of potential field trial sites, incorporating leachate recirculation, were discussed with the Environment Agency Project Manager and five selected for evaluation as possible sites for detailed tracer investigations. The five sites selected include:

- Howley Park landfill, Leeds - potential demonstration scale project, but no current R&D study (site operated by Biffa Waste Services Ltd.).

- Mid Auchencarroch test cell project, Dumbartonshire - small-scale recirculation field trials, shortly to move into a 2nd phase of funding (site operated by Barr Environmental).

- Mucking Marsh landfill, Essex - leachate irrigation field trial, now in a 2nd phase of funding (site operated by Cory Environmental Ltd.).

- Walpole Drove landfill, Somerset - leachate recirculation study, using vertical well injection techniques (site operated by Wyvern Waste Ltd.).

- Yanley landfill, Bristol - possible demonstration scale project, but no current R&D project (site operated by Terry Adams, now a subsidiary of Haul Waste Group Ltd.).

Information on each of these sites has been gathered from personal knowledge, telephone discussions and, for all but the Howley Park landfill, a site visit. This information has been used to devise a series of outline project briefs which the Environment Agency can use to develop more detailed specifications for future landfill related R&D project work.

CONCLUSIONS AND RECOMMENDATIONS

The Howley Park and Yanley landfill projects present full-scale operational opportunities for conducting investigations into the hydraulic behaviour of waste under leachate recirculation regimes.

Although no recirculation work is being conducted at the Howley Park site, all the main infrastructure is in place and for a relatively small investment a useful project could be initiated quickly. We recommend that the main source of funding should come through an appropriate landfill Body with the Environment Agency involvement principally funding the tracer studies.

On the other hand, the site manager at the Yanley landfill is already carrying out leachate addition to wastes in an attempt to raise the landfill moisture content. However, no monitoring of the exercise is being undertaken and therefore the full benefits of this site strategy are not being evaluated. We recommend that this trial site is considered seriously by the Environment Agency as a demonstration scale project. Most of the infrastructure is in place apart from essential monitoring equipment. Again, funding could come from a suitable landfill Body with Environment Agency involvement.

The three remaining projects are all part of current R&D initiatives. Tracer work is already included in the project specification for the Mucking trial and is likely to be included in the tender brief for the 2nd phase of the Mid Auchencarroch test cells project. This leaves the Walpole Drove landfill where no tracer study work is planned as part of the recirculation trials shortly to be undertaken. The report draws attention to the key constraints in mounting a tracer study at this site. However, this is the only study where vertical well injection of leachate is being attempted. Despite the constraints, we recommend that the Environment Agency explores the possibility of mounting a tracer study at this site, as part of the current programme.

KEY WORDS

Tracer; landfill leachate; landfill hydraulics; water tracing; fluid flow; tracer use.

1. BACKGROUND

1.1 Preamble

The current approach to landfill in the UK is to promote methods of design and operation which achieve environmental protection and subsequent beneficial after-use. In the drive to make landfilling more sustainable, this is generally considered to involve the physical, chemical and biological stabilisation of the wastes within one human generation (i.e. in the range 30 to 50 years), such that problems do not remain for future generations. For biodegradable wastes, this entails adoption of a landfill strategy which emphasises controlled bioremediation rather than one of uncontrolled biodegradation in 'dry tomb' containments.

Sustainable landfilling is widely believed to involve the passage of larger volumes of liquid through the waste mass than has hitherto been allowed by waste regulators. In the first instance, this might involve the addition of liquid to landfilled waste to raise the moisture content to field capacity and hence accelerate the biological processes that generate landfill gas. Later in the life of the landfill, the strategy might change to one of progressively increasing the moisture addition process in a way that promotes the leaching and subsequent flushing of soluble inorganic pollutants. One way of achieving this is through the recirculation of generated leachate through the waste mass.

Optimum conditions for achieving uniform, controllable flushing will involve changes to current landfill practices. Physical pre-treatment of the waste may include shredding and screening processes to promote beneficial processes in the landfill, whereas emplacement techniques might involve less use of traditional daily cover materials, in a drive to improve the behaviour of moisture flow within the waste.

A particular problem arises in the case of sites where such fundamental measures are not possible (i.e. existing sites which have recently been filled or are nearing final levels). Many such sites contain numerous potential barriers to the flow of leachate and gas, but are still subject to the completion conditions of the Waste Management Licensing Regulations 1994. It is therefore important to establish how effective recirculation and high rate flushing may be at conventional landfills.

A number of projects have demonstrated the advantages of leachate irrigation and recirculation. But practical experience of meeting design criteria and demonstration of how well leachate percolates through waste masses is still not sufficient to convince landfill operators to adopt such accelerated stabilisation, either in a new design or at an appropriate existing site.

One way of investigating the effectiveness of leachate percolation and migration in landfill is using tracer techniques, either through direct injection or using other non-invasive methodology.

1.2 The project

The wider aim of this study is to review how landfill tracer techniques have been applied in the past as well as identifying additional methods, used successfully in other disciplines, which may find application in the landfill environment. Work related to these objectives has been reported in R&D Technical Report CWM 171/98 (Blakey *et al* 1998).

To complete the study, recommendations are required for specific tracer studies on landfill sites where leachate recirculation trials are currently being undertaken. The aim of the studies is to investigate how well leachate is being distributed throughout the waste by the various application techniques adopted. As part of the recommendations, indications of project timescale, limitations, expected outcomes and possible contractors are required.

1.3 Report structure and outline content

This report is a compilation of recommendations for leachate recirculation tracer studies.

Section 2 (Site identification and selection) describes the objectives and the outline approach adopted for the selection of possible trial sites.

Sections 3 to 7 are devoted to each individual trial site recommendation and cover the general background of the project, suggested tracer study objectives, the outline programme of work, limitations and constraints of the proposed study, timescale, funding arrangements and summary details.

Section 8 (Conclusions and recommendations) summarises the scope of work put forward and makes more general recommendations about the conduct of future tracer studies.

2. SITE IDENTIFICATION AND SELECTION

2.1 Objectives

In compiling this second report, of the study investigating the application of tracer studies for monitoring leachate recirculation in landfills, the following objectives have been observed:

- To assess landfill sites where recirculation trials are ongoing (maximum of six) to recommend specific methods to be used to determine how well leachate is being recirculated within the study area.
- To report the recommendations for each site indicating timescales, limitations of the methods, expected outcomes and if necessary suitable contractors to undertake the work.

2.2 Outline approach

Using our knowledge of current field trial studies incorporating leachate recirculation, a list of projects were discussed with the Environment Agency Project Manager at an early progress meeting. Potential projects included:

- Mucking Marsh landfill - Phase 4 leachate irrigation trial;
- Walpole Drove landfill leachate recirculation study;
- Mid Auchencarroch test cell project in Dumbartonshire;
- Brogborough test cell project in Bedfordshire;
- Landfill 2000 test cell project in West Yorkshire;
- Howley Park landfill, Leeds - demonstration scale project;
- Yanley landfill, near Bristol - demonstration scale project.

The Landfill 2000 trial was rejected because the trial site had been decommissioned and was no longer available for study. In addition, no detailed examination of the Brogborough test cell project was thought necessary since tracer study work was already in progress and producing results. The five remaining projects are discussed in the following sections, in alphabetic order.

3. HOWLEY PARK LANDFILL, YORKSHIRE

3.1 Background

This landfill is situated near Leeds and is operated by Biffa Waste Services Ltd. A 4-hectare, composite lined, disposal cell within the landfill (between 20 - 40 metres in depth) is hydraulically isolated from other areas of waste deposition. It has been engineered to current standards, including grading of the cell base, the installation of a basal drainage blanket and leachate collection drains, all leading to a single extraction sump. The landfilled wastes comprise a typical mixture of domestic, commercial and industrial wastes, including Difficult wastes. These latter wastes comprise around 25% of the inputs to the site by weight and mostly consist of dewatered filter cake from waste water treatment. Daily cover has been applied, using material brought to the site for disposal, some of which is known to be clay-rich. Daily cover is not removed before emplacement of subsequent lifts of waste.

With waste inputs and operational practices being typical of a large number of currently engineered landfills, this site presents a real opportunity to investigate the hydraulics of leachate recirculation.

3.2 Objectives

3.2.1 Overall aim

To determine the hydraulic characteristics of a conventional mixed domestic/commercial/ industrial co-disposal landfill under recirculation conditions.

3.2.2 Specific objectives

(a) Assess the performance of the sub-cap leachate re-injection system by measuring its ability to deliver leachate to the full surface area of the cell under the conditions required to achieve an hydraulic retention time of around two years within the landfill cell.

(b) Determine the effective bed volume of the cell during recirculation and compare it with theoretical expectations.

(c) Determine the degree of short-circuiting which occurs within the landfill cell during recirculation.

(d) Determine the extent of mixing and plug flow which occurs during recirculation.

3.3 Outline programme

A leachate abstraction/recirculation regime has been established at the trial site, based on achieving a mean hydraulic retention time (HRT) of two years. The main features of the

infrastructure are a series of leachate re-injection trenches, which have the design capability of allowing recirculation flows of around 250 m^3 d^{-1} (equivalent to an aerial application rate of approximately 2300 mm a^{-1} over the 4 ha cell area).

Each independent trench runs parallel to the surface contours of the landfill to encourage even distribution. Each trench is separated by some 25-30 metres laterally and 5 metres vertically. Each trench is approximately 1 m wide x 1-2 m deep, with leachate being introduced via slotted drainage pipework (80-100 mm diameter). The trench is backfilled with high voidage drainage media and protected with geotextile fabric to prevent fines being deposited from the capping/restoration layer above.

Chemical tracer should be added to the re-injected leachate and the recovery pattern monitored in order to determine apparent bed volume and HRT. The breakthrough behaviour of the tracer will indicate the extent of short-circuiting. The pattern of tracer recovery will indicate the extent of mixing and plug flow during percolation through the cell.

Total volumes re-injected should be measured and compared with total leachate volumes abstracted. This may provide useful information on the uptake of absorptive capacity.

Leachate levels in the cell base should be monitored at points well away from the abstraction sump. The response of these levels to different rates of re-injection should be monitored, possibly requiring the use of an automatic level recording device.

The quality of the collected leachate should be monitored regularly for a range of parameters in addition to tracer concentrations. The results should be used to assess any changes attributable to the practice of recirculation.

In outline the monitoring programme should include:

- fortnightly leachate level readings in all leachate monitoring boreholes;
- continuous level recording on one monitoring borehole (moveable);
- flowmeter with totaliser, on abstraction pump and on re-injection pumps.
- weekly analysis of sump leachate quality (chloride, ammoniacal nitrogen, TOC and tracer e.g. Li);
- monthly analysis of sump leachate quality (as weekly plus temperature, pH, conductivity, total organic nitrogen, BOD, major ions, heavy metals plus iron and manganese);
- quarterly monitoring of leachate monitoring boreholes (as monthly schedule for sump leachate).

3.4 Limitations and constraints

Key limitations and constraints of the trial include:

- Clay-rich daily cover has been used at the trial site which may impact on the full design capability of the recirculation scheme. Although a potential constraint, similar circumstances are likely to present themselves at many operational landfills where leachate recirculation may be contemplated and therefore is worth investigating.

- The level of tracer adopted must be high enough to be detectable during monitoring but low enough not to compromise the trade effluent consent conditions for off-site disposal to sewer.

- The effect of recirculation on the leaching of co-disposed wastes is unknown, but should not compromise disposal of leachate to sewer.

Adequate monitoring, particularly during the early part of the investigations, would need to be established to address these issues.

At the time of writing this report, leachate quantities available at the test site are not thought to be significant. Therefore, the availability of recirculation liquid would need to be given some thought before instigating this high rate leachate recirculation trial.

3.5 Timescale

It is anticipated that the objective can be met within a 2-3 year research programme.

3.6 Funding arrangements

The initiative for this project has been taken by Biffa Waste Services, in conjunction with Knox Associates. Although some funding should be expected from Biffa Waste Services, additional funds will be required from the Environment Agency and/or an Environmental Body.

3.7 Summary details

Trial site	**Howley Park, Yorkshire**
Description	Investigation of hydraulic characteristics of a conventional mixed waste landfill, using tracer addition during high rate recirculation through a sub-cap trench system. 4 Ha cell (20-40 m deep) with composite liner and drainage blanket feeding a central leachate abstraction sump.
Recirculation infrastructure	Reception lagoon feeding a series of independent trenches, following the surface contours of the landfill (5 m vertical interval; 25-30 m lateral interval).
Key objectives	• Determine degree of short-circuiting. • Determine effective Bed Volume. • Determine extent of mixing and plug flow.

	• Assess the performance of sub-cap trench injection system.
Funding	Biffa Waste Services Ltd. A.N. Other (Environment Agency or Environmental Body project).
Potential contractors	Biffa Waste Services Ltd. Knox Associates.
Dates	2 - 3 year study (awaiting funding).
Project status	• Recirculation system installed and operational. • Awaiting funding for tracer study.
References	No technical reports available.

4. MID AUCHENCARROCH TEST CELLS, DUMBARTONSHIRE

4.1 Background

The trial site is situated 40 km west of Glasgow on a landfill site owned and operated by Barr Environmental. The project is currently managed by EnviroCentre Ltd., an environmental consultancy affiliated to the Department of Civil Engineering, University of Strathclyde.

Four purpose-built test cells were constructed in the indigenous clay drift, being filled with waste between August and November 1995, when monitoring began. Each cell is roughly 28 x 30 metres in area and approximately 5 metres deep. To enable the efficient collection of gas and leachate, and subsequent re-distribution of leachate, each cell has a drainage blanket at the top and base of the waste deposit. The basal drainage blanket consists of 50-100 mm crushed rock with a nominal voidage of around 50% laid in a 300 mm thick layer, graded towards a central access well. The surface irrigation blanket is constructed of similar material, although is only 150 mm thick and protected from the capping material with a geotextile.

The main variables of the trial include examination of wet pulverisation versus crude wastes, mixing waste with inert granular material to improve hydraulic properties and recirculation of leachate. The four cells were filled as follows:

- Cell 1 - Wet pulverised waste, mixed with red sand (silt/clay fraction 13%) and leachate recirculated.
- Cell 2 - Crude waste, no added sand and leachate recirculated.
- Cell 3 - Wet pulverised waste, no added sand and leachate recirculated.
- Cell 4 - Crude waste, no added sand and no leachate recirculated.

Given the different waste treatments and the experimental nature of the trial, the site presents an opportunity to investigate the hydraulics of leachate recirculation under different landfilling conditions and, more importantly, under high-rate recirculation conditions.

4.2 Objectives

4.2.1 Overall aim

To determine the hydraulic characteristics of modified and un-modified municipal solid wastes under high-rate leachate recirculation conditions.

4.2.2 Specific objectives

(a) Assess the performance of the sub-cap leachate re-injection system in each recirculation cell under the conditions required to achieve an hydraulic retention time of around two years.

(b) Determine the effective bed volume of each cell during recirculation and compare it with theoretical expectations.

(c) Determine the degree of short-circuiting which occurs within each cell during recirculation.

(d) Determine the extent of mixing and plug flow which occurs within each cell during recirculation.

4.3 Outline programme

Currently, the recirculation rate adopted at the trial equates to an HRT of around four years. In order to provide complementary data with the Howley Park trial, for instance, we suggest that initial steps are taken to investigate ways of reducing the HRT of the trial to two years. This would involve recirculating at a rate of 16-20 m^3 wk^{-1}. This may not be possible, but would provide more useful data within a typical study period of two to three years.

The project should proceed in much the same way as outlined for the Howley Park trial (see Section 3). Chemical tracer should be added to the recirculated leachate and recovery patterns monitored to determine apparent bed volume and HRT. Breakthrough behaviour of tracer will indicate the extent of short-circuiting, which in these trials is likely to be via the central leachate abstraction well. The pattern of tracer recovery will indicate the extent of mixing and plug flow during percolation through the cell.

The monitoring requirements for the trials should remain broadly similar to the Howley Park project, with leachate volume (extracted versus recirculated), leachate levels and leachate quality being recorded.

Leachate level data from the trial may not be as informative as in the Howley Park project, because only one access well is available in each of the cells and this is used for pumping leachate back to the recirculation blanket. This may not be a serious problem because pumping is intermittent, only occurring once a week. Nevertheless, it may be sensible to include construction costs of four leachate monitoring boreholes in the budget for the project, along with instrumentation costs allowing continuous leachate level recording. As well as providing useful monitoring points, separate from the main leachate abstraction wells in each cell, these boreholes would also provide valuable solid samples for detailed characterisation work. Four shallow boreholes could be constructed and instrumented for around £6-7K (1998 prices).

4.4 Limitations and constraints

Key limitations and constraints of the trial include:

- The cells are currently operated on an HRT of around four years. If this cannot be reduced to around two years, comparison with other high rate recirculation trials may not be possible and the full benefit of the trial may not be realised within a two - three year time frame for the project.

- The trials are small in comparison with some of the field-scale demonstration projects listed in this report. Nevertheless, one of the strengths is that tracer studies can be conducted on four cells with contrasting waste characteristics and emplacement techniques.

- Short-circuiting effects have already been observed via the central leachate access well. This will impact adversely on the full value of the data generated if steps are not taken to correct the problem.

On this last point, the design fault lies with the central well, which is perforated all the way up to the granular blanket, in which gas is collected and leachate recirculated. When leachate recirculation is carried out, the blanket is allowed to fill and a proportion of this liquid flows back directly to the basal drainage blanket, through the slotted casing of the central well. The proportion of leachate short-circuiting in this way is unknown, but is likely to be high since cascading leachate is audible in the central well after a recirculation event.

The solution would be to excavate at least two metres into the waste layer beneath the granular blanket, around the circumference of the central well creating a void. This void should be backfilled with a clay or bentonite grout curtain. This will not solve the problem entirely but will go a long way towards encouraging more of the leachate to penetrate the waste mass rather than passing directly to the basal drainage layer. A tracer study carried out after such remedial work would provide added confidence on the degree of short-circuiting in the trials, and would help to put the wider results of the study into context with the hydraulic behaviour of the cell; a feature of the data analysis which is currently missing from this project.

Shortcircuiting effects are a serious short-coming of this study and, unless the remedial work is carried out, there is little point embarking on the tracer study outlined above.

4.5 Timescale

The recommended work would be conducted over a two - three year time frame.

4.6 Funding arrangements

This test cell facility is a valuable resource and as such any tracer study work should be conducted alongside further routine monitoring work as well as more specific programme objectives. A second phase project is likely to be commissioned by the Environment Agency

shortly. The recommendations for the tracer studies described above could be incorporated into the technical specification of the tender invitation, or let as a separate contract.

4.7 Summary detail

Title	**Mid Auchencarroch Test Cells, Dumbartonshire**
Description	Enhanced MSW stabilisation in four ~3000 t shallow (<5 m) clay-lined cells, by varying waste composition, pre-treatment and cell management techniques. Cell 1 - pulverised and inert waste with leachate recirculation; Cell 2 - untreated waste with leachate recirculation; Cell 3 - pulverised waste with leachate recirculation; Cell 4 - Control, untreated waste, no leachate recirculation;
Recirculation infrastructure	Granular drainage blankets laid to a central collection point, MSW tipped on top. Surface drainage media placed over the waste and capped with impermeable material. Infiltration is only through the recirculation. Submersible leachate pumps installed in sumps. Each recirculation event involves 6 to 16 m^3 (one day per week). Some short-circuiting problems with leachate emerging in gas/leachate cell at the end of the recirculation period.
Key objectives	• Assess the performance of sub-cap trench injection system. • Determine degree of short-circuiting. • Determine effective Bed Volume. • Determine extent of mixing and plug flow.
Funding	Environment Agency, with additional support from Scottish funding bodies (e.g. SEPA, Scottish Office, SNIFFER or a landfill Body).
Potential contractors	EnviroCentre Ltd., or other suitably qualified local university/ consultant partnership.
Dates	Two - three year study
Project status	• Recirculation carried out manually although permanent electricity supply will allow automated strategy. • Some remedial work required before the start of tracer studies.
References	Wingfield-Hayes *et al* 1997

5. MUCKING MARSH LANDFILL, ESSEX

5.1 Background

The Mucking Marsh landfill is situated on the northern bank of the river Thames near Stanford-le-Hope in Essex and is operated by Cory Environmental. A moisture limited, 7-hectare cell (approximate depth - 20 metres) within the landfill has been the subject of recent study, examining the effects of leachate irrigation on the rate and extent of gas production. The cell has been engineered to current standards, but does not include a basal drainage blanket or leachate collection drains. However, access to the basal saturated layers of waste is achieved via the single leachate abstraction sump, situated at the eastern end of the cell. The landfilled wastes comprise a typical mixture of domestic and commercial/industrial wastes. Daily cover has been applied, using silty sands available on the site. These materials are of relatively low permeability and are not removed before emplacement of subsequent lifts of waste.

Leachate has been added to a system of irrigation trenches installed beneath a temporary surface capping layer of silty sand between October 1995 and January 1997. In addition, leachate has been pumped direct to the basal layers of waste using the access sump. Both activities have been monitored extensively and results indicate that landfill gas production has been enhanced along with the rate of waste stabilisation.

Given the specific constraints of the irrigation pipework and the lack of a basal drainage layer, tracing work at the site should be limited to the investigation of the horizontal distribution of leachate achieved by the pipework under short, intensive, irrigation events. In addition, the combined effect of natural infiltration and irrigation could be measured in the shallow vertical profile of the trial.

5.2 Objectives

5.2.1 Overall aim

To investigate the effectiveness of a sub-cap leachate irrigation system operated under an intermittent dosing regime. Effectiveness should be judged by the extent of the horizontal distribution of irrigant and the effect of this liquid on the development of the vertical moisture profile within the wastes.

5.2.2 Specific objectives

(a) Assess the performance of the sub-cap leachate irrigation pipework by measuring its ability to deliver leachate to the full surface area of the cell under an intermittent dosing regime.

(b) Determine whether any short-circuiting occurs within the landfill cell as a result of irrigation.

(c) Follow the progression of tracer in the vertical profile of the trial by carrying out a programme of destructive sampling and analysis of recovered waste materials.

5.3 Outline programme

This study should only be carried out as part of a much wider study designed to investigate the effects of leachate irrigation and consequential waste wetting on landfill gas production and leachate management.

At least two additional, full depth, monitoring boreholes should be constructed within the current leachate irrigation area. Solid waste samples should be taken from the profile of removed wastes during construction work and used to determine the extent of waste wetting in the vertical profile as well as characterisation of the wastes and the extent of chemical and/or biological stabilisation. One borehole should be constructed at the beginning of the work programme, with the second borehole being completed towards the end of the project. This will allow some comparative analysis.

Tracer study work should be carried out primarily to investigate the effectiveness of the sub-cap leachate irrigation pipework; effectiveness being measured by the even distribution of leachate (or otherwise) within the irrigation area. We suggest that this could be investigated in two ways:

1. By injecting inorganic tracer (e.g. lithium bromide) into the irrigated leachate and then carrying out a retrospective grid sampling exercise (e.g. at relatively shallow depth -say 2-3 metres) using a portable lightweight sampling device, to recover samples from the extremities of the trial site and within the vicinity of the irrigation pipework.

2. By constructing a grid network of shallow sampling ports into which adsorption media (e.g. activated carbon) could be placed for qualitative determination of dye tracer.

A testing strategy based on the second option would allow the use of dye tracer, since the trial would be conducted at shallow depth where absorbency effects would be kept to a minimum. In addition, this testing technique would allow additional use of alternative dye tracer to measure the effects of different leachate irrigation strategies.

In practice, it is recommended that a combined tracer application is used to investigate leachate distribution behaviour and possible short-circuiting effects. Preliminary work should concentrate on finding the best irrigation strategy for even distribution of leachate (using dye tracing techniques) whilst short-circuiting effects should be explored (using inorganic tracer application) after an optimised leachate irrigation strategy has been implemented.

The monitoring requirements for the trial will include:

- weekly leachate level readings in all available boreholes and the access sump;
- continuous level recording on the leachate access sump;
- recording volumes of leachate added and removed form the trial site;
- monthly and quarterly analysis of leachate quality in the access sump, feed liquor lagoon and at least one monitoring borehole (determinands to be broadly similar to those itemised for the Howley Park trial, described above).

5.4 Limitations and constraints

- The suggested work programme should be conducted as part of a wider monitoring project at the trial site. At the time of writing this report, a Phase 2 project has been accepted for funding by the Environment Agency.
- Low level irrigation will only allow the study of leachate distribution characteristics of the installed irrigation system (unless significant short-circuiting is encountered). The effective bed volume of the trial site will not be determined.

5.5 Timescale

The recommended work programme would be conducted within a two year project time frame.

5.6 Funding arrangements

This project has been accepted for funding by the Environment Agency. The contract will be managed by Cory Environmental, with WRc acting as sub-contractors. The tracing studies described are included in the agreed working programme.

5.7 Summary detail

Trial site	**Mucking, Essex**
Description	Monitoring of a sub-cap leachate recirculation system, retrofitted to a moisture-limited waste mass which was not generating gas uniformly, intended to enhance gas production rate at a completed landfill cell. • 1 M m^3 refuse, 20m deep. • Capping of Thanet Sands, clay lined cell. • Surface water catchment lagoon, lightly contaminated with leachate, used as source of irrigant.

Recirculation infrastructure	• Spine lines introduce leachate below 1 m silt cover. • 4500 m^3 a^{-1} leachate has been pumped over an area of 70 000 m^2, equivalent to additional infiltration of 65 mm a^{-1}. • Irrigation system, is in close proximity to capping layer which has limited the amount of leachate that can be safely added without causing breakout. • Basal 4 m is saturated and methanogenic, but no drainage media installed.
Key objectives	• Assess performance of sub-cap trench irrigation system. • Determine degree of shortcircuiting. • Determine progression of irrigant in the vertical profile of the wastes.
Funding	Environment Agency, with industrial support from Cory Environmental.
Contractors	Cory and WRc.
Dates	Summer 1998 to Autumn 2000.
Project status	Key infrastructure is installed, although some refurbishment required to restore full operational capability. Working programme to start on completion of negotiations on acceptable terms and conditions.
References	Blakey *et al* (1997)

6. WALPOLE DROVE LANDFILL, SOMERSET

6.1 Background

The site is located near Junction 23 of the M5 motorway, near Bridgwater and is operated by Wyvern Waste.

The landfill has been developed in a number of phases running in relatively thin strips from west to east, with the restored areas containing household/commercial wastes (approximately 50/50) deposited between 1988 and 1994. The thin strip operation allows the use of a mobile net gantry to keep wind blow and bird nuisance to an acceptable level. The fill occupies a void of around 2.5 Mm^3 which is excavated 2 metres below, and filled up to 15 metres above, ground level. As part of the progressive restoration scheme for the site, all wastes are currently dressed with clay before the installation of an LDPE capping membrane which is overtopped with a metre of clay and topsoil before seeding to grass.

Leachate flow is predominantly from south to north of the site where it drains to a series of manholes along the northern boundary of the site. From here it is fed into a leachate treatment plant on the north eastern extremity of the site.

Landfill gas is actively extracted from gas wells installed in the vertical profile of the waste. Landfill gas flow metres have been installed as part of the monitoring instrumentation for the planned recirculation trials. All extracted gas is passed to an on-site power plant which generates electricity for off site sale. The operation and maintenance of the landfill gas extraction and power generation system is currently under the control of Gravesons.

A series of seven vertical leachate injection wells have been installed to roughly 2 metres depth in part of the restored area of the landfill, on the western boundary (Phases 1 and 2). One group of three boreholes run down the western side of this restored area, with a further four on the more easterly flank. All the wells are positioned away from the gas abstraction points. Each well has been drilled to a diameter of roughly 300 mm with the internal 50 mm slotted standpipe surrounded by a coarse gravel pack.

A control area (roughly Phase 3 of the landfill) contains no recirculation wells. However, a different design of leachate injection point has been devised for trials on Phase 4 and further injection points of this type are planned for Phase 5. These alternative injection points are constructed as a 5 m long x 2 m wide x 2 m deep stone filled trench (40-75 mm stone). A 90 mm HDPE pipe with a 3 m long T-bar at its base is placed in the trench before filling with stone to act as a conduit for injecting recirculated leachate. The top of each stone trench is restored with geotextile before replacing the surface cover materials, to prevent blockage of the stone voids with fines. The idea behind the injection trench is that each unit will act as a reservoir, possibly allowing greater volumes of leachate to be recirculated in comparison to the vertical wells in Phases 1 and 2.

At the base of the cells, cross flows and head flows are believed to occur, with none of the phases being discretely confined. There is also believed to be some mixing with local groundwater.

At the time of writing this report, irrigation work had not yet started but was imminent.

6.2 Objectives

6.2.1 Overall aim

To compare and contrast the behaviour of liquid in a mixed household/commercial waste landfill using two different vertical well injection techniques.

6.2.2 Specific objectives

(a) Assess the performance of the two different vertical well leachate injection systems in terms of their effectiveness in raising the moisture content of surrounding wastes under the constraints of the irrigation strategy adopted.

(b) Determine the overall area of influence of each leachate injection system and make suggestions about the effectiveness of vertical wells in leachate recirculation applications and how these may be improved or optimised (i.e. construction and design spacings for application at full scale).

(c) Comment on the relative merits and disbenefits of each system.

6.3 Outline programme

This site presents a unique opportunity to study the relative merits of two different vertical well leachate injection techniques. We suggest that trials are designed to examine the effectiveness of each system in raising the moisture content of waste in close proximity to each injection point. This is likely to involve the construction of additional monitoring wells around, say one or two randomly selected injection points so that comparisons can be drawn between the two techniques of liquid addition.

Initial desk work should concentrate on reviewing the performance characteristics of existing vertical well injection systems in landfills. This work will proceed relatively rapidly since we believe that experiences in this area are not likely to be extensive.

For the field investigation phase of the project, each monitoring array would need to be designed in a way that allows the recovery of depth related waste samples for the measurement of moisture content as well as tracer analysis in interstitial liquids. Care in sample recovery will yield additional samples for more extensive waste characterisation if budgets allow.

6.4 Limitations and constraints

The restoration scheme includes the use of an LDPE membrane beneath the clay capping material. The requirement for intensive monitoring arrays around one or two of each type of leachate injection point are likely to compromise the integrity of this liner and may prove a problem in negotiating rights of access with the site operator.

Gas management and utilisation is the responsibility of a third party. Any project work which is likely to impact on the performance of the gas extraction system, and the supply of gas to the power plant, is not likely to be viewed favourably by this third party.

6.5 Timescale

We envisage that this demonstration project would be conducted over a six month time frame, in conjunction with the current field studies at the site.

6.6 Funding arrangements

This trial provides a good opportunity to carry out a direct performance comparison of two different vertical well leachate injection systems, as part of the wider leachate recirculation work at this site. Although some of the infrastructure is in place, additional monitoring boreholes will need to be constructed to allow the trial to proceed. We suggest that funding for this project should be arranged in conjunction with the current research contractors, with a subcontractor providing the specialist design and programme details as well as support during certain key stages of the additional field investigation work.

6.7 Summary detail

Trial site	**Walpole Drove landfill, Somerset**
Description	Investigation of recirculation of leachate by means of vertical wells, and impact of this on waste decomposition rates. Study conducted on large restored area of active landfill. (Pre-composted MSW used for basal lift). • 2.5 Mm^3 filled over 20 years, 50/50 household/commercial waste mix. • Excavated 2 m below to 15 m above ground level. • Operated with mobile net in long thin cells from west to east. • LDPE capping membrane installed.
Recirculation infrastructure	• Two leachate lagoons with aerators. • Vertical wells installed away from gas wells and potential

flow paths.

- Leachate shows well established methanogenic conditions, with low C, pH 7.7 to 8.3.

Key objectives

- Compare performance of both injection systems (i.e. ability to raise waste moisture content).
- Determine the area of influence of both systems and suggest full-scale design spacings.
- Comment on relative merits/disbenefits of each system.

Funding

Environment Agency (through revision of current contract).

Potential contractors

C.H. Enterprises in association with any suitably qualified consultant, preferably within a three hour driving distance of the site.

Project status

- Recirculation trials about to start.
- Additional sampling wells required for tracer studies.

Dates

Six month study (to be co-ordinated with current research project at the site).

References

None available.

7. YANLEY LANDFILL, BRISTOL

7.1 Background

This operational landfill is situated approximately 6 km south west of Bristol, off the A38 to Taunton. The site is owned and operated by Terry Adams, now a subsidiary of Haul Waste Group Ltd.

The site has been developed in a number of phases and progressive restoration is well advanced in some of the older areas of the site. The site is a natural containment facility relying on the native Mercia Mudstones, which are reworked where necessary, to provide permeabilities of less than 10^{-9} m s^{-1}. Earlier phases of the site were constructed without an engineered drainage system at the base, but later phases have a basal herringbone drainage system feeding to a single reception lagoon, where leachate discharge can be made to a sewer which runs adjacent to the landfill.

The majority of the leachate comes from Phase 8 of the landfill, being generally low in degradable carbon content and of modest ammoniacal nitrogen concentration (i.e. COD 300-3000 mg l^{-1}; NH_4-N 200-300 mg l^{-1}).

Current waste inputs to the site are very approximately 40% domestic waste and 20% contaminated 'soils', with the remaining balance being trade and commercial wastes. Older phases of the site were constructed with a higher proportion of inert infill, but have been recently surcharged with domestic wastes before reaching final restoration levels. Mercia Mudstone has been used as daily cover material although the temporary capping layer was stripped back before the surcharge took place.

A leachate recirculation scheme has been installed in one of the older areas of the site (Phase 7) where leachate irrigation pipework has been installed under a 1 m mineral cap layer overtopped with 1.5 m of top soils. The plan is to restore the land to community forestry and planting work has been started. Leachate is fed to the irrigation pipework under gravity from two header tanks installed in the ground. Currently leachate is tankered from the reception lagoon up to the tanks but plans are being made to automate this activity. Irrigation is conducted at the rate of approximately 6m^3 hr^{-1} maximum (over three - four months per year) although leachate breakout on the lower reaches of the scheme have been noted at this maximum rate.

Vertical gas wells in this area of the landfill are spaced at approximately 55 metre intervals and are available for leachate level measurements as well as sample recovery. Some silting in these wells has been noted recently. Gas is actively pumped from the restored phases of the landfill and fed to a 1.3 MW power plant. Excess gas is periodically flared. Approximately 70% of the gas feeding the power plant is from the recirculation phase of the landfill.

In newer phases of the site, leachate is mixed with incoming wastes at the tipping face to encourage waste wetting and a minimum of daily cover material is used. Contaminated soils and trade wastes are mixed with domestic wastes to improve potential hydraulic properties

within the fill. In addition, the development of perched leachate levels is alleviated by the use of vertical aggregate columns, spaced at random within the landfill.

This site represents current best practice containment landfill, incorporating gas recovery and power generation. It also represents typical problems that operators will have to face retrofitting leachate recirculation schemes in far from optimum conditions. It therefore presents a good opportunity to investigate, more closely, what is happening to recirculated leachate, applied primarily to accelerate the rate of gas production for the benefit of the power generation scheme.

7.2 Objectives

7.2.1 Overall aim

To determine the hydraulic characteristics of a mixed domestic/commercial/industrial waste landfill under leachate recirculation conditions.

7.2.2 Specific objectives

(a) Assess the performance of the sub-cap leachate re-injection pipework by measuring its ability to deliver leachate to the full surface area of the phase under the constraints of the irrigation system design.

(b) Determine the degree of short-circuiting that occurs as a result of the irrigation strategy adopted.

(c) Determine the extent of mixing and plug flow which occurs during recirculation.

7.3 Outline programme

Experience in operating a leachate collection/recirculation strategy has been developed at the site over recent months. The strategy has been adopted in order to encourage better gas production in the landfill for the supply of gas to the on-site power plant. The main features of the infrastructure are two submerged header tanks positioned at the high point of the irrigation trial. These tanks feed ten separate irrigation lines connected to the header tanks by a manifold outlet.

The irrigation lines have been positioned in a way that takes advantage of the natural contouring of the landfill. The relative positioning of the individual supply lines is not dissimilar to that described for the Howley Park landfill (see Section 3).

Consider the following figures in relation to the recirculation phase of the landfill:

Landfill depth	approximately 20 metres beneath the irrigation pipework

Average field capacity moisture content of wastes actively generating leachate	40% (wet weight)
Bed volume requirement to remove the pollution load	Seven bed volumes
Equivalent volume of water per tonne of refuse	2.8 m^3 (i.e. 0.4 x 7)
Unit area liquid requirement for a 20 metre landfill	56 metres of leachate (i.e. 2.8 x 20)
Assuming a 30 year period of flushing, equivalent annual requirement	approx. 2 m a^{-1} (i.e. 56/30)
Area of recirculation zone	31 200 m^2 (i.e. 120 x 260 m)
Equivalent recirculation requirement	approx. 1200 m^3 wk^{-1} (i.e. 2 x 31,200/52)
Currently irrigating at 6m^3 hr^{-1} over 3-4 months of the year	approx. 220 m^3 wk^{-1} (i.e. 6 x 24 x 20 x 4/52 - assuming 20 days of irrigation per month over a maximum of four months per year) i.e. approx. 20% of the full flushing requirement

Like the Mucking trial (Section 5), site operational practice at Yanley does not allow a flushing biological reactor strategy to be adopted. Nevertheless, the landfill scheme in progress is one which the operator assumes to be encouraging accelerated stabilisation within the wastes, with the resultant gas being used as fuel in the on-site power generation plant. However, little technical evidence of the advantages or effectiveness of adopting leachate irrigation as part of the operational scheme is currently being generated.

Apart from a wider case study monitoring project which could be mounted at this site, a tracer study should be carried out to investigate the effectiveness of the design and operation of the sub-cap leachate re-injection system. Two key issues should be investigated; the even distribution of leachate within the irrigation area (or otherwise) and the level of leachate short-circuiting. However, the current leachate irrigation strategy will not allow the investigation of bed volume of the trial site. At 1200 m^3 wk^{-1} it would take four years to see plug flow effects to emerge. However, current irrigation rates are approximately 20% of this full flushing requirement which would elongate the time frame further.

Although gas abstraction boreholes are available for basal layer monitoring of leachate, some additional leachate monitoring boreholes and other relatively shallow destructive sampling work will need to be carried out to achieve the stated objectives. The work programme and monitoring requirements, required to achieve the objectives, should be conducted along similar lines as outlined in Section 5 above, for Mucking Marsh landfill.

7.4 Limitations and constraints

Key limitations and constraints of the trial include:

- Low permeability daily cover material has been used at the trial site and some leachate breakout might be expected for irrigation rates applied to achieve full flushing criteria.
- Additional infrastructure and access wells may be required to provide adequate facilities for monitoring the behaviour of the leachate irrigation trial.
- The operational company has recently changed to Haul Waste. The practice of leachate recirculation may not be company policy and this would need to be checked before planning a study along the lines described above.

7.5 Timescale

We envisage that the wider demonstration project would be conducted over a two - three year time frame. However, results from the initial tracer trials, investigating the surface distribution of leachate, could be obtained over a period not exceeding six months.

7.6 Funding arrangements

This trail site provides an ideal opportunity for the industry to carry out a demonstration scale project of leachate irrigation and recirculation where much of the infrastructure is already in place. Therefore we suggest that, although the Environment Agency might consider funding the tracer study work, other sources of funding, possibly through an Environmental Body, should be sought to cover the main initiative of the trial.

7.7 Summary detail

Title	**Yanley landfill, Bristol**
Description	Investigation of surface distribution and short-circuiting of liquid in a conventional mixed waste landfill, using tracer addition during modest application of recirculated leachate to a sub-cap irrigation system.
Recirculation infrastructure	Reception lagoon feeding two header tanks installed at the irrigation site. Leachate fed under gravity to a series of buried irrigation trenches. Tanks currently filled manually but plans to automate the system are being discussed with involved parties.
Description of recirculation	Currently irrigating to around 3 ha of restored landfill at a rate of 6 m^3 hr^{-1} over three - four months of the year. Some

	leachate breakout problems from the cap have been encountered but overcome by reducing the irrigation rate.
Key objectives	• Assess performance of the installed irrigation pipework in relation to leachate distribution. • Determine the degree of short-circuiting. • Determine the extent of mixing and plug flow.
Funding	Industry, through an Environmental Body, with support from the Environment Agency.
Potential contractors	Any suitably qualified consultant, preferably within a three hour driving distance from the site.
Dates	Two - three year study, although the early tracing work could be completed within a six month time frame.
Project status	• All critical infrastructure is in place. • Additional monitoring boreholes and some shallow sampling work required to achieve the stated objectives.
References	No technical reports available.

8. CONCLUSIONS AND RECOMMENDATIONS

The Howley Park and Yanley landfill projects present full-scale operational opportunities for conducting investigations into the hydraulic behaviour of waste under leachate recirculation regimes. Because of the lack of 'retrofit' demonstration scale projects, for investigating accelerated landfill stabilisation under enhanced moisture regimes, these sites should be considered for wider research funding.

Although no recirculation work is being conducted at the Howley Park site, all the main infrastructure is in place and for a relatively small investment a useful project could be initiated quickly. We recommend that the main source of funding should come through an appropriate landfill Body with the Environment Agency involvement principally funding the tracer studies.

On the other hand, the site manager at the Yanley landfill is already carrying out leachate addition to wastes in an attempt to raise the landfill moisture content. However, no monitoring of the exercise is being undertaken and therefore the full benefits of this site strategy are not being evaluated. We recommend that this trial site is considered seriously by the Environment Agency as a wider demonstration scale project. Most of the infrastructure is in place apart from essential monitoring equipment. Again, funding could come from a suitable landfill Body with Environment Agency involvement.

The three remaining projects are all part of current R&D initiatives. Tracer work is already included in the project specification for the Mucking trial and is likely to be included in the tender brief for the second phase of the Mid Auchencarroch test cells project. This leaves the Walpole Drove landfill where no tracer study work is planned as part of the recirculation trials shortly to be undertaken. The report draws attention to the key constraints in mounting a tracer study at this site. However, this is the only study where vertical well injection of leachate is being attempted. Despite the constraints, we recommend that the Environment Agency explores the possibility of mounting a tracer study at this site, as part of the current programme.

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