Disposing of waste to land is an activity as old as the human race itself. Any ancient deposits still in existence are now principally of archaeological interest. However, with the advent of the industrial revolution the volume of man’s waste started to rapidly increase and with it the problems.

In Britain and other similar developed countries the nature and composition of waste has evolved over the decades, reflecting contemporary industrial and domestic practices. Perhaps the most significant such trend concerns the gradual change from the relatively high-density, low putrescible content of Victorian and early to mid-twentieth century waste, when it was the practice to burn domestic waste and dispose of the ashes, to modern unburnt, low-density, highly putrescible domestic waste. The 1950s and 1960s witnessed the most rapid period of change in this respect.

The manner in which waste has been disposed of to land has similarly undergone a process of gradational evolution, but with three key events taking place in the UK in modern times. Historically, waste has been disposed of either heaped on the ground, with the natural strata beneath remaining essentially undisturbed, or in convenient holes previously excavated for other purposes, generally quarries of one sort or another. In the latter case the waste abuts natural strata in the side walls and, often different, strata or the groundwater table beneath.

Any attempts to engineer the containment of waste and control the spread of pollution from it were the exception not the rule until the Control of Pollution Act (1974), COPA, which came into effect on 1st January 1976. This date, with a few enlightened older exceptions, represents the start of modern landfill science and engineering practice in Britain.

The second notable event was the explosion of landfill gases in March 1986 which destroyed a house at Loscoe adjacent to a landfill in Derbyshire (Williams & Aitkenhead 1989). This brought landfills very much to the attention of central government, local authority Environmental Health Departments and planners.

The third major event was the passing of the Environmental Protection Act (1990), EPA, which in general terms introduced the concept in law of ‘the polluter must pay’ principle, followed by the proposed ‘Landfill Tax’ introduced in the 1994 budget. The EPA contains specific requirements relating to landfills, some of which have yet to come into force.

In addition to these headline events, regulations on water quality, particularly the EC Groundwater Directive (80/68/EEC) emanating from Europe, have helped to transform the standards pertaining to acceptable landfilling practice.

In the investigation and assessment of existing landfills a working understanding of this historical background can be helpful. These studies are almost always complex, requiring the application of multidisciplinary skills in science and engineering. A clear understanding of the risks involved in waste disposal by landfilling should be sought by owners, operators, regulators and their advisers and contractors. Jefferies et al. in their keynote paper on risk assessment provide a wide-ranging review of this vital topic.

Investigation

In the study of existing closed landfills it is often helpful to remember that they are essentially geological deposits, albeit very recent and of a rather specialized nature. From this starting point the geologist will seek to understand the source of the sediment in the deposit, i.e. the waste, and the manner in which it was laid down—by not the normal agents of water and wind but the less predictable hand of man. The geologist will then expect that deposit to change with time, both physically by settlement and possibly slumping, and chemically by degradation processes, leaching and so on. These changes will go on certainly for decades, if not centuries, and lead to complex four-dimensional situations.

The investigation team can usually only take a relatively short exposure snapshot of the characteristics of a landfill. Reynolds & Taylor provide a useful list of potential unknowns for any landfill site at the start of an investigation. All these variables add up to low predictability and emphasize the need for the careful design of investigations.

A significant number of ground investigations carried out each year for the construction industry have proved inadequate for one or more reasons. Such investigations typically deal with ‘normal’ geology with well-established principles which make for reasonable predictions. Working with landfill is less predictable. It therefore cannot be stressed enough that the Site Investigation in Construction (Anon 1993) initiative led by Professor

Stuart Littlejohn to improve standards in site investigation applies doubly so to landfill work. This initiative promotes the view that 'in site investigation the greatest scope for misjudgements leading to unsatisfactory service is in the conceptual and planning stages'. The main stages of a typical landfill investigation are set out in Fig. 1.

Forth & Beaumond in their paper on coal-carbonation sites provide a review of some of the early steps, emphasizing the benefits of the desk study and discussing sampling strategies. ICRCL Guidance Note 17/78 (1990) sets out many of the factors to be taken into account in the investigation of landfills.

Because of the relatively high cost of chemical analysis, it has become apparent in the last few years that adopting a massive regular sampling and testing exercise along the lines advocated in BS DD175 (Anon 1988) is by no means always appropriate, particularly in the first instance.

In the search to home in on problem areas and obtain rapid general characterizations of landfills, geophysical techniques have very much come to the fore. This is reflected in the papers in this volume. Reynolds & Taylor provide a sound overview of geophysical techniques and Maurenbrecken describes shallow over-water seismic reflection technique from the Netherlands.

The importance of investigating the geological and hydrogeological character of the host ground around a landfill is brought out in many of the papers, particularly the case histories by Bell et al. from South Africa, by Coppola et al. from Italy and by McShane & Gregory working in Northern Ireland.

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Fig. 1. Stages of investigation for existing landfills.
There are many omissions in the subject matter covered by the papers on the topic of investigations. Landfill gas is rarely mentioned, a tribute perhaps to documents such as Waste Management Paper No. 27 (1991) on landfill gas, which is the standard reference on this topic. Problems with leachates clearly stand out as the area of greatest current concern.

Leachate investigations in particular can generate quantities of data. Data management is therefore a key issue. Bentley et al. describe one commercially available software package, Strata 3, designed to aid the presentation and interpretation of information.

This volume also contains three papers on rather special investigations. Di Stefano presents stimulating data on settlement measurements within landfills and their implications for long-term settlement prediction, challenging elements of current practice. Mosley & Crozier describe a technique for leak detection in newly laid geomembrane landfill liners. Mahmoud & Morley describe the engineering properties of two types of pfa in a waste disposal situation.

**Assessment**

There are always at least two main elements to assessment: the physical side of landfill behaviour and the chemistry. Neither area is comprehensively covered here. The British Government’s published guidelines on many aspects of assessment are summarized in ICRCL Guidance Note 17/78 (1990) and this provides a useful first point of reference. Where it is proposed to build over a closed landfill, reference should also be made to Leach & Goodger (1991).

Coppola et al.’s paper is principally concerned with physical aspects of stability and makes the important point that landfills in relatively dry terrain can profoundly change the groundwater regime to the detriment of stability, in their case by supporting a shallow perched water-table beneath the waste. Bell et al. discuss the equally important question of water balance within a landfill.

The assessment of landfill chemistry is, by any measure, a complex task in which chemists should work with geologists. Matter exists in three physical states, namely gas, liquid and solid, and all landfills comprise a delicate and shifting balance between the three states. Any assessment of the state of a landfill and its environs must embrace consideration of the substances present in the landfill, their mobility now and in the future, the potential pathways along which pollutants can travel and the targets potentially at risk from the substances involved.


Published guidelines for soils and other solid forms of contaminated ground are incomplete and in part contradictory. Waste arriving at a UK landfill site for disposal is generally ‘controlled waste’ and could be one of several categories; namely, household, industrial, commercial or clinical waste. These terms describe the origin of the waste but not its toxicity. The latter is normally determined to be either non-hazardous, hazardous or special waste. Further guidance on the legal definitions of these is given by Attewell (1993). For industrial waste the distinction between non-hazardous and hazardous wastes can be crucial to the cost of its disposal. Although there is no single set of government-approved values or finite list of chemical determinands, it is often the case that ‘hazardous’ waste is classified as such by the presence of one or more substances at concentrations in the ‘heavily contaminated’, or worst, category formulated by the former Greater London Council and published by Kelly (1980).

For the redevelopment of closed landfill sites reference is made in ICRCL Guidance Note 17/78 (1990) to the ‘threshold and action trigger’ concentrations published in ICRCL Guidance Note 59/83 (1987). These trigger concentrations only cover a relatively limited range of determinands, albeit including some of the more common substances involved. The interpretation of Tables 3 and 4 in ICRCL Guidance Note 59/83 (1987) is however rather subjective, with the majority of data often falling into the area between the threshold and action values where Fig. 1 therein states that the ‘significance of risk depends on intended use and form of development, USE PROFESSIONAL JUDGEMENT TO DECIDE WHETHER ACTION IS NEEDED’. This provides both designers and regulators with plenty of scope for disagreement.

The third set of guidelines commonly referred to are those published by the Dutch Government (Keuzenkamp 1990). These employ the definition of three categories (A to C) of contamination by a rather longer list of determinands than ICRCL Guidance Note 59/83 (1987), where A is the reference value below which soils are probably uncontaminated, B is the value above which there is a need for further investigation, and C is the value above which a clean-up is indicated. Recently amendments have been made to these guidelines (Denneman 1993) introducing a simpler system of ‘target values’ and ‘intervention values’.

For liquids, assessment standards are crucially dependent upon the target to be affected by mobile contaminants. In the UK there are standards specifically for surface water courses (EC Directive 75/440/EEC) and for groundwater (EC Directive 80/68/EEC) to be abstracted for potable water supplies but little general guidance. Many people again rely on Dutch Government...
assessment standards for groundwater. Some South African water-quality standards are also presented in Bell et al. paper. Forth & Beaumont make some mention of data interpretation and in particular the need to interpret data with the end-use of the site borne in mind.

Remediation

The remediation of ‘failed’ landfills can be achieved by a variety of methods, with the principal options given in Table 1. The most appropriate method for any particular landfill will depend upon many factors covering technical issues, planning considerations and economics. At the feasibility stage of remediation as wide a view as possible should be taken of the options. It is probable that the economic, planning and licensing conditions that pertained when the landfill was started have significantly changed by the time the failure has to be dealt with. One likely scenario in the future is that extra new landfill space may be available to operators at a particular site but tied in with a requirement to redeposit unsatisfactorily contained old waste. Reprocessing the old waste in transit, by such techniques as accelerated composting of degradable matter and solids reclamation of metals and inert rubble, could result in a major net gain in the final new landfill space once the original landfill space has been relined to contemporary standards of containment.

The principles of containment and control techniques are given in several standard texts including ICRCL Guidance Note 17/78 (1990) and Waste Management Papers No. 26 (1986) and No. 27 (1991). A bibliography of landfill gas-related remediation is given by Hartless (1992). The literature on leachate containment and control is rather fragmented but reference can usefully be made to Fetter (1992) and Jefferies (1990), amongst many.

There are three papers in the conference giving useful case histories of remediation projects. Leachate containment by drainage and cement: bentonite cut-off wall techniques is the main subject of the case histories reported from South Africa by Bell et al. At the peat-bog landfill site in Northern Ireland described by McShane & Gregory, an HDPE lined bund was the preferred solution. Drainage measures, essentially to reduce pore water pressures but with the added advantage of controlling pollution are described by Coppolla et al. from a site in Italy.

Confidentiality is certainly a major restriction at present to the free dissemination of data and experience in landfill investigation and remediation. A useful source of references specifically on methane and associated hazards including remediation schemes is contained in Hartless (1992).

Concluding remarks

The selection of topics contained in papers submitted to the conference has reflected the evolving state of the art with emphasis being placed on investigating leachate problems at the expense of gas problems. A very wide range of investigative and monitoring techniques is now available and many useful data have been presented supporting their uses. The authors endorse the current trend towards tipping the balance of resources a little more in favour of initial rapid ‘mass characterization’ techniques, principally by geophysics, compared with more traditional sampling and testing programmes.

The current situation in the UK concerning criteria for the assessment of the condition of an existing landfill and its host environment is unsatisfactory. In general, criteria are only qualitative and not consistently applied across administrative boundaries. With particular reference to landfill chemistry, only the assessment of landfill gas has been reasonably satisfactorily set out in government-approved publications. Guidelines for assessing leachates and solid residues remain incomplete and often potentially contradictory.

Remedial works on existing landfills have been extensively carried out over the last decade or so, mainly to control the migration of gas. This technology is now relatively well proven. Leachate control has proved, and is likely to remain, more challenging to the industry. This arises from the chemical aggressiveness of many leachates combined with the long timescales in engineering terms during which systems will be required to operate.

Table 1. Options for remediation

| Removal off-site | i) Bulk of selective excavation |
| Redeposition on-site | i) Bulk transfer to new containment cells |
|                    | ii) Process for volume reduction and place residue in new cells |
| Containment and control | |
| Passive systems | i) Create flow paths, e.g. venting trenches for gases and drains for leachates |
|                  | ii) Create barriers, e.g. vertical and horizontal |
| Active systems | i) Pumped collector systems |

References


INVESTIGATION OF EXISTING LANDFILLS


