

# **Sustainable Landfill Review**

## **Appendix 1. Detailed summary of R & D projects to date**

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**APPENDIX 1. DETAILED SUMMARY OF RESEARCH AND DEVELOPMENT PROJECTS TO DATE**

1. LANDFILL STUDIES			
Title	1.1 Warm gas injection, Belfast	1.2 Mucking, Essex	1.3 Mucking, Essex: Phase 2
<b>Description</b>	Enhancement of gas generation by re-injecting heated, saturated landfill gas. The landfill gas stream is split, one part being burned to warm the other. The warmed raw gas is then saturated and re-injected.	Monitoring of a sub-cap leachate recirculation system intended to increase gas production rate at a completed landfill cell.	Continued study of effect of sub-cap irrigation and leachate recirculation on gas production rates at a completed landfill cell
<b>Funding</b>	Belfast City Council; DTi (ETSU).	Dti (ETSU)	Environment Agency
<b>Participants</b>	Aspinwall & Company Ltd.	WRc; Cory Waste Management.	Cory Waste Management; WRc
<b>Dates</b>	1995-1996	1994-1996	1999 - 2001
<b>Techniques investigated</b>	Heating of wastes by re-injection of gas at 70°C  Introduction of moisture to unsaturated wastes via saturated gas	Recovery of tracer added to recirculated leachate;  Monitoring response of leachate levels to recirculation events;  Monitoring gas recovery before and after recirculation, and comparison with control area;  Monitoring leachate quality changes following recirculation.	Leachate recirculation at higher rates than in Phase 1;  Characterise solid waste samples before and after periods of prolonged recirculation;  More extensive monitoring than in Phase 1;  Prolonged field demonstration of time of travel gas flow meter
<b>Results to date</b>	Trials nearly complete by mid-1996  Evidence of increased gas generation.	Irrigation led to increased gas production rate compared with control area.	Upgraded monitoring equipment in place by July 1999;  Awaiting completion of upgrade of gas power station;  Re-start leachate recirculation expected ~May 2000.
<b>References</b>	Crowcroft, 1996	Young et al. (Sardinia 1999 paper)  WRc report: Blakey et al. (1997)	

<b>1. LANDFILL STUDIES (cont.)</b>			
<b>Title</b>	<b>1.4 Walpole, Somerset</b>	<b>1.5 Trials of alternative daily covers</b>	<b>1.6 New factors affecting landfill settlement</b>
<b>Description</b>	Investigation of leachate recirculation by means of vertical wells, and impact of recirculation on gas production, in a full-scale landfill cell. (Pre-composted MSW used for basal lift)	Field trials conducted at Calvert landfill.	Effects on settlement, due to leachate recirculation and changes in waste composition.
<b>Funding</b>	Wyvern Waste; DoE/EA (contract no. EPG 1/7/49).	EB Nationwide/Enventure	Landfill tax money
<b>Participants</b>	C.H.Enterprises	ADAS Consulting Ltd.	BRE
<b>Dates</b>	1995-2000, ongoing	1997-99; Phase 2 ongoing	1999 - 2002
<b>Techniques investigated</b>	Leachate injection rates achievable via shallow vertical wells and stone-filled pits;  Hydraulic distribution of leachate injected via shallow wells;  Impact on gas generation of recirculating leachate;	Comparison of the effectiveness for fly control, of hessian, woven polypropylene netting, chemical application, and conventional soil cover.	Desk studies and field studies at 5 landfills;  100m <sup>3</sup> test pit at BRE
<b>Results to date</b>	Feasibility study completed;  Delays in implementation due to problems setting up gas abstraction and flow measurement infrastructure.  Practical phase of project now under way.	Alternatives very successful if applied correctly.  Polypropylene netting suffered some bird damage.  Routine insecticide spraying not necessary  Phase 2 to include;  trials of additional materials;  trials of additional insecticides  review of ecology of flies on landfills.	None yet
<b>References</b>	None yet.	Wastes Management, June 1999, p27.	None yet.

2. LARGE SCALE TEST CELLS			
Title	2.1 Landfill 2000 test cells	2.2 Brogborough test cells, Phase 1	2.3 Brogborough test cells, Phase 2
<b>Description</b>	Enhancement of MSW stabilization rate by sewage sludge addition and leachate recirculation in two large (1,000t) shallow (<5m) test cells.	Enhancement of gas production in six large (15,000t) MSW test cells by varying waste composition and cell management techniques.	Hydraulic study of leachate recirculation in Cell 2.
<b>Funding</b>	Yorkshire Water; West Yorkshire Waste Management; DoE.	DTi, DoE/EA, Shanks and McEwan Ltd.	Environment Agency
<b>Participants</b>	WRc; (main research contractor) Knox Associates (data review with Brogborough)	AEA Culham, WRc; (main contractors) Knox Associates (data review with Landfill 2000)	Mouchel (main contractor); AEA, Richard Beaven Associates (sub-contractors)  Knox Associates (technical advice)
<b>Dates</b>	1991-1995 (completed)	1986-1999 (continuing with EA funding)	1997-99 (completed)
<b>Techniques investigated</b>	Inclusion of ~12% dewatered digested sewage sludge;  Addition of sewage effluent;  High-rate recirculation (~600mm/a through shallow refuse layers).	Low density tipping;  Addition of dewatered primary sewage sludge;  Inclusion of ~50% commercial/industrial waste;  Post-infilling addition of water;  Post-infilling injection of air.	Abstraction from a single vertical well, re-injected via sub-cap trench at opposite end of cell.  Hydraulic analysis of piezometric gradients within cell at different abstraction rates;  Tracer study using lithium bromide.
<b>Results to date</b>	<ol style="list-style-type: none"> <li>1. Recirculation increased gas production rate from ~8m<sup>3</sup>/t.a to ~17m<sup>3</sup>/t.a in otherwise identical cells;</li> <li>2. High rates of gas production were achievable at low temperatures (&lt;15°C);</li> <li>3. Methanogenesis in drainage blankets may be a high proportion of total gas production;</li> <li>4. H<sub>2</sub>/CO<sub>2</sub> utilization may be an important route.</li> </ol>	<ol style="list-style-type: none"> <li>1. Gas production rate approximately doubled by air injection and water addition;</li> <li>2. Enhanced rates, up to ~22m<sup>3</sup>/t.a after 7 years, are greater than typical UK rates;</li> <li>3. Gas production rates still increasing in most cells after 7 years;</li> <li>4. Initiation of methanogenesis accelerated by initial addition of moisture in sewage sludge.</li> </ol>	<p>Tracer addition showed rapid flow paths, reaching all parts of cell after recirculation of only ~0.1 bed volumes;</p> <p>Hydraulic analysis indicated saturated storage coefficient of only ~3%;</p> <p>Results consistent with 2-domain model, with rapid flow in channels constituting a low proportion of total moisture, and rapid equilibration with non-mobile water comprising the bulk of the moisture content.</p>
<b>References</b>	WRc report: Blakey et al. (1996) Contract report: Knox (1999); Sardinia 99 paper: Knox et al.(1999)	AEA report:: Caine et al. (1996) WRc report: Blakey and Bradshaw (1994) Review: Knox (1999); Knox et al., Sardinia 99 paper	Mouchel (1999)

2. LARGE SCALE TEST CELLS (cont.)			
Title	2.4 Auchencarroch test cells, Strathclyde	2.5 Auchencarroch II: recirculate nitrified leachate	
<b>Description</b>	Enhanced MSW stabilization in four ~4,000t shallow (~5m) cells, by varying waste composition, pre-treatment and cell management techniques.	Recirculating nitrified leachate into one cell, to examine efficiency of denitrification and any effects on landfill metabolism.	
<b>Funding</b>	(i) Mr George Munn; now (ii) Barr Environmental DoE (now Environment Agency).	EA	
<b>Participants</b>	(i) Centre for Environmental Management Studies (CEMS), University of Strathclyde; superdeded by (ii) Caledonian University.	University of Strathclyde	
<b>Dates</b>	1994-2002 (on-going?)	1998 - 2000	
<b>Techniques investigated</b>	Pre-treatment by wet pulverization (2 cells); Addition of ~20% v/v inert wastes to MSW during infilling (one cell); Leachate recirculation since 1997 via sub-cap irrigation system at rate equivalent to HRT of ~3-4 years (3 cells).	Leachate treatment plant commissioned and providing a source of nitrified leachate from summer 1999.	
<b>Results to date</b>	Cell construction, infilling and capping completed in 1995; Recirculation and monitoring now under way. Earlier gas production from pulverised wastes.		
<b>References</b>	Wingfield-Hayes et al. (1997) Fleming et al. (1998)	Burton and Watson-Craik (1999)	

3. LABORATORY AND PILOT-SCALE STUDIES			
Title	3.1 Laboratory and field studies of drainage systems	3.2 Total pollution load from domestic refuse	3.3 Denitrification in refuse
<b>Description</b>	Investigation of the removal of BOD, and clogging by bio-fouling, in leachate drainage blankets, using 230-350mm diameter laboratory columns and a 35m <sup>3</sup> field trial.	Six laboratory columns (500 litre) of pulverized MSW run under different flushing/recirculation regimes to determine total pollution load which may be released during waste stabilization.	Passage of nitrified leachate through refuse bed in a 3m <sup>3</sup> pilot reactor to study flushing of contaminants and kinetics of denitrification.
<b>Funding</b>	SERC/EPSRC	DoE	DoE (contract no. PECD 7/10/304)
<b>Participants</b>	Queen Mary and Westfield College, Southampton University, WRc, UK Waste Ltd., SME Ltd.	Cleanaway Ltd.	Knox Associates
<b>Dates</b>	1993-1995 (complete; supplementary work continuing)	1990-1996 (completed)	1992-1995 (completed)
<b>Techniques investigated</b>	Synthetic acetogenic leachate passed through beds of different drainage media types and different particle sizes, for periods of 400-800 days, at 16-72mm per day.	recirculation, flushing, heating and pH correction, in various combinations. Up to 4 Bed Volumes of leachate or water passed through wastes during ~5 year period.	Young (<2 years) pulverized MSW and old (>30 years) composted MSW studied.  Up to 16 Bed Volumes passed.  Recirculation and heating used, to establish methanogenesis in young waste.  Irrigation rates varied from 23-83mm/day.
<b>Results to date</b>	<ol style="list-style-type: none"> <li>1. High levels of methanogenic activity developed.</li> <li>2. Loss of drainable pore volume ranged from 2% (v/v) to 25% v/v.</li> <li>3. Particle size was the principal factor affecting clogging. A D<sub>10</sub> size of at least 10mm was recommended to guard against long-term clogging.</li> <li>4. Mineralogy of media had no impact on clogging.</li> <li>5. Clogging was fastest when the degree of saturation was varied, and slowest when either fully saturated at all times or never saturated.</li> </ol>	<ol style="list-style-type: none"> <li>1. Pollutant release from gassed-out columns was: - 88-122kg carbon per wet tonne MSW, - 1.25-1.77kg nitrogen per wet tonne MSW, - 1.56-1.90kg chloride per wet tonne MSW;</li> <li>2. Nitrogen release was ~20% of total N content.</li> <li>3. Carbon released mainly as gas, nitrogen and chloride entirely in leachate.</li> <li>4. 5-15 m<sup>3</sup> of leachate required per dry tonne of MSW to fully flush out pollutants.</li> <li>5. No build-up of chloride during recirculation.</li> </ol>	<ol style="list-style-type: none"> <li>1. Complete denitrification occurred, at loadings up to 30gN/m<sup>3</sup>.d in young MSW.</li> <li>2. Rate fell as waste degraded; old waste did not support denitrification in spite of having 28% organic content.</li> <li>3. Denitrification and methanogenesis continued simultaneously.</li> <li>4. Flushing followed exponential pattern.</li> </ol>
<b>References</b>	Paksy et al. (1995) Paksy et al. (1996)	Beaven (1996a) Harwell paper Beaven (1996b) Report	Knox and Gronow (Sardinia 1995) Knox (1996) report

3. LABORATORY AND PILOT-SCALE STUDIES (cont.)			
Title	3.4 Hydrogeological properties of waste, (1)	3.5 Hydrogeological properties of waste, (2)	3.6 Nitrogen balances in landfills
<b>Description</b>	Large-scale (2m diameter x 3m high) compression cell used to measure variation in geotechnical and hydrogeological properties of crude and pulverized MSW under different loadings.	Further measurements of compressibility and hydraulic conductivity of wastes, using compression rig at Pitsea.	A laboratory and literature investigation into the distribution, role and fate of nitrogen in landfills. (Experimental study using bench-scale microcosms to simulate landfill degradation processes)
<b>Funding</b>	DoE; Cleanaway Ltd	EPSRC and Cleanaway Ltd.	DoE (contract no.EPG 1/7/16)
<b>Participants</b>	Cleanaway Ltd.	Southampton University	University of Strathclyde
<b>Dates</b>	1992-1995 (completed)	1996-1999	1994-1996
<b>Techniques investigated</b>	Density, settlement, absorptive capacity, effective porosity and hydraulic conductivity measured at loadings up to the equivalent of 60m depth of landfill.	Effect of sorting and pre-treatment on the properties of wastes;	Characterization of the chemical forms of nitrogen present in refuse.  Mineralization patterns and mechanisms, and distribution of nitrogen species during refuse degradation.  Effect of supplementing refuse and leachate with various forms of nitrogen during degradation.
<b>Results to date</b>	<ol style="list-style-type: none"> <li>1. Large increase in density with applied stress.</li> <li>2. Hydraulic conductivity fell from 1.7E-4m/s at surface to 1E-7m/s at 60m equivalent depth.</li> <li>3. Pulverized MSW had lower hydraulic conductivity, 1-3.5E-9m/s at 60m depth.</li> <li>4. Effective porosity fell from 30% at 0m depth to ~2% at 60m depth.</li> </ol>	Ratio of $K_h:K_v$ in MSW varied from ~2:1 at 40kPa to ~5:1 at 600 kPa, due to anisotropy resulting from vertical compaction.	Total N in MSW was 3.86% dry weight;  Released $NH_3-N$ constituted ~10% of total N;  $NH_3-N$ and $NO_3-N$ at high concentrations inhibited methanogenesis;  $NO_3-N$ was denitrified very rapidly;  No significant anaerobic removal mechanism to $NH_3-N$ was found.
<b>References</b>	Beaven and Powrie (Sardinia 1995) Beaven (1996 Harwell paper)	Hudson et al. (1999)	Burton and Watson-Craik (1997)

3. LABORATORY AND PILOT-SCALE STUDIES (cont.)			
Title	3.7 Biochemical methane potential test	3.8 Long term fate of heavy metals in landfill	3.9 Gene probe for methanogenic DNA
<b>Description</b>	Refinement of the BMP test to produce a standardised methodology for testing solid waste samples, especially during completion monitoring.	MSW with artificially enhanced concentrations of heavy metals, subjected to accelerated leaching and introduction of aerobic conditions to examine potential for re-release as landfills age.	The development of nucleic acid probes for monitoring microbial activity in landfill sites.
<b>Funding</b>	DoE (contract no. EPG 1/7/25)/EA	EA	EPSRC
<b>Participants</b>	Minton, Treharne and Davies; Reading University;	W S Atkins; Minton Treharne and Davies.	Liverpool University; CAMR, Porton.
<b>Dates</b>	1994-1999	1996 - 1999	1996-1999
<b>Techniques investigated</b>	<p>Establish correlation between BMP test results and other tests such as cellulose content and calorific value;</p> <p>Refinement of sample preparation, incubation conditions, bacterial seed source and gas volume measurement to improve reproducibility;</p> <p>Demonstration of the refined test by application to samples from domestic and inert waste landfills.</p>	<p>Six experimental columns leached at ~330 mm/a for &gt;3 years;</p> <p>Three columns subjected to aerobic conditions, once stable methanogenesis established;</p> <p>More than 5 bed volumes passed;</p> <p>LiBr tracer used;</p> <p>Geochemical modelling using PHREEQC, MINTEQA2 and CHEMVAL.</p>	<p>Aim is to use genetic molecular technology to describe the structure and activity of the microbial populations that mediate the key steps in waste stabilization in landfills.</p> <p>The project should allow quantification of species activity, as opposed to microbial numbers, to aid in the monitoring and control of landfill processes.</p>
<b>Results to date</b>	Validated protocol has been developed and will be included in new EA guidance on landfill completion.	<p>BMP tests showed wastes fairly well degraded;</p> <p>Evidence of changes in redox, oxidation of sulphide and release of increased sulphate concentrations;</p> <p>No significant enhancement of metals leaching in the aerobic columns, despite evidence of changes in speciation.</p> <p>Incidental evidence of removal of NH<sub>3</sub>-N in the aerobic columns</p>	
<b>References</b>	none yet	Revans et al. (1999)	KK CHECK WITH ANDY MAULE

3. LABORATORY AND PILOT-SCALE STUDIES (cont.)			
<b>Title</b>	<b>3.10 Application of methane oxidation</b>		
<b>Description</b>	Laboratory and field-scale experimental study of the ability of different cover materials to support methane oxidation.		
<b>Funding</b>	DoE (contract EPG 1/7/45); now EA.		
<b>Participants</b>	Minton, Treharne and Davies; WS Atkins Environment; Reading University.		
<b>Dates</b>	1995-1999 (may be extended)		
<b>Techniques investigated</b>	<p>Review available information.</p> <p>Identify suitable materials for study.</p> <p>Laboratory trials: CH<sub>4</sub> passed through 1m columns containing minerals, soil or reclaimed materials, at 20-40 m<sup>3</sup>LFG/m<sup>2</sup>.a</p> <p>Field trials on best materials: delayed due to loss of proposed study site. Alternative site now identified.</p> <p>Produce specification and field demonstration.</p>		
<b>Results to date</b>	<p>CH<sub>4</sub> oxidation efficiency = f(concentration, flow rate), so varies with barometric pressure;</p> <p>Efficiency best at medium soil moisture content, poorer when saturated or dry;</p> <p>Simulated LFG mixtures gave ~30% CH<sub>4</sub> removal.</p>		
<b>References</b>	De Rome et al. (1997)		

4. MODELLING, THEORETICAL AND REVIEW STUDIES			
Title	4.1 Sustainable landfill study	4.2 Behaviour of fluids in landfills	4.3 Gas yield enhancement techniques
<b>Description</b>	Feasibility study to assess the potential for developing a bioreactor cell rotation landfill.	Literature search and collation of practitioners' and consultants' experiences on fluid flows in landfills, including both water and gas.	Cost-benefit evaluation of various options for enhancing landfill gas recovery rates.
<b>Funding</b>	DTi (ETSU)	DTi (ETSU)	DTi (ETSU)
<b>Participants</b>	AERC Ltd.	Aspinwall & Company Ltd.	BJW Manley Associates
<b>Dates</b>	1993 (completed)	1994-1995 (completed)	1995-1996 (completed)
<b>Techniques investigated</b>	<p>Focus of study is completion of biodegradation in three years.</p> <p>Flushing of soluble pollutants not considered.</p> <p>Economics evaluated using spreadsheet sensitivity model.</p>	<p>Addresses only the movement of fluids, not their microbiological or chemical properties.</p> <p>Includes many examples of closed circuit TV pictures of fouling and deformation in gas extraction wells.</p>	<p>Concerned primarily with maximising gas <b>recovery</b> at least cost, rather than solely at maximising gas generation rate.</p> <p>Included research visit to German gas enhancement schemes.</p>
<b>Results to date</b>	<p>Concludes that costs will be less than for either incineration or anaerobic digestion.</p> <p>Recommends selection of organic-rich fractions and pre-treatment in Dano drum or similar wet pulverization method.</p> <p>Proposes ~10,000m<sup>3</sup> cells, ~5m average depth, used in sequence, with 2-month filling time.</p> <p>Degradation accelerated by inoculating with leachate from earlier cell and recirculating leachate, with pH control if necessary.</p>	<p>The behaviour of fluids in landfills is complex.</p> <p>Landfill fluids best regarded as a multi-phase fluid, rather than discrete single-phase fluids.</p> <p>Much essential information on the physical characteristics of the waste mass is lacking at present.</p> <p>Improved gas yields may be gained by a better understanding of fluid flows within wastes.</p> <p>This understanding is needed to design efficient collection of the greater gas generation rates that will result from measures to accelerate stabilization.</p>	<p>The most cost-effective measures are likely to be:</p> <ul style="list-style-type: none"> <li>- addition of unheated water or leachate,</li> <li>- seeding,</li> <li>- improved capping techniques,</li> <li>- collection system design optimisation.</li> </ul> <p>Pulverizing and shredding appear to be much less cost-effective.</p> <p>Modest sub-cap addition of water at a German landfill produced 10% increase in gas rate.</p>
<b>References</b>	AERC (1993)	Aspinwall & Company (1995)	BJW Manley Associates (1996)

<b>4. MODELLING, THEORETICAL AND REVIEW STUDIES (cont.)</b>			
<b>Title</b>	<b>4.4 Connon Bridge feasibility study</b>	<b>4.5 Review of landfill microbiology research</b>	<b>4.6 Application of tracer studies</b>
<b>Description</b>	Feasibility of enhanced stabilization and gas generation.	A review of the Department of Trade and Industry's programme of research into landfill microbiology.	Evaluation of the suitability of different tracers for the study of leachate recirculation (desk study)
<b>Funding</b>	DTi (ETSU)	DoE	EA
<b>Participants</b>	Aspinwall & Company Ltd.	WRc	WRc
<b>Dates</b>	1995 (completed)	1994-1995 (completed)	1997-98
<b>Techniques investigated</b>		The microbial community of the landfill.  Microbial behaviour and methane production.  Physical influences on landfill processes.	
<b>Results to date</b>	Study suggests that the proposed 4-phase, 18-cell site offers the potential to assess a range of enhanced stabilization options. Proposals for Phase 1 are: <ul style="list-style-type: none"> <li>- monitor moisture balance,</li> <li>- utilize alternative cover materials,</li> <li>- use operational techniques to avoid temperature loss.</li> </ul>	The review concludes that further microbiological research is still needed, in the areas of: <ul style="list-style-type: none"> <li>- identification of microbial species and activity, using nucleic acid probes,</li> <li>- develop a rapid waste toxicity screening test for co-disposal, using the mRNA probe,</li> <li>- study anaerobic methane oxidation within landfills,</li> <li>- develop systems for even distribution of moisture in landfills.</li> </ul>	Tracers considered most suitable are lithium and bromide;  Tritium is ideal chemically but is likely to be unsuitable in most landfills because of high background concentrations;  Other tracers considered unsuitable because of attenuation and/or high background, include fluorescent dyes, CFCs, chloride, spores.  Tracers with unknown potential, that have been used successfully in other milieus, include bacteriophages, fluorobenzoate and chlorobenzoate.
<b>References</b>	Latham (1995)	Archer et al. (1995) report Blakey et al. (1995) Sardinia paper	Blakey et al. (1998)

4. MODELLING, THEORETICAL AND REVIEW STUDIES (cont.)			
Title	4.7 Design of a HRFB demonstration cell	4.8 Modelling vertical wells for landfill flushing	4.9 Use of pre-composted basal layer
<b>Description</b>	Design and costing of a high rate flushing bioreactor demonstration cell in part of an existing operational landfill. (desk study)	Modelling the use of vertical wells for abstraction and re-injection to achieve flushing in landfills that do not have basal leachate collection systems installed.	Investigation into the use of pre-composted basal layers in order to accelerate methanogenesis and avoid generation of acetogenic conditions in the basal drainage layers of landfills. (desk study)
<b>Funding</b>	SUnRISE (Environmental Body) ENTRUST reference 727168.002	EPSRC (ref GR16149); Cleanaway Ltd (via SUnRISE)	EA
<b>Participants</b>	Knox Associates; Richard Beaven Associates	Richard Beaven Associates	AEA Environment
<b>Dates</b>	1998-99 (completed)	1997-1999	1998-99 (on hold)
<b>Techniques investigated</b>	The objectives of the design were: <ul style="list-style-type: none"> <li>achieve the majority of waste degradation and settlement within 5 years;</li> <li>transfer 90% of releasable nitrogen into leachate phase within 5 years;</li> <li>determine whether recirculation rates of ~3,500 mm/a can be maintained over 5 years;</li> <li>flush at least one bed volume of leachate with clean water, to validate flushing models;</li> <li>investigate leachate pathways during high rate flushing;</li> <li>determine the additional settlement resulting from accelerate stabilisation.</li> </ul>	Uses MODFLOW and Groundwater Vistas	
<b>Results to date</b>	The proposed design comprises: <ul style="list-style-type: none"> <li>1.6 ha cell containing 128,000t MSW at 8m depth;</li> <li>complete basal, side and top liners, to ensure total collection of gas;</li> <li>shredding and pre-wetting/inoculation of MSW using methanogenic leachate;</li> <li>7 discrete re-injection/gas collection blankets below top liner, to allow rotation of leachate recirculation;</li> <li>simple leachate treatment during recirculation loop to reduce risk of clogging re-injection blankets;</li> <li>comprehensive instrumentation and scientific programme;</li> </ul> The estimated cost of implementation as a demonstration study is £2.1M.	The modelling has shown that a 30m deep landfill may need a grid of wells at 20m spacing and a 20m deep saturated zone, to achieve flushing rates necessary for sustainability criteria.	Anecdotal evidence pursued, but full-scale case histories encountered to date lack proper documentary evidence.  Project on hold, to consider next steps.
<b>References</b>	Beaven and Knox (1999)	Beaven and Powrie (1999)	

<b>4. MODELLING, THEORETICAL AND REVIEW STUDIES (cont.)</b>			
<b>Title</b>	<b>4.10 Linking degradation and flow models</b>	<b>4.11 Stochastic modelling of landfill processes</b>	<b>4.12 Deterministic modelling of biodegradation</b>
<b>Description</b>	A parametric sensitivity analysis of landfill processes.	Modelling of biodegradation and leachate generation	
<b>Funding</b>	EPSRC	SITA, France	ARC via ESART
<b>Participants</b>	Prof JK White, QMWC (now Southampton University); Card Geotechnics; DG Environmental; Mouchel Consulting; Southampton University; Richard Beaven.	Imperial College, London	Napier University, Edinburgh
<b>Dates</b>	1998- ongoing	1997-99	1997-99
<b>Techniques investigated</b>	Modelling degradation processes in landfill, incorporating a link to a water flow model in order to track changes in moisture content and hence include the effect of moisture content on waste degradation rates in different zones of the landfill.		
<b>Results to date</b>			Modell incorporates the effects of moisture content on degradation rates.
<b>References</b>		Butler et al. (1999); Zacharof and Butler (1999)	McDougall and Pyrah (1999)