Pollution Potential of Cemetaries
Draft Guidance

R&D Technical Report P223

Pollution Potential of Cementries

Draft Guidance

R&D Technical Report P223

C P Young, K M Blackmore, P Reynolds and A Leavens

Research Contractor:

WRc plc

Publishing Organisation
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, BRISTOL, BS32 4UD.
Website: www.environment-agency.gov.uk

Tel: 01454 624400   Fax: 01454 624409

ISBN: 1 85705 021 5

Dissemination Status
Internal: Released to Regions
External: Released to Public Domain

Statement of Use
This report is intended to provide guidance to Agency staff when considering development proposals for new or existing cemeteries. Through the use of this document a consistent, risk based approach, will be adopted Nationally by the Agency. It is envisaged that the report will also be of use to local authorities, parish councils and other parties interested in developing and planning future burial sites. In this respect early consultation with the Environment Agency is advisable.

Key Words
Cemetries, Burial grounds, Groundwater, Surface water, Soil, Air, Pollution

Research Contractor
This document was produced under R&D Project P2-024 by:
WRc plc, Frankland Road, Blagrove, Swindon, Wiltshire, SN5 8YF

Tel: 01793 865000   Fax: 01793 865001 Website: www.wrcplc.co.uk

Environment Agency Project Manager
The Environment Agency's Project Manager for R&D Project P2-024 was:
David Hybert, Thames Region.

Further copies of this report are available from:
Environment Agency R&D Dissemination Centre, c/o
WRc, Frankland Road, Swindon, Wilts SN5 8YF

tel: 01793-865138 fax: 01793-514562 e-mail: publications@wrcplc.co.uk

FOREWORD

The question of the potential for adverse environmental impact of burial grounds is an emotive subject about which few reliable data are available. The need to develop a nationally unified approach to commenting on applications for extension to old, or the establishment of new burial grounds has been identified by the Environment Agency. The guidance should be based on verifiable technical information and use risk assessment techniques. The guidance should be framed in such a way that the effort expended on considering each application is proportional to the environmental risk.

In order to address this the Environment Agency let a contract to WRc plc to undertake the requisite literature reviews and discussions with interested parties, with the objective of preparing practical guidance for Agency staff considering applications.

The authors acknowledge the support of the Environment Agency, for technical discussions during progress meetings and for other contributions to the progress of the work. In addition, the authors acknowledge the information freely provided, and the time given to discussion, by persons engaged in all levels of the funeral industry. The opinions expressed in this report are those of the authors and do not necessarily represent those of the Environment Agency.

CONTENTS

Page

APPENDICES

LIST OF TABLES

Page

LIST OF FIGURES

EXECUTIVE SUMMARY

This project has been carried out in order to be able to provide guidance which will enable Environment Agency staff to adopt a consistent approach when assessing the risks associated with the development of human or animal burial grounds. The guidance is directed principally at the potential threats to groundwater resources, but account is taken also of possible risks to surface waters, soils and the atmosphere.

The work relied on desk studies, without direct field investigations. An initial appraisal of relevant information, seeking particularly the results of published site studies, was carried out through computer based literature searches of appropriate databases and by use of contacts established on the Internet. Contacts generated during this phase were maintained throughout the study, in order that up-to-date information could be added to the Project Record (P/024/1) and incorporated into the conclusions and recommendations. Information on the existing procedures and guidance offered to Applicants by the Regions was collected using appropriate questionnaires, followed up by visits and discussions with Regional staff. The Regional visits provided additional names of contacts with specific interests in the matter, in particular amongst the Planning and Environmental Health departments of Local Authorities. At the same time, contacts were sought and developed within the funeral industry, with advice and information being obtained from, *inter alia*, cemetery and crematorium managers, embalming specialists, manufacturers of embalming preparations, companies specialising in responses to emergencies which may involve large numbers of fatalities, operators of pet cemeteries and proprietors of green (woodland) burial sites.

The literature surveys and discussions demonstrated that a potential exists for environmental pollution by the decay products of burials. Recorded examples of pollution relate principally to groundwater, with evidence also of surface water contamination. In both cases the contaminants noted were similar to those commonly found in the vicinity of non-contained putrescible landfills (dissolved organic carbon, ammonia, chlorides, sulphates, alkali metals) and which are associated with anaerobic digestion. Increased microbial populations, including specifically *Pseudomonas aeruginosa*, have been found in the vicinity of some burials. No examples were found of atmospheric pollution from modern burial practices, with the very rare exception of the irregular production of the spontaneously ignitable gas diphosphane from burials into water logged ground.

Estimation of the potential impacts on groundwater quality of burials at three "model" cemeteries (large urban centre, with >200 burials per year; a green burial ground accepting 30 burials per year; a small cemetery/churchyard taking 10 or less burials per year) indicates that potential problems are most likely with the larger sites, and in particular if they are located on very free draining ground with a shallow water table. A flow chart based methodology is developed for ranking the threat posed by a particular proposal and the vulnerability of the local environment so that the need for additional information and investigations may be decided.

Once the overall risk associated with a particular proposal has been assessed, advice is given on the appropriate level of additional investigation which may be required in order to resolve uncertainties and on which decisions may be made with confidence, either to accept a

proposal, possibly with conditions, or to object. Worked examples of estimating the level of threat posed by burial ground proposals are included in the Appendices.

KEY WORDS

Cemeteries, Burial grounds, Groundwater, Surface water, Soil, Air, Pollution.

1. INTRODUCTION

1.1 Objectives and background

A cemetery or other form of burial ground, e.g a "green" site, is likely to have the potential to cause pollution of the environment. The investigation of such sites has been found to be limited, but it is likely that the main receptor for contaminants will be the water environment, and in particular groundwater.

The need for new burial grounds can be an emotive subject amongst local residents. This will often result in concerns being raised that are disproportionate to the real environmental risks. In determining new planning applications for such proposals, the Local Planning Authority will seek the views of the Environment Agency, which is a statutory consultee for such matters.

Historically, the response to such proposals by the Agency (and by its' predecessors) may not always have been consistent, either Nationally or Regionally. This may be due in part to the lack of a single decision-making framework. However, more significantly there has been limited investigation and research into cemeteries and, as a consequence, it has been difficult to assess the potential impact on the environment.

The main objectives of this report are therefore:

1. To review critically published research and case studies related to the potential environmental threat posed by cemeteries and to identify and quantify the actual risks of pollution illustrated, where possible, by reference to published cases.

2. To collect, collate, compare and review the approaches currently employed by each Region of the Environment Agency in the assessment of proposals for the extension of existing, or development of new, cemeteries.

3. To identify, and describe in detail, those factors which require consideration when assessing the potential impact of a cemetery and to provide guidance on assessing their relative importance on a site specific basis.

The first two objectives are detailed fully in the Project Record (P/024/1), and are summarised in this R&D Technical Report. The third objective forms the main part of this R&D Technical Report.

Chapter 1 of the Technical Report summarises the legal responsibilities and the current procedures adopted by the Agency. Chapter 2 summarises the findings of the literature review and of communications with interested parties. Chapter 3 expands on the characteristics of cemeteries as a source of pollution. Chapter 4 discusses attenuation of contaminants in pathways from burial sites. Chapter 5 provides guidance on the assessment of risk from cemeteries, with Chapter 6 giving the Conclusions and Recommendations.

1.2 Legal responsibilities

Legislation controlling the location, development and operation of cemeteries has been in force since the Cemeteries Clauses Act of 1847 and information on that and subsequent Acts is summarised in Chapter 4 of R&D Project Record P2/024/1.

Under current legislation the Local Planning Authority are the principal body controlling new cemetery developments under the Town and Country Planning Act 1990 and the Planning and Compensation Act 1991. Planning consent is not required for the burial of individuals on their own land, nor for the re-ordering of graves within Anglican Churchyards, but in other cases planning permission is needed. Where planning permission is required, often the only control is by means of conditions on the permission document, an obligation (agreement or undertaking) under Section 106 of the 1990 Act, or by refusal of the permission. The Agency is a statutory consultee for cemetery applications and its views must be considered unless the Planning Authority can justify why its requirements are not to be included.

The functions and responsibilities of the various authorities and organisations with respect to the planning, operation and monitoring of burial grounds are summarised in Table 1.1 below.

Table 1.1 Legal functions and responsibilities

Authority	Function and responsibility
Planning	Receive planning applications for new cemeteries or extensions to existing ones. Forward these to all statutory consultees (includes the Environment Agency) .
Environmental Health	Maintain details of private water abstractions.
Ecclesiastical authorities	Operation of church graveyards. With the exception of the Anglican Church, graveyards operated by church authorities are subject to normal Planning law. In the case of graveyards associated with Anglican churches, some actions may be carried out under Diocesan Faculty jurisdiction.
Ministry of Agriculture, Fisheries and Food (MAFF)	Code of Good Agricultural Practice for the Protection of Water details rules that must be met for burying of carcasses on farms.
Private cemetery companies	Operation of cemeteries. Activities principally controlled by provisions of the Local Authorities Act, 1972. Subject to full Planning control.
Environment Agency	Statutory consultee - want to know how the developers will protect the environment. Will raise objections or request Conditions as appropriate.

Under the Water Resources Act 1991 the Agency has a duty to protect and conserve the quality of both surface water and groundwater resources. Unfortunately, this gives limited powers to control directly proposals for such developments. However, in order to satisfy the requirements of the EC Groundwater Directive (80/68/EEC), the Agency has developed a policy framework for the protection of groundwater, entitled the Policy and Practice for the Protection of Groundwater (1998). The Policy and Practice seeks to influence planning decisions relating to the location of any new development that may have an impact on groundwater.

More recently, the Groundwater Regulations 1998 have completed the transposition of the EC Groundwater Directive (80/68/EEC) into UK legislation. The Regulations came into force between 2 December 1998 and 1 April 1999 and have given the Agency greater powers to prevent or control activities which may result in the discharge of either List 1 or List 2 substances to groundwater.

Groundwater protection legislation relevant to cemetery development and directly implemented by the Agency is listed in Table 1.2.

Table 1.2 Groundwater protection legislation directly implemented by the Environment Agency (from Environment Agency, 1998)

Origin	Legislation	Agency Role
European	EC Groundwater Directive (80/68/EEC)	Competent authority
UK	Water Resources Act 1991 (s.92)	Powers to control discharges to controlled waters
	Water Resources Act 1991 (s.88)	Powers under regulations to require pollution prevention measures to be taken
	Water Resources Act 1991 (s.93)	Provision for statutory water protection zones
	Waste Management Licensing Regulations 1994 (made under s 33 of the Environmental Protection Act 1990)	Powers to prevent pollution by substances listed in EC Groundwater Directive
	Groundwater Regulations 1998	Powers to prevent or control activities which may result in the direct or indirect discharge of specified pollutants to groundwater.

Relevant details of other bodies with responsibility for aspects of groundwater protection in England and Wales are listed in Table 1.3.

Table 1.3 Organisations with responsibility for aspects of groundwater protection in England and Wales (from Environment Agency, 1998)

Organisation	Area of Responsibility	Relevant Legislation	Locus of Agency
MAFF	Code of Good Agricultural Practice	Water Resources Act 1991	Consultee
District Councils and Unitary Authorities	Development planning	Town & Country Planning Act 1990	Statutory Consultee
	Private water supply register / monitoring	Private Water Supply Regulations	Advisory contact
Local and Regional Planning Authorities	Forward Planning Policies, Local Structure and Development Plans (Minerals/waste Disposal)	Town & Country Planning Act 1990 (Planning and Compensation Act) 1991	Statutory Consultee

1.2.1 EC proposals for strengthening groundwater protection.

In recognition of the limitations of existing regulations, the European Commission has published a proposal for a Groundwater Action Programme[1] (GAP) with the objective of ensuring the - *protection and use of groundwater through integrated planning and sustainable management aiming at preventing further pollution, maintaining the quality of unpolluted groundwater, restoring, where appropriate, polluted groundwater.*

The Annex to the proposal lists potential sources of pollution including ... *graveyards and animal burial sites*. Such sites would not be considered major facilities subject to control under the provisions of the proposed Directive on Integrated Pollution Prevention and Control (IPPC - 96/61/EC). However, the GAP states that protection of groundwater against pollution by smaller installations (non-IPPC's) should equally be ensured. It appears from this that burial grounds would be legitimate subjects of the programme.

A proposal has been presented by the European Commission for a Council Directive establishing a framework for Community action in the field of water policy[2]. Three Articles in the proposal may be of importance in relation to the authorisation of burial grounds:

- Article 1 (a) which provides for the protection of groundwater.

[1] November 1996 - Proposal for a European Parliament and Council Decision on an action programme for integrated groundwater protection and management (96/C355/01 - COM (96) 315 final)

[2] The Water Framework Directive; 97/C 184/02 - COM(97) 49 final - Brussels, February 1997.

- Article 2, which includes the same definition of "groundwater" as found in the Groundwater Directive (80/68/EEC) and now transposed to UK law under Regulation 15 of the Waste Management Licensing Regulations 1994 and the Groundwater Regulations 1998.

- Article 13 (Programme of measures) 3 (g) prohibits the direct discharge into groundwater of the substances listed in Annex VIII. The annex contains a list of twelve pollutants, that includes - *substances which have an unfavourable influence on the oxygen balance (and can be measured using parameters such as BOD, COD, etc.).*

The combination of these provisions would suggests that burials in areas of high water table may be prohibited.

The Groundwater Action Plan (GAP) remains a proposal, and its requirements are essentially incorporated into the proposed Water Framework Directive. It is intended that the Water Framework Directive will ultimately replace the Groundwater Directive.

1.2.2 Green burials

Green, woodland or nature reserve burial refers to the practice in which a body is buried usually in a rapidly degradable coffin, but possibly only shrouded. A tree is normally planted on the grave, in lieu of an headstone. During 1997 there were more than 50 green burial grounds operating in Great Britain, with 40 more subject to planning permission (Institution of Burial and Cremation Authorities). Information received during 1998 (K West, Cemeteries Manager Carlisle) indicated that more than 70 green burial sites were then in operation in Great Britain.

The law in the UK related to burial on farmland and in private gardens has been reviewed by The Natural Death Centre (Bradfield, undated). A recent case in England, and a planning appeal in Scotland, have confirmed that no planning permission is required for "a limited number of unmarked and unfenced graves". The Institution of Burial and Cremation Authorities recommends that people contemplating private burial should consult the Environment Agency and their local Council's Environmental Health Department about possible pollution of the environment and public nuisance. There is no law against burial in one's own garden, however it must be recorded in the Property Deeds and be deep enough to stop animals digging up the body.

1.2.3 Pet cemeteries

The majority of domestic animals are either buried on the premises of the owner, or disposed of to landfill by veterinary practices. However, an increasing minority of persons opt either for cremation of the remains, or burial. As a consequence, pet cemeteries are increasing in number across the UK. Guidance given by the self-regulatory Association of Private Pet Cemeteries and Crematoria (Ricketts, 1998) recommends burial of unembalmed remains in biodegradable cardboard coffins at a depth of not less than 0.9 metres (below plough depth), with grave plots avoiding water courses, drains and wells. Up to 30% of pet burials may be in small chipboard coffins. The density for canine burials (most common subjects in pet cemeteries) is between 9000 and 10 000 per hectare (about four times human occupancy rate).

Pet cemeteries are not included in the List 1 of the Waste Management Licensing Regulations 1994 (as amended 1997). This refers to those types of waste disposal facility for which the person managing the site must be technically competent and a holder of a Certificate of Technical Competence awarded by the Waste Management Industry Training and Advisory Board (WAMITAB). Pet cemeteries are not included in the exempt activities listed in Schedule 3 of the same Regulations. In these cases, because the competence of the site managers is not covered by WAMITAB, the Agency are seeking to assess competence separately in a consistent, fair and transparent way. Guidance on the proposed method is being incorporated in a draft Environment Agency Technical Competence Assessment Manual, currently subject to external consultation.

1.2.4 Abnormal situations - human disasters or animal epidemics

Mass burials of human and animal subjects are normally the result of a natural or man-made disaster and it may be a requirement, for reasons of public health, that the interments are not delayed. The infrequent and non-routine nature of these events make forward planning difficult, but essential, if consequent environmental impact problems are to be avoided. Such planning should involve liaison with appropriate Local Authority (Environmental Health, Planning, Legal, Social), Emergency Services and Ministry of Agriculture, Fisheries and Food (MAFF).

Human mass burials

Arrangements for the disposal of bodies from disasters depends on the scale of incident and whether the bodies can be identified. If not possible to identify the bodies (e.g. plane crash) then the remains are likely to be cremated and all the ashes buried together in a single coffin. If the bodies (or parts) can be identified, then relatives may want individual burial (or cremation). Some bodies may be taken away for burial or cremation elsewhere, but if mass burial is decided then the Local Authority (Environmental Health and Planning) will need to identify, procure and prepare a suitable burial area within, at most, three weeks of the disaster. In view of the sensitivity of the situation the procedures are likely to be "fast tracked" and the time for assessment of potential environmental impacts will be very short. A large-scale disaster may overwhelm the capacity of local mortuaries and temporary premises may be required. There are no guidelines on the siting of temporary mortuaries, but warehouses or aircraft hangers and vehicle storage sheds at military depots are often considered. In all cases a "wet" area (to contain body fluids/wastes and chemicals resulting from forensic/pathological examination of remains) must be designated. If external drain discharges from the "wet" area are unsatisfactory (for example to soakaway or to local surface waters) then sealing of the outlets should be carried out and arrangements made for the safe collection and disposal of liquids by a specialist contractor.

In many cases the Local Authority will not have the necessary in-house expertise to deal with the problems of identification of remains, managing the press, and arranging bereavement counselling, and specialist contractors may be employed (Statham, 1998).

In mass burial, coffins are typically placed in a large excavation, at a spacing which provides a local density of about one coffin per 2 m^2, which is some six times that of normal "lawn" burial. The large number of bodies entering the ground at one time and within a restricted area imposes a high potential pollution load.

Animal mass burials

Although large numbers of animals may be killed as a result the same types of disasters related to human fatality, the most probable reason for mass burial would be the onset of epidemic disease, for example, Foot and Mouth in cattle, Swine Vesicular Disease in pigs, Newcastle Disease in poultry. Burial would be expected to be in conformity with the guidance given by MAFF (1991, revised 1998), with the numbers of corpses interred at one place reflecting the size of the herd or flock slaughtered.

1.3 Current Environment Agency procedures for assessing cemetery applications

The principal guidance document used is the Policy and Practice for the Protection of Groundwater, 1992 (PPPG), updated under the auspices of the Environment Agency (1998). In Agency Regions where additional guidance is given, it is frequently to be based on that given by the Ministry of Agriculture, Fisheries and Food (MAFF) (1991) for the disposal of farm animals, in their Code of Good Agricultural Practice for the Protection of Water (now revised MAFF 1998).

The PPPG provides a policy framework and decision matrices for the protection of groundwater. It is based on the delineation of Source Protection Zones around groundwater abstractions, defined by travel times of biological and other contaminants in groundwater. Aquifers are defined according to their relative importance in yielding water supply into three main types - Major, Minor and Non-Aquifers. Reference is also made to the vulnerability of soils in terms of leachability and attenuation of contaminants. Policy H of the PPPG includes reference to graveyards and animal burial sites. The guidance offered is that:

- the establishment of new or extension of existing burial sites (human and animal) falling within Zone I (Inner Source Protection, 50 day travel time) be opposed through the planning process. Restrictions may also be sought for proposals within Zone II (Outer Source Protection, 400 day travel time), subject to evaluation and assessment.

The MAFF Code states that animal carcass can be buried on the farm, if other ways of disposing of carcasses are not practical and that a notifiable disease is not suspected or has been ruled out. In order to meet the criteria of the Code, the site must:

- be at least 250 metres away from any well, borehole or spring that supplies water for human consumption or is used in farm dairies;
- be at least 30 metres away from any other spring or watercourse, and at least 10 metres from any field drain;
- have at least one metre of subsoil below the bottom of the burial pit, allowing a hole deep enough for at least one metre of soil to cover the carcass;

- when first dug, the bottom of the hole must be free of standing water.

The last condition of the MAFF code indicates that burial must be above the local water table. It is noted that this guidance relates to corpses some 5 to 10 times greater mass than the average human corpse, and that the distances and depths differ from those attached to aquifer and groundwater protection guidance or from legally enforceable standards (Local Authorities Cemeteries Order 1977 - minimum burial depth 3 feet (0.9 m), or 2 feet (0.6 m) in friable soil).

The application of the PPPG/MAFF Guidance by Agency Regions is summarised in Table 1.4. It is noted that a more relaxed view has developed in the Southern and Midland Regions regarding minimum distances from water supply sources. Both these Regions have gained experience and confidence in the attenuating capacities of their aquifers from application of Groundwater or Aquifer protection guidance in the past. The North West Region, with the presence of a partially karstic limestone aquifer with groundwater quality problems associated with discharges from silage stores and septic tanks, specifically opposes sites at which burials would take place below the base of the soil/subsoil zone. The North West Region has extended the PPPG and MAFF Guidance as a proforma letter, which includes suggestions of possible technical precautions which may be taken and advises prospective developers to check details of unlicensed potable abstractions with the local Environmental Health Department.

Table 1.4 Summary of guidance followed in Agency Regions

Region	Guidance followed	Distance from well, borehole or spring (m)	Distance from other spring or watercourse (m)	Distance from field drain (m)	Burials into water table allowed?	Specific Regional Variations
Anglian	PPPG & MAFF	250	30	10	No	
Midland	PPPG & MAFF	100	10	10	No	Criteria for distance from water supply or watercourses reduced compared with MAFF
NE	PPPG & MAFF	250	30	10	No	
NW	PPPG & letter based on MAFF	250	30	10	No	1m subsoil below burial pit (1m above solid rock), allowing 1m of soil above body. Ground to water table - 2.4 m minimum.
Southern	PPPG & MAFF	250	10	10	No	Criteria for distance from watercourses reduced compared with MAFF
SW	PPPG & MAFF	250	30	10	No	
Thames	PPPG &	250	30	10	No	Initial assessment based

Region	Guidance followed	Distance from well, borehole or spring (m)	Distance from other spring or watercourse (m)	Distance from field drain (m)	Burials into water table allowed?	Specific Regional Variations
	MAFF					on MAFF
Welsh	PPPG & MAFF	250	30	10	No	

1.4 Relationship to other guidance on environmental risk assessment

The method adopted in this report to assess the risks associated with cemetery development follows the Source - Pathway - Receptor protocol, put forward by the Department of the Environment (1995). This approach allows local conditions and site specific factors to be taken into account. It is important that the level of prior investigation should be proportional to the potential risks posed by the proposed cemetery development, and this aspect is developed in Chapter 5.

The risk-based methodology is consistent with the Agency's approach to implementing the Groundwater Regulations, assessing the requirements for contaminated land remediation and groundwater clean-up criteria, and the prior investigation of landfill sites with regard to Regulation 15 of the Waste Management Regulations.

2. EVIDENCE FOR ENVIRONMENTAL POLLUTION FROM CEMETERIES

2.1 Introduction

An extensive literature search was combined with discussions between WRc, Agency staff, Environmental Health Officers and members of the burial and funeral industry. It appears that within the United Kingdom there are few or no data relating to the impact of cemeteries on groundwater, or on the environment as a whole. Where information does exist, then it is generally of an anecdotal, rather than verifiable, nature. Other information relates principally to changes to embalming and burial practices with time.

Globally, the extent of published information is very limited, with studies having been reported from, Australia, Brazil, Germany, the Netherlands and North America. However, due to differences in climatic, geological and cultural conditions, not all these may provide information relevant to the situation in the United Kingdom.

For more detailed information on the literature search and information gained from discussions, please refer to Project Record P2/024/1.

The most complete examinations of the current situation have been made in Canada (Beak Consultants Ltd, 1992 and Soo Chan *et al*, 1992) and Australia (Knight and Dent, 1996 and 1998, Dent and Knight, 1998). In Australia, the National Study of Cemetery Groundwaters, is an on-going study which has been underway since 1996. Whilst both Canada and Australia have cultural and ethnic similarities with the United Kingdom, both have climatic factors which depart from the normal United Kingdom range. Nevertheless, common patterns are present in many of the available accounts, which serve to indicate both the most probable forms of contamination which may arise, and the combinations of local circumstances which favour their occurrence.

2.2 Pollution of groundwater

2.2.1 Introduction

The majority of reported examples of groundwater contamination by burial grounds come from areas of shallow aquifers developed in sand grade (or coarser) alluvial, aeolian or glacial deposits. Few examples come from areas characterised by fractured or karstic limestone.

The observed impact of burial ground effluent on groundwater is generally similar to that of landfill leachate. The common contaminants are labile organic compounds, ammoniacal nitrogen, principal mobile anions (Cl, SO_4 in particular,) and alkali earth metals (Na, K etc.). Significant decreases in concentrations, in particular of pathogenic indicators, have been noted in those cases where measurements have been made at increasing distance along groundwater flow paths from the grave site (Bouwer, 1978). A summary of all the groundwater chemistry data gathered during this project is presented and referenced in Appendix A of Project Record P2/024/1.

2.2.2 Inorganic chemical compounds

Investigations at Botany Bay Cemetery, New South Wales, Australia (Knight and Dent, 1996) found a plume of increased salinity in groundwater immediately adjacent to the graves. The concentration of contaminants diminished rapidly with distance from the graves. The plumes were found to be high in Cl, NOx, NH_4^+, PO_4, Fe, Na, K and Mg ions with, on average, higher pH than background (consistent with the decay processes at work). It was concluded there was little overall impact on the groundwater quality, although with slight elevation in Cu and Zn close to recent interment areas. Increased boron levels were also noted, but no explanation was offered.

Information regarding the presence of heavy metals is limited to reports from the Netherlands (van der Honing *et al*, 1988) and Canada (Beak Consultants Ltd, 1992). These indicated low leaching potential, but that their availability/mobility corresponds with that of landfill leachate (Zn > Cu > Ni). Compared with domestic wastes, corpses contain little iron. Hence the high levels of dissolved, reduced iron, typical of many fresh landfill leachates, would not be expected in burial ground effluent.

Significant decreases in contaminant concentrations at increasing distance along groundwater flow paths from the burial area have been noted elsewhere (Bouwer, 1978). For example, at one site ammonia decreased from 6 mg l^{-1} half a metre from the grave, to 0.75 mg l^{-1} one and an half metres away. This reduction is principally by dilution in groundwater, but in the case of ammonia this may be assisted by both cation exchange processes and by oxidation to nitrate.

In the United Kingdom, monitoring data from a borehole located within a cemetery at Branston, Lincolnshire was made available by the Anglian Region of the Agency. Chemical data and hydrographs from the two nearest abstraction boreholes was also supplied. These data showed that the groundwater level at the site is approximately 4 m below ground, and that ammonia concentrations ranged from less than 0.3 to 0.8 mg l^{-1} N.

2.2.3 Organic compounds

Index measures of organic contamination, including Total Organic Carbon (TOC), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), were reported in 26 of the 52 examples of groundwater analyses from burial grounds. At Branston, COD levels ranged from 23 to 461 mg l^{-1} O. The peaks in COD and ammonia do not necessarily coincide, but a peak in one or other appears to occur between two and three months after the maximum recorded groundwater level. The data suggest that contaminants may accumulate in the soil during the drier months and are flushed into groundwater at the onset of the recharge period. The data set spans only two years and no medium or long term trends can be recognised.

Analyses for trace organic compounds appear to be restricted to the presence of formaldehyde, which is the principal preservative ingredient of embalming fluids. At six sites in Ontario, Canada, formaldehyde levels were generally below 0.01 mg l^{-1} (Soo Chan *et al*, 1992) and in another Canadian study they were below detection levels (Beak Consultants Ltd, 1992). In the United Kingdom, a single example of a concentration of nearly 9 mg l^{-1} was found in water which had accumulated in a grave, at a London cemetery, excavated in clay soils developed from the clays of the Reading Beds (pers. comm., Nash 1997). The grave was at the edge of an area in which recent burials had taken place.

2.2.4 Pathogenic organisms

The presence of coliform bacteria in groundwater has long been considered an indicator of contamination by organic material, in particular faecal material or decomposing flesh. Studies from Australia (Dent and Knight, 1998; Knight and Dent, 1998), Brazil (Pacheco *et al*, 1991), Canada (Beak Consultants Ltd, 1992) and Germany (Bouwer, 1978) have all reported the results of microbial monitoring of groundwater at cemeteries.

The National Study of Cemetery Groundwaters in Australia included surveys at cemeteries on permeable silty sands in Adelaide, Sydney and Perth, and on a clay at Melbourne. The results have recorded variable numbers of total coliforms from piezometers placed within the confines of the burial grounds, with only low counts of faecal coliforms and streptococci. However, it was noted that the pathogenic organisms *Pseudomonas aeruginosa* and *Faecal streptococci* were present at many sites, albeit in small to very small numbers (Dent and Knight, 1998). These results suggest that, in some hydrogeological settings, microbial organisms may be carried into the groundwater.

The results from a suite of indicator and pathogenic bacteria at another Australian cemetery showed no significant bacteriological presence with the exception of the bacterial pathogen *Pseudomonas aeruginosa* (Knight and Dent, 1998). The authors suggested that the presence of this organism and the absence of others, may reflect the organism's survival in alkaline conditions found in the immediate proximity to graves.

In Brazil, Pacheco *et al*, (1991) examined three cemeteries with shallow water tables. Significant numbers of indicator organisms (total and faecal coliforms, faecal streptococci) were found in the groundwater. In addition, lipolytic and proteolytic bacteria were found in large numbers, indicating that the products of organic decomposition were being actively transported to the water table. Measurements at a control site away from the cemeteries showed an absence of the lipolytic and proteolytic bacteria in groundwater.

In contrast, investigations in Toronto, Canada (Beak Consultants Ltd, 1992), of three different parts of a large cemetery (two with a water table at between 6 and 8 metres depth, but the third with waterlogged conditions extending to within about one metre of the surface) found faecal coliform counts of less than 4 per 100 ml. This suggests effective removal or filtering of bacteria.

In Germany, Bouwer (1978) provided evidence of the attenuation of pathogens at increasing distance along groundwater flow paths from the burial area. Here bacterial numbers fell from 6000 per ml at 0.5 m from the grave, to 180 per ml at 5.5 m. This reduction reflects the combined effects of immobilisation (filtration and adsorption onto aquifer framework materials) and loss of infectivity (die-off) of the bacteria.

There have been no studies to determine whether the Bovine Spongiform Encephalopathy prion protein, reputed to be the infective agent in human new variant Creuztfeld Jakob Disease (nvCJD), may be present and persist in burial grounds, or be leached to groundwater. A detailed risk assessment of the threat posed to groundwater of prions was completed by the Environment Agency (1997) for a Public Inquiry in Kent into a discharge of effluent from a cattle rendering plant to the Chalk aquifer. The assessment concluded that the risk was extremely low. The proportion of sufferers of nvCJD in the human population is very small compared with the proportion of cattle infected with BSE during the early 1990s. Consequently, the risk from human burials is likely to be very small.

An analogous source of pathogenic material may be found in landfilled putrescible waste which may include faecal matter, as well as decomposing animal and plant protein. A survey of 19 leachates from UK domestic waste landfills (Robinson, 1995) indicated the presence of bacterial indicators and pathogens at significant levels. However, studies by the USEPA (1988) have indicated that very few of these microbes are transported away from the waste mass at landfills and that no groundwater impact can be attributed to the disposal of infectious waste in controlled landfill sites. In addition, specific studies of the survival of pathogenic viruses and protozoa in landfills containing disposable nappies (Suflita *et al*, 1992) showed that none survived within the wastes for a period of much greater than four years.

The potential for waterborne pathogens to cause disease varies with the type of pathogen and the susceptibility of the individual receptor. In order to cause an infection, the pathogen must be viable. Once micro-organisms become separated from their hosts they generally begin to die-off. The rate of attenuation in groundwater may be slower than in either fresh surface waters or sea water (Gerba and Bitton, 1994). However, the decay rates are such that declines to very small numbers take place within a few tens of days of their release into groundwater.

These results suggest that the general lack of evidence, in the United Kingdom and elsewhere, of widespread pathogens in groundwater around burial grounds is due to the relative immobility and attenuation of the organisms in the ground.

2.3 Pollution of surface water

No information was found which unequivocally related changes in composition of surface waters to the presence and operation of burial grounds. However, anecdotal information suggested that adverse change in quality (presence of "grey" water) of surface waters in close proximity to burial grounds has occurred following heavy rain.

2.4 Pollution of soil

2.4.1 Introduction

Active burial grounds normally support a cover of grass, possibly interspersed with smaller trees and shrubs. Once burial has taken place, soil disturbance is minimal, and the exposure of potentially polluted material is unlikely. Development of closed burial grounds is unlikely for up to 100 years. Therefore, the types of problems reported in London during the Nineteenth century (Holmes, 1896), where human and animal illness or death occurred due to contact with incompletely decayed human remains, exposed as a result of new burials after a short interval, should not be repeated.

A detailed soil and groundwater investigation was carried out at Mount Pleasant Cemetery, Toronto (Beak Consultants Ltd., 1992). The site covers an area of 81 hectares and is 120 years old. The soil conditions were generally fine grained silts with seams of coarser sand. Leach tests and chemical analyses were undertaken, with analyses undertaken for chemicals used in embalming processes and in coffin construction, both historically and at present. These included formaldehyde, methanol, arsenic, solvents and various metals, as well as TOC.

2.4.2 Inorganic chemical elements and compounds

At the Mount Pleasant site it was concluded that inorganic contaminants were neither present nor leached from the soil at significant levels. This contradicts results from the United States (Anon, 1990), where soil accumulation of arsenic has been found at Civil War burial sites.

In the United Kingdom the use of arsenic in embalming preparations has been prohibited since 1951, as have all other toxic heavy metals, as well as a range of alkaloid compounds. Consequently, potential problems related to such contaminants will not arise from proposals for the extension of existing burial grounds or the establishment of new cemeteries.

2.4.3 Organic compounds

Soils at the Mount Pleasant site were examined for Polychlorinated biphenyls (PCBs), formaldehyde, methanol and TOC. The results provided no evidence of soil contamination by organic compounds.

2.4.4 Pathogenic organisms

No data relating to the pollution of soil by pathogenic organisms from cemeteries were found during the literature search or as the result of other communications.

2.5 Pollution of the atmosphere

The generation of gaseous by-products from the decomposition of corpses is recorded in all standard texts (see for example Polson and Marshall, 1975) and is the result of anaerobic decomposition. The gases generated are dominantly carbon dioxide and methane, with lesser volumes of odorous, sulphur containing gases and occasionally, under conditions of water-logged burial, the spontaneously combustible gas diphosphane (Pentecost, 1997, 1998).

The estimation of gas yield from putrescible waste materials is a matter of practical interest to the waste management industry (Polytechnic of East London, 1992) and values in the range 100 to 400 m^3 per tonne of readily degradable material are employed. Assuming a 70 kg body, of which 75 percent is readily or moderately degradable, then the total theoretical gas volume (CO_2 + CH_4) could be between 10 and 40 m^3 during the decay period. This theoretical estimate assumes that all the carbonaceous material is converted under fully anaerobic conditions, which may be applicable to a mass of waste within a large landfill, but which would be unusual in the case of a single corpse buried into an essentially aerobic environment. It is concluded that, with the exception of burials into stagnant, water-logged ground, the total potential gas emission from a burial is only a small proportion of the theoretical maximum.

There is little information available on atmospheric pollution from cemeteries. The limited details found are summarised below.

2.5.1 Inorganic chemical compounds

An infrequent, and unusual type of contamination may be found in the appearance of "corpse candles" over graves. The "candles" are the result of spontaneous combustion of diphosphane gas as it comes into contact with oxygen. Diphosphane may be generated by anaerobic decomposition where a significant source of phosphorus is present (skeletal material). There have been thirteen recorded examples in Britain since 1900, and all, but one, were associated with human or animal burials in waterlogged ground.

2.5.2 Organic compounds

It is possible that compounds having low vapour pressures may contribute to gaseous emissions. For example, formaldehyde, which is associated with the preparation of cadavers and also present in the Medium Density Fibreboard (MDF) which is widely used to make coffins, may give rise to concern. This was seen during the excavation of a grave in a west London cemetery where there was concern over potential health effects on the grave diggers. Personal samplers were fitted to the grave diggers, which were operated whilst they were digging. No formaldehyde was detected (<0.01 mg m^{-3} detection limit). The atmosphere at the base of the grave was also sampled using Draeger tubes, again no formaldehyde was detected (pers. comm., Nash 1997).

Offensive odours resulting from crowding of burial grounds and poor control of burial procedures were a feature of many inner city graveyards during the Nineteenth century (Holmes, 1896). However, modern environmental health requirements and increased public awareness have eliminated this source of atmospheric contamination.

No measurements or estimates have been found of the rate or detailed composition of gases emitted from burial grounds.

2.5.3 Pathogenic organisms

No evidence was found during the literature search, or through other lines of communication, of aerial dispersion of pathogens from burial grounds.

2.6 Monitoring groundwater pollution from cemeteries

2.6.1 Overview

From the data which have been examined, it is found that groundwater in close proximity to graves *may* have increased concentrations of one or more of the following determinands:

- chlorides (up to several 100 mg l^{-1} have been reported);
- sulphate (up to several 100 mg l^{-1} have been reported);
- ammonia (up to 400 mg N l^{-1} have been reported, but typically lower, at about 4 mg l^{-1});
- nitrate (up to several 10 mg N l^{-1} reported);
- Chemical Oxygen Demand (COD) (few 10s to few 100 mg l^{-1} reported);
- Bacterial indicators (faecal streptococci, clostridium, *Pseudomonas aeruginosa*);
- Sodium, potassium, magnesium.

Comparison of the available data with accepted quality standards, such as those in the Water Supply (Water Quality) Regulations 1989, indicate that ammoniacal nitrogen is the parameter most likely to be exceeded, with occasional exceedance of maximum permissible concentrations (MPCs) by chloride and sulphate. The limited data which exist indicate that the concentrations of heavy metals do not exceed MPC values. Of the alkali earth metals, only potassium has been reported above limit (one example from ten recorded values, 13 mg l^{-1} compared with MPC of 12 mg l^{-1}). In that case there was a Na:K ratio of less than 10:1, typical of organic contamination.

3. CHARACTERISTICS OF CEMETERIES AS SOURCES OF POTENTIAL POLLUTION

3.1 Introduction

This section examines the possible contaminant loading that may be derived from burials in the United Kingdom. The processes controlling the release of potential contaminants are complex, involving the interaction of hydrogeological and climatic factors, cemetery management practices and variations in practices associated with the preparation of bodies for burial, for example coffin manufacturing and embalming processes.

In considering human interments, it is assumed that current UK practices are followed regarding the preparation of the body and in the method of burial. In particular:

- Embalming - that no toxic metals or alkaloid substances have been used in preparation of corpses since 1951, when their use was banned. Half of all human burials having undergone some embalming with a formalin solution;

- Coffins - constructed predominantly of chipboard or MDF with a paper veneer;

- Depth of single burial 1.8 m (bottom of coffin 1.8 metres below ground level).

For other interments it is assumed that:

- Burial of farm stock follows the Code of Good Agricultural Practice for the Protection of Water (MAFF 1998);

- Commercial burial of pets (pet cemeteries) is in accordance with the voluntary code of conduct advanced by the Association of Private Pet Cemeteries and Crematoria;

- At green burial site the corpse is enclosed in a readily degradable coffin, or only shrouded in woollen cloth. Burial at depth of 1.3 metres. Grass or shrub cover to grave.

3.2 Potential pollution loads from human and animal burials

3.2.1 Composition of corpses and accompanying burial material

Table 3.1 illustrates that the composition of human and animal bodies is very similar, although there will be some variation as a consequence of differences in build between individuals. Forbes (1987) estimated the broad elemental composition of the human body, which was reported as percentage dry weight basis. The composition, shown in Table 3.2, is consistent with the range of principal chemical contaminants found at cemeteries, as described in Chapter 2.

Table 3.1 Comparison of composition of human and bovine bodies (percentage weight).

Component	Human[1]		Bovine[2]
Water	64		56
Protein +	20	)	
Carbohydrate +	1	)	28 (as Meat and
Mineral salts	5	)	Bone Meal)
Fat	10		16 (as Tallow)

[1] van Haaran (1951)
[2] Taylor, Woodgate and Atkinson (1995)

Table 3.2 Elemental composition of typical human body (values % dry weight)

Component	Percentage, dry weight
C	80.6
N	9.2
Ca	5.6
Mg	0.1
Na	0.3
K	0.7
P	2.5
S	0.7
Cl	0.3
Fe	<<0.01
Heavy metals	Trace

The balance of elements in the table is consistent with the observation that the principal pollutants which derive from corpses are dissolved and gaseous organic compounds and dissolved nitrogenous forms (particularly ammoniacal nitrogen), with a potential for increased pH resulting from the high proportion of calcium ions.

3.2.2 Factors affecting the rate of release of contaminants from burials

The process which controls the production, release and potential migration of pollutants from buried corpses is microbial decay and is essentially the same as that which controls the stabilisation of wastes in landfills. Landfill decay processes are described in some detail in Appendix A of Waste Management Paper No 26A (Department of the Environment, 1993). In the case of landfilled wastes, the initial aerobic phase is completed rapidly and, because the input of wastes exceeds the rate at which oxygen may gain access to the degrading mass, the greater part of decomposition takes place under anaerobic conditions. The analogy with landfilled putrescible waste is useful in assessing potential impacts and Dent and Knight, (1998) have remarked - "Cemeteries are best thought of as special kinds of landfill in that they mostly comprise a limited range of organic matter covered by soil fill". However, a comparison of the elemental compositions of vertebrate bodies with typical domestic waste highlights some important contrasts:

- The water content of a human body is about twice that of domestic refuse (65-70% in a corpse, compared to 34% in domestic waste). Lack of available moisture may inhibit both aerobic and anaerobic decay (Department of the Environment, 1993).
- The C:N:P ratio in vertebrate cadavers (about 30:3:1) provides a good balance between the principal microbial nutrients; whereas the ratios in domestic wastes show a deficiency in terms of phosphorus.

Both these factors encourage rapid and complete degradation of corpses, when compared with domestic waste. The relative rate of degradation of different types of carbon compounds has been estimated by the Environment and Industry Research Unit, Polytechnic of East London (1992). This indicates that 70% of the weight (including water) comprises rapidly degradable protein, carbohydrates and lipids, with some 30% comprising resistant bone, enamel (teeth) and keratin (nails and hair). Allowing for a 70 kg corpse, buried in a 10 kg chipboard coffin, the proportions of readily to slowly degraded matter are recorded in Table 3.3.

Table 3.3 Proportions of readily and slowly degraded matter in a coffined human corpse

	Category %			
Component	**Readily degradable**	**Moderately degradable**	**Slowly degradable**	**Inert (Non-degradable)**
Human corpse	60	15	20*	5*

Note * Assumes mineral salts (ashes) represent final stable residue; slowly degradable component of bones may be considered essentially inert for practical purposes.

Farm or domestic animals and poultry corpses show degradation characteristics either comparable to those of a human or with increased proportions of less rapidly degraded tissues, particularly poultry feathers.

In human corpses that are not embalmed, aerobic bacteria are initially inhibited due to changes in body tissues. The only exception is the skin surface which is exposed to the atmosphere. The principal agents of putrefaction are therefore anaerobic bacteria essentially akin to those found in solid waste degradation processes. However, the analogy with landfill is likely to cease as the decay products migrate from the grave, where they may encounter aerobic conditions within the ground. At a normal burial density the volume of soil adjacent to, and overlying, each coffin will be equal to some eight times the volume of the burial (see Assumptions in Appendix B1).

Consequently, the zone in which anaerobic conditions persist during decay of the body is likely to be restricted to the immediate vicinity of the grave, particularly in the case of free draining soils. Subsequent transformations of initial degradation products will be essentially aerobic. At sites where poor drainage causes waterlogging, rather more extensive anaerobic conditions may develop. The extent will, however, be a function of the rate of burials and the initial oxygen content of the water accumulating in the ground. In contrast, at landfill sites the large relative mass and loading rate of decomposing waste creates long-term anaerobic conditions.

Manufacturers of embalming fluids claim that high index cavity and arterial embalming may inhibit "wet" anaerobic degradation. Instead, dry aerobic decay is believed to take place.

Coffins and shrouds are composed of less rapidly degraded materials than the corpses which they enclose. Nevertheless, in modern burial practice chipboard and MDF coffins may begin to disintegrate rapidly in the ground compared with solid wooden boxes. Decay and collapse of chipboard coffins is reported to be evident within one month of burial, compared with 15 to 20 years in the case of pine or over 60 years for elm boxes, whilst cardboard coffins are reported to collapse onto the cadaver almost immediately on infilling the grave (West, 1998).

The rate of decay is also influenced by climatic and physical factors, including:

(a) Climate - warm temperatures accelerate decomposition, whilst freezing will inhibit or suspend the process;

(b) Soil lithology- a well drained soil, such as a coarse sand, will accelerate decomposition, whereas a poorly drained soil has the reverse effect. Peat bogs have been found to inhibit bacterial growth and bodies may remain preserved for thousands of years.

(c) Burial practice - including the depth of burial and construction of the coffin. Both these factors control the ease with which invertebrates and vertebrates may gain access to the corpse and hasten its decay.

Table 3.4 illustrates the effects of burial conditions on the rate of decay.

Further details are given in Section 5.6 of the Project Record (P2/024/1).

Table 3.4 Condition of burial affecting decay rate

Condition of burial	Timescale to skeleton	Comment
Body unburied, without clothes	3 to 4 months	Destruction by bacteria and scavengers
Body unburied, fully clothed	considerably shorter than 3 to 4 months.	Agents of decay work faster under cover.
Uncoffined body buried 2 metres deep - in friable soil and body not embalmed	10 to 12 years	Analogous to many modern burials, with rapid collapse of coffin
Bodies buried deep outlast those in shallow graves: 0.5 m deep 1.5 m deep	 <1 year (months even) many years	Any increase in depth makes a body less accessible to worms and maggots.
Body wrapped in polythene	Increases time to decompose	

3.2.3 Potential contaminant release rates

Humans

A human corpse normally decays within a period of 10 to 12 years (Table 3.4). It is estimated that over half of the loading will be leached within the first year. In successive years there will be a declining source term, in which half the residual loading is leached. After 10 years less than 0.1% of the original loading may remain. An example of such a potential release rate is given in Table 3.5.

A similar estimate of the release rate for formaldehyde can be made using figures from Davies (1998) and Soo Chan *et al* (1992). This would result in a potential total loading of 0.1 litres of formaldehyde per corpse. If all were leached in the first year it would result in an effluent containing 40 mg l^{-1} formaldehyde. Following the source depletion term model, the concentration after 10 years would be estimated to be less than 5 mg l^{-1}. These estimates take no account of the natural degradation of formaldehyde in the ground. The absence of reports of widespread groundwater contamination by formalin leads to the conclusion that natural attenuation processes in the ground prevent contamination.

The embalming of bodies for green burial is discouraged. In view of the positive choice that is made by persons wishing green burial (or on their behalf by relatives) it is concluded that such burial sites do not provide a significant potential source of formaldehyde release.

Table 3.5 Potential annual release (kg) of principal components from a single 70 kg burial

Year	TOC	NH_4
1	6.0	0.56
2	3.0	0.44
3	1.5	0.22
4	0.75	0.11
5	0.37	0.05
6	0.19	0.03
7	0.10	0.01
8	0.05	<0.01
9	0.02	<0.01
10	0.01	<0.01

The discussions in the previous section have focused on single burials, or possibly the interment of a second body in a family grave (currently second burials in a family grave may account for up to 40% of interments in large municipal cemeteries (Nash, 1997). In addition, common graves are still prepared in large cemeteries, in which such burials may represent 2 or 3% of annual interments. Common graves are typically dug to 2.7 metres (9 feet), to contain three coffins, each covered by 150 mm of soil above the lid before the next is placed. In some areas common graves may be extended to 3.4, 4.0 or 4.6 metres (11, 13 or 15 feet) to accommodate 4, 5 or 6 burials. Common graves are normally completed (filled to the top) within one year of opening and the potential pollution load may be assessed by scaling from that associated with a single interment.

Animals

With respect to animal carcasses, it is suggested that the potential release rates are estimated by the use of multiplier factors to account for the differences in body weight and burial practices. Suggested conversion factors are given in Table 3.6

Table 3.6 Factors to modify human cadaver pollution indices to animal corpses

Animal type	Weight factor (x human value)	Infiltration factor (x human grave size)
Cattle and horses	8 - 10	4
Pigs	1	1
Sheep	0.8	1
Dog	0.15	0.25
Cat	0.03	0.1

Estimation of pollutant flux

The time taken to flush out contaminants will be directly related to the effective rainfall and soil infiltration rate for the burial site. As a worst case, it could be assumed that infiltration capacity exceeds effective rainfall at all times, so that surface evapo-transpiration determines the net infiltration rate. This will vary according to how the grave is restored after burial. Four principal restoration conditions will exist:

1. Paved surface to grave (grave slab) - slight evaporative loss, but rainfall likely to run-off around perimeter and infiltrate surrounding grass.

2. Surface of grave covered by stone chippings - evaporative losses only, similar to bare soil evaporation.

3. Surface of grave grassed - evapotranspirative loss appropriate to short rooted vegetation.

4. Shrub or tree planted on grave (green burial) - evapotranspirative loss appropriate to long rooted vegetation.

The first three conditions predominate in the majority of municipal cemeteries. Many Diocesan authorities now prohibit the erection of grave slabs or chipping surfaces in churchyards. Pet cemeteries are similar to human burial grounds in this respect. The fourth condition is found at all green burial or woodland burial sites.

The annual rate of burial will influence both the potential volume of contaminated water which may form by leaching from graves and the composition and strength of the effluent. In order to illustrate the influences, worked examples of the estimation of water fluxes and effluent (leachate) composition are included in Appendix B, for three model burial sites:

1. a small churchyard, 10 burials per year;
2. a large municipal cemetery, 350 burials per year; and
3. a green burial site, 30 burials per year.

The results of estimates of the potential average concentration of ammoniacal nitrogen in the drainage, the volume of drainage and the annual nitrogen load at one and ten years after the start of burial at each of the model sites are summarised in Table 3.7.

Table 3.7 Potential ammoniacal nitrogen concentrations, volumes and loads leached from model cemeteries.

	NH_4 mgl^{-1}		Volume m^3 yr^{-1}		Load kg yr^{-1}	
	1 year	10 years	1 year	10 years	1 year	10 years
Small churchyard	348	69	25	250	8.7	17.25
Municipal cemetery	331	66	920	9190	304.5	696.5
Green burial	305	61	86	855	26.2	52.2

Comparison of the estimates for the three scenarios indicates only a small difference in predicted average effluent concentrations, apparently suggesting comparable threats to water quality. However, if for the three scenarios, potential loadings of nitrogen are considered in terms of in terms of kg N ha^{-1} yr^{-1} (Table 3.8) the greater potential impact of the large cemetery is clearly illustrated.

Table 3.8 Changes in N loading (kg N ha^{-1} yr^{-1}) from model cemeteries during first ten years operation

Year	1	2	3	4	5	6	7	8	9	10
Small cemetery	8.7	13.1	15.3	16.4	16.9	17.1	17.2	17.3	17.4	17.4
Large cemetery	305	459	408	328	270	228	197	173	154	138
Green burial	26	39	46	49	51	51	52	52	52	52

Notes: Times for model cemeteries to cover 1 hectare: small churchyard 80 years; large municipal cemetery 2 - 3 years; green burial site 21 - 22 years.

4. ATTENUATION OF CONTAMINANTS IN PATHWAYS FROM BURIAL SITES

4.1 Potential pathways from burial grounds

The first pathway which contaminants from burial grounds follow is through the soil in which the burial has taken place. In the case of gaseous contaminants the pathway may be directly to the atmosphere with further dispersion by the wind. Consideration in Chapter 3 of the characteristics of burial grounds as sources of potential pollution, demonstrates that the main problems which may arise are linked to the transport of dissolved and particulate pollutants, including pathogens, to groundwater. Three principal components of the pathway may be recognised:

1. The soil surrounding the burial.

2. The unsaturated zone of the underlying aquifer (if present).

3. The saturated zone of the aquifer (if present).

In situations where the water table fluctuates seasonally, the importance of the unsaturated zone as a pathway may vary with time, or even disappear intermittently. This may take place in areas where the water table fluctuates to the extent that part, or all, of the grave depth is inundated regularly or occasionally. The principal characteristics of the three pathway segments are summarised below.

4.1.1 Soil pathways

Soils are generally more complex in terms of composition, chemistry and biological activity than the underlying rocks or sediments from which they are derived. They may be the site of relatively intense biochemical reactions, so that contaminants may undergo change as they pass through them. Air access to soils is generally good and unless they are waterlogged, soils are likely to be aerobic, encouraging oxidation of pollutants. The physical and chemical processes of filtration, absorption, adsorption and cation exchange, may all be important attenuating processes in soil layers.

4.1.2 Unsaturated zone pathways

The sediments or rocks forming unsaturated zones are commonly less biologically and chemically active than their overlying soils. The rate of re-oxygenation from the surface is lower than in soils and anoxic conditions may be developed. Nevertheless, chemical and biochemical reactions may continue to attenuate pollutants, whilst filtration, adsorption and cation exchange may continue to immobilise particulate and some dissolved pollutants. Hydrogeological factors have an important influence on the attenuating capacity of the unsaturated zone, and are discussed below. Movement of dissolved and particulate pollutants in the unsaturated zone is dominantly vertical, in response to gravity.

4.1.3 Saturated zone pathways

Pollutants entering the saturated zone become mixed with, and transported in, groundwater flows. The principal attenuation process is dilution as the result of dispersion in the flow. The concentrations of both dissolved and particulate contaminants are reduced by dispersion. Filtration of particulates by the aquifer matrix may also take place. The groundwater into which the contaminated infiltration mixes may be of a different composition, and chemical reactions may continue. The oxygen level of groundwaters in coarse, shallow aquifers may be high, but in deep, finer grained aquifers low dissolved oxygen concentrations, or anaerobic conditions, may persist.

4.2 Influence of hydrogeological factors

Pathways which pose the greatest threat to groundwaters from dissolved and particulate contaminants, are those where hydrogeological factors allow rapid movement of pollutants from the source to the groundwater. The mineralogy of the unsaturated and saturated zones also has an important bearing on attenuation capacity. Rocks and sediments with a mixed mineralogy, including the presence of clay and carbonate minerals, provide a better medium for chemical, biochemical and physical/chemical reactions than do materials composed predominantly of a single mineral, for example silica sand or pure limestone.

Consequently, coarse granular or heavily fractured sub-soils, fissured aquifer materials, or those of restricted mineralogy, are unlikely to offer significant opportunities for attenuation by many of the processes. An exception is oxidation, where the rapid flow and ease of entry of gases into the system may maintain a higher oxygen status than would be the case for finer grained materials. The maximum benefit is present in coarse granular material, where not only is oxygen free to gain access to the water table from surrounding areas, but significant storage (often in the range 10 - 25%) of oxygenated groundwater is possible. Non-porous fractured materials may have a potential for rapid groundwater flows, but the very limited storage (often <1%) may prevent the efficient replenishment of oxygenated groundwater.

By contrast, aquifers composed of sediments or rocks of mixed mineralogy, and in which groundwater flows are intergranular, provide more effective protection of groundwater from surface derived pollution. The protection arises from the slower flow of water through the unsaturated and saturated zones and the greater opportunities for chemical, biochemical and physical reactions between the water and the matrix within the pathway.

4.3 Processes controlling attenuation.

4.3.1 Chemical and biochemical processes

The effects of the processes of cation exchange, neutralisation, oxidation/reduction, precipitation/solution, complex formation and degradation on pollutants, in the unsaturated and saturated zones of aquifers, have been observed in studies of both point and diffuse sources of pollution. The influence of factors such as the pore size distribution and mineralogy on the attenuation of dissolved organic pollutants (Blakey and Towler, 1988), and the effects of the clay mineral content and cation exchange capacity on the migration of ammoniacal nitrogen (Lewin *et al*, 1996) are well documented for the principal aquifer materials.

In the case of organic contaminants, microbial degradation and oxidation may be effective in aquifer materials with a significant buffering capacity (that is, the capacity to neutralise acid solutions). In formations with a low buffering capacity, degradation and oxidation have been found to be less effective.

Similarly, the presence of clay minerals, and other base exchange media in the soil and unsaturated zone, has been shown to be beneficial in retarding the movement of ammoniacal nitrogen towards the water table.

4.3.2 Immobilisation of particulates

The immobilising capacity of soils and geological materials is of importance when considering the potential for movement of particulate pollutants, especially the transport of pathogens, which is of particular concern when assessing the risks to groundwater from burial sites.

The removal of particulates is a combination of two effects:

- adsorption; and
- filtration.

Adsorption of particulates is due to the presence of electrical charges on the surfaces of the mineral grains forming the soil or aquifer matrix, and of opposite charges on particulates, leading to attraction and capture. Adsorption is most effective at a pH of about 7.0, which is a typical value for many natural soils and groundwaters. In general terms, materials of mixed mineralogy, especially those containing a proportion of clay minerals, provide greater opportunity for retention or retardation of particles by adsorption than do formations composed principally of silica (for example, clean sands and sandstones) or calcium carbonate.

Filtration takes place when a liquid containing suspended particles passes through a layer of porous material. It is a complex process and represents the combined effects of a number of factors:

- a straining action which takes place at the surface of the filter medium, and which may be repeated if the liquid passes through a series of beds with different porosity and pore size characteristics;
- sedimentation and straining of particles within the body of a filter medium.

Surface straining relies on the retention of particles which have a greater diameter than the pores of the filter medium. Many suspended particulates are of irregular shape and may pass through a pore in one orientation, but be retained ("strained") if they reach the pore in a different orientation. If the pore throat diameters are larger than the suspended particles, then it would be expected that the particles would pass through the pores. However, if the difference in diameters is modest (a factor of perhaps two or three times) and a number of particles approach a pore at the same time, the particles may become lodged across the pore ("bridging") leading to the build-up of a filter cake, which will then be able to retain smaller particles.

Although filtration may be expected to take place principally at the surface of a uniform porous medium, the range of pore diameters which is typical of natural media may allow further retention of appropriately sized particles within the body of the medium, by a combination of straining and bridging.

The potential for retention (immobilisation) of pathogens in aquifer materials is controlled primarily by the size distribution of interconnected pathways (pores and fissure) through which they may be transported. The ranges of pore and fissure sizes recorded in the principal aquifer materials present in the United Kingdom are compared with the general dimensions of pathogenic organisms in Figure 4.1

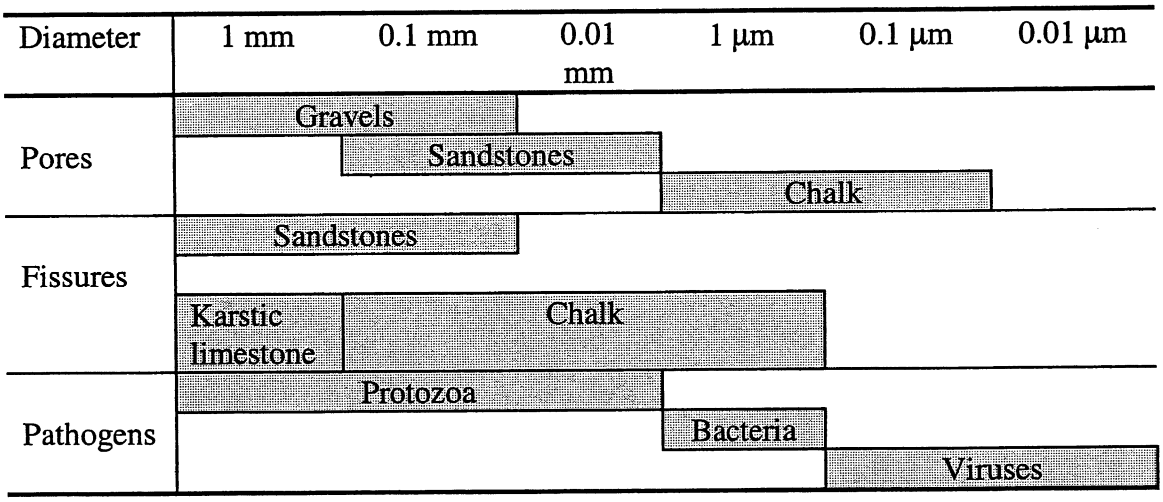

Figure 4.1 Pathogen diameters compared with typical aquifer material apertures

Examination of Figure 4.1 confirms that shallow groundwaters, protected by only a thin unsaturated zone and composed of coarse grained or heavily fissured materials, are vulnerable to contamination by pathogens. Groundwaters in finer grained, unfissured materials, and with a significant depth of unsaturated zone, are better protected. A recent survey by Pedley and Guy (1996) concluded that flow paths which bypass the filtering/attenuating effects of the unsaturated zone represent the greatest threat to the microbiological quality of groundwater.

4.3.3 Processes attenuating gas from burials

Little or no information relating to the fate of gas arising as a consequence of burials has been found. Studies of the passage of gas from the degradation of landfilled wastes to the atmosphere (Jones and Nedwell, 1989) have shown the presence of active methane oxidising bacteria in the cover soils on landfills. Odours from composting activities may be controlled by a cover of organic rich soil material. It is likely that the soil cover on a grave will have similar effects, so that an active pathway to the atmosphere is not established.

5. ASSESSMENT OF RISKS FROM CEMETERIES

5.1 Introduction

This section provides a framework for assessing the risks associated with cemeteries and other burial grounds. Evidence has been sought of the impacts on air, soil and water, but only limited information has been found relating to air and soil. The risk methodology is, therefore, based primarily on risks to groundwater and surface water.

It is suggested that a tiered or staged approach, consistent with other risk assessment procedures employed by the Agency, should be adopted for dealing with proposed cemetery (or other burial) sites. In this respect an initial site assessment is undertaken to define potential pathways and receptors in proximity to the site (the source). Where the apparent risks are considered to be low, then pragmatic controls based on best practice guidelines should provide sufficient protection to the environment. If the initial assessment suggests the risks may be greater, for example because of the presence of a private groundwater abstraction in the vicinity, then a more detailed assessment, perhaps with limited site investigation, will be required. In the event that risks remain uncertain at this stage, then a detailed site investigation and hydrogeological assessment will be necessary. In most cases it should be possible to agree appropriate measures to prevent pollution of the environment. However, at any stage of the assessment process, it is possible to object to a proposal if there is considered to be an unacceptable risk.

It is important to note that the nature and extent of information required at any stage of the risk assessment will be specific to individual sites. This should be subject to review throughout the consultation period and agreed by both the Developer and Agency officers. Officers should be satisfied that the information received is sufficient to allow an objective and defensible decision to be made.

5.2 Assessment criteria

Assessment of the environmental risk posed by a burial ground should be based on an estimation of the potential pollution load (the source, in terms of the amount and strength of pollutant), taking into account the attenuation characteristics afforded by pathways, so that impacts on receptors may be judged.

Where groundwater is identified as not permanently unsuitable for use the requirements of the EC Groundwater Directive (80/68/EEC) must be met. For an activity to be acceptable, it needs to be shown that there would be no noticeable impact on groundwater from List I substances, nor pollution by List II substances, taking account of background groundwater quality.

In particular, the impact from ammoniacal nitrogen, which is a recognised by-product of burials and which occurs in List II of the Annex to the Directive, will need to be considered. Earlier chapters show that List I substances and pathogens pose only limited risks, which would normally only require further consideration in more detailed assessments. The

Groundwater Regulations 1998, apply to burial grounds, because the activity may lead to direct or indirect discharge to groundwater of ammonia, which is a List II substance.

If surface water is a receptor, either directly or via springs or baseflow, the provisions of the EU Aquatic Environment Directive (76/464/EEC), which also includes ammoniacal nitrogen in List II of the Annex, should be taken into account. Any water quality objectives will also need to be considered.

For the burial of livestock, advice given in the Code of Good Agricultural Practice for the Protection of Water (MAFF, 1998) should also be taken into account.

5.3 Risk assessment methodology

5.3.1 General

Figure 5.1 illustrates the approach that should normally be adopted in assessing the risks associated with a burial ground proposal.

Stage 1: Preliminary site assessment

This stage will be fundamental to all levels of the risk assessment process. It will provide an initial review of the potential pathways and receptors in proximity to the site, and should be undertaken using all readily available information. This will include reference to published topographical, geological and hydrogeological maps, abstraction licence records and Environment Agency Groundwater Source Protection Zone maps.

Table 5.1 lists the principal factors that will control site vulnerability. By assessing each of these in turn a judgement can be made as to the overall vulnerability class into which a site will fall. For example, a site located directly on a Major Aquifer, with an unsaturated zone of less than 5 metres, could be considered highly vulnerable, whereas a site on a Non-Aquifer, with no superficial deposits, would represent a low vulnerability class. Examples of using a ranking procedure of the type shown in Table 5.1 to determine vulnerability class are included in Appendix A.

Stage 2: Determination of the appropriate level of risk assessment

Having assigned the site to a vulnerability class, it is then necessary to consider the appropriate level of risk assessment required. This will be a function of the scale of the development, in terms of the number of burials per year, and whether the bodies are human or animal. Figure 5.2 illustrates a schematic relationship between the scale and vulnerability of a site, and relates this to the level of risk assessment required.

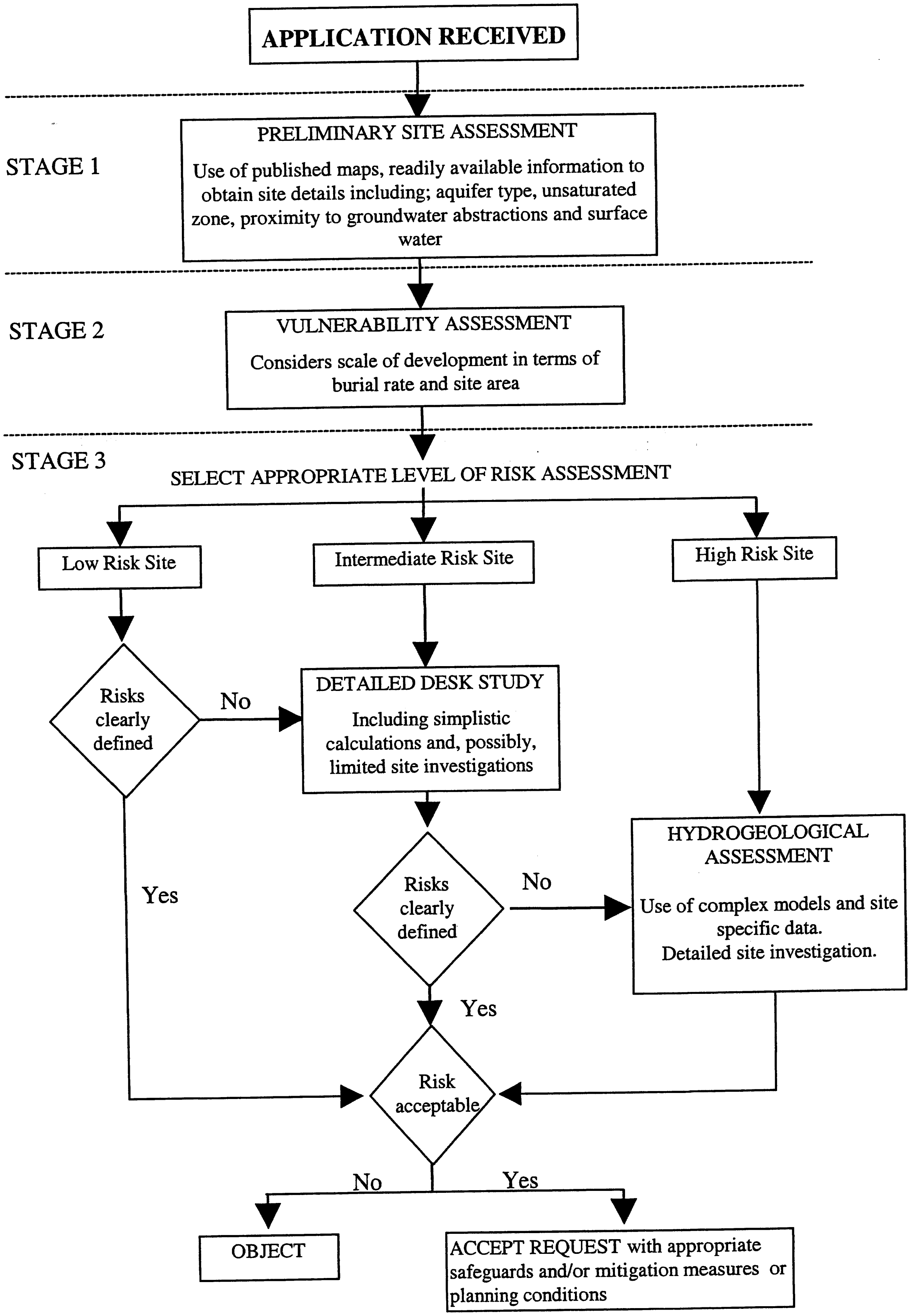

Figure 5.1 Flow chart for assessment of proposals

Table 5.1 Groundwater vulnerability ranking chart

Ranking	Very low	Low	Moderate	High	Very high
Drift type	Clay	Silt	Silty sand	Sand /gravel	Absent
Drift thickness	>5 m	>3 - 5m	3 m	0 - 3m	Absent
Depth to water table	>25 m	11 - 25m	10 m	5 - 9m	< 5m
Flow mechanism	Intergranular				Fissured
Aquifer	Non-aquifer		Minor aquifer		Major aquifer
Abstraction and SPZ	Outside Zone III	Within Zone III	Close to boundary of Zones II & III	Within Zone II	Within Zone I or <250 m from private source
Watercourses, springs	>100 m	>70 <100 m	>50 <70 m	>30 <50 m	<30m
Drains	>100 m	>40 <100 m	30 - 40 m	>10 <30 m	<10 m

Stage 3: Scale of risk assessment

a) Low risk sites

Where it is evident from Stages 1 and 2 that the risks of development are likely to be low, then the proposal should be accepted without the need for a more detailed assessment. It may be necessary to request compliance with industry best practice, possibly through the use of Planning Conditions, for example -" No burials within 10 metres of any field drain".

Borderline cases should be dealt with in more detail, and would fall into the next level of the assessment process. However, in some cases clarification of certain details may allow the site to be dealt with at this level. Two examples illustrate this point. In the first, an application is made for a small, low input extension to the graveyard attached to a parish church, and in proximity to a minor watercourse. This may be acceptable if there are no records of adverse effects on the stream from past burials. The second proposal is for a low input site on a clay subsoil. Because of the low permeabilty of the soil, an open grave may collect water during times of heavy rain. However, the water trapped in the hole does not connect with any groundwater body from which a supply may be taken, and a Planning Condition to the effect that any accumulated water should be pumped from a grave before the burial takes place, would provide adequate environmental protection.

In summary, for a site assessed as low risk the appropriate operational safeguards are:

- No burials within Protection Zone 1 around a spring, well or borehole;
- Minimum distance from grave(s) to well, borehole or spring used for water supply - 250 metres.

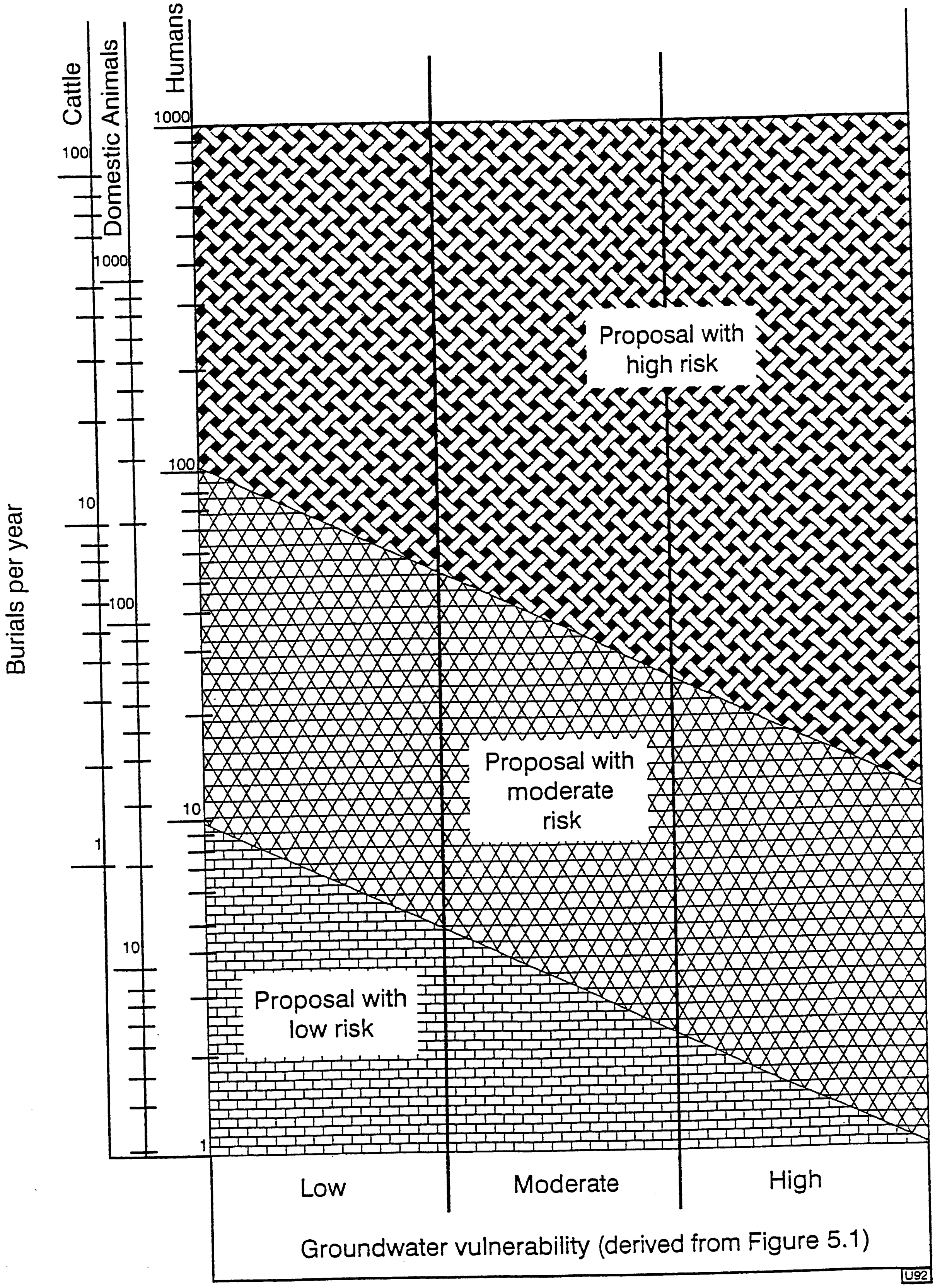

Figure 5.2 Schematic relationship between burial rates, vulnerability class and level of risk

- Minimum distance from grave(s) to other springs or watercourses - 30 metres;
- Minimum distance from grave(s) to a field drain - 10 metres;
- No burial into standing water, base of grave to be above local water table.

In certain situations, for example where a thick unsaturated zone with good attenuating properties is known to be present, local knowledge may allow some relaxation of the minimum distance from a water supply source, without an automatic need to move to a complete intermediate risk assessment.

b) Intermediate risk sites

A site judged to fall within this category should be subject to a more detailed desk study, supported with limited site specific data. The Applicant should be required to provide the data. This may include an assessment of the potential contaminant loading and likely attenuation within pathways, through the use of simplistic calculation. Other factors that might warrant consideration are detailed in Table 5.2

Appendix B provides information that may assist in estimating the potential contaminant loading from a variety of burial sources. For example, an annual release of ammoniacal nitrogen of about 2.5 grammes per kilogram bodyweight would be appropriate for load estimation for the ten year period following modern burial, decreasing to an average of less than 0.1 gramme per kilogram within a further ten years. For a grass covered grave in an area of average rainfall (say 650 mm yr^{-1}), the average annual infiltration through the grave surface would be of the order of 500 litres, but up to 2500 litres if the infiltration through the shared area of lawn surrounding each grave is taken into account. Consideration should be given to the attenuating characteristics of soils and underlying strata and to the potential dilution in receiving waters. A semi-quantitative assessment may provide sufficient information at this stage.

For the proposal to be acceptable the assessment should show that there would be no noticeable impact on groundwater by List 1 substances and, ideally, none by List 2 substances. As a worst case, any impact by List 2 substances would not amount to pollution as defined in the Groundwater Directive. Where it is accepted the proposal can proceed, appropriate conditions should be requested to ensure that pollution does not take place. Alternatively, an objection should be raised, or a detailed risk assessment undertaken by the Applicant, as discussed below.

Table 5.2 Typical information requirements for assessment of intermediate risk sites

Information required	Source of information
Site description	Local survey to supplement data on appropriate Ordnance Survey maps (e.g. Superplans).
Number, type and sequence of burials	Projections on which annual numbers are based should be given and explained.
Meteorological factors	Long-term average Met. Office values, supplemented by local MORECS soil moisture data.
Soil/sub soil characteristics	Interpretation/interpolation from Soil Survey maps. Limited site investigation (trial pits) if proposed area extends across soil type boundaries.
Superficial geology / hydrogeology	Interpretation of geological/hydrogeological maps and memoirs (Geological Survey). Limited site investigation (trial pits or shallow drilling) if uncertainty/lack of information or proposed area extends across geological boundaries.
Solid geology/hydrogeology	Interpretation of geological/hydrogeological maps and memoirs (Geological Survey). Limited site investigation (drilling) if uncertainty/lack of information or proposed area extends across geological boundaries. Assessment of aquifer characteristics from appropriate published data of local or regional origin.
Groundwater quality	Evidence of seasonal and other variations in composition based on quarterly sampling/analysis for not less than 12 months. Analytical suites as recommended for groundwaters at proposed landfill site in Appendix C, Waste Management Paper No 4 (Department of the Environment, 1994). The data may be derived from other outcrops of the aquifer(s) in the region.
Surface water quality	Evidence of seasonal and other variations in composition based on quarterly analysis for not less than 12 months. Analytical suites as recommended for groundwaters at proposed landfill site in Appendix C, Waste Management Paper No 4 (Department of the Environment, 1994).
Proximity to water source/resource	Check with Environment Agency and appropriate Environmental Health Department data bases. Search to include groundwater and surface water.
Proximity to housing , and other developments	Check with Local/Regional/National Planning Authority for potential residential, educational, commercial/industrial developments, roads, rail, mineral extractions.
Data assessment protocols	Simple pollutant flux and water balance calculations appropriate.

c) High risk sites

Where a proposal is considered to be a potential high risk, a more detailed site investigation and risk assessment is required. The use of groundwater modelling techniques, or other stochastic models, would normally be required. The onus will be on the Applicant to appoint an appropriately qualified person to undertake such work, in order to present a case to the Agency. In the absence of such information, it may be necessary for Agency staff to object to the proposal.

It is expected that sites falling into this category would be large developments, both in terms of input rates (burials per year) and size (total area). Assessments should be conducted on a similar basis to that which is required for non-hazardous waste landfills, but recognising that the input rate is likely to be small compared with that for landfills. A burial rate of 1000 per year, which would be typical of a town with 150 000 to 250 000 inhabitants, would represent a disposal rate of only about 70 tonnes per year. The results of adequate direct investigation of soils and rock to at least one metre below grave depth would be expected. Hydrogeological assessments should be based on site specific data and if they are not available then an appropriate site investigation should be agreed between the Applicant and the Agency, taking account of the vulnerability of potential receptors. Verified information on the site and potential receptor characteristics should be used in the consideration of various scenarios, including worst case situations, with the development of management options to mitigate potential impacts.

Typical information requirements are listed in Table 5.3. Assessments should be quantitative, taking particular account of the potential for ammoniacal nitrogen to impact on groundwater or surface water. Consideration of List I substances and other hazards such as microbiological contaminants may also need to be taken into account. Use of deterministic or probabilistic models may be appropriate.

For the proposal to be acceptable, the assessment should show that there would be no noticeable impact on groundwater by List I substances and, ideally, none by List II substances. As a worst case, any impact by List II substances should not constitute pollution. Risks from microbiological contaminants should not endanger water resources or supplies. Where it is accepted that a proposal may proceed, the outcome should be ensured by requesting the application of appropriate conditions. If this cannot be achieved, an objection should be raised.

Table 5.3 Check list of information requirements for assessment of high risk sites

Information required	Source of information
Site description	Location, area and topography based on accurate site survey. Any proposed modification from pre-burial form to be clearly identified.
Number, type and sequence of burials	Projections on which annual numbers are based should be given and explained. Plan showing proposed sequence of burial areas should be available, with indications of expected progression with time.

Information required	Source of information
Meteorological factors	Analysis of locally derived meteorological data to give monthly means, maxima and minima for effective rainfall, and soil moisture deficit, for bare soil, short rooted vegetation and long rooted vegetation.
Soil/sub soil characteristics	Based on site survey (augering and trial pits as necessary). Sampling method and pattern to take account of advice given by the Standing Committee of Analysts (1986).
Superficial geology / hydrogeology	Site investigations, to characterise in terms of lithology (mineralogy, grain size distribution), vertical and lateral compositional variations. Presence/absence of shallow groundwater, fluctuations in water table (seasonal or otherwise - not less than 1 year data, based on monthly measurements).
Solid geology / hydrogeology	If non-aquifer, proof from direct investigation of lithology to not less than 10 metres below base of superficial deposits. If aquifer, minimum of 3 boreholes, one on upgradient boundary of proposed site, two close to down gradient boundary. Boreholes to penetrate to not less than 10 metres below minimum groundwater level and to be constructed so that they may continue to be used as monitoring points during the operational phase of the burial ground. Geological/hydrogeological logs to be prepared by professional geologist/hydrogeologist. Estimates of permeability (k) based on falling head or bailing tests. Cation exchange capacity (CEC) measurements from drilled samples.
Groundwater quality	Evidence of seasonal and other variations in composition based on monthly sampling/analysis for not less than 12 months. Analytical suites as recommended for groundwaters at proposed landfill site in Appendix C, Waste Management Paper No 4 (Department of the Environment, 1994).
Surface water quality	Evidence of seasonal and other variations in composition based on monthly sampling/analysis for not less than 12 months. Analytical suites as recommended for groundwaters at proposed landfill site in Appendix C, Waste Management Paper No 4 (Department of the Environment, 1994).
Proximity to water source / resource	Check with Environment Agency and appropriate Environmental Health Department data bases. Search to include groundwater and surface water, potable and non-potable use (particularly irrigation).

Information required	Source of information
Proximity to housing , and other developments	Check with Local /Regional/National Planning Authority for potential residential, educational, commercial/industrial developments, roads, rail, mineral extractions.
Data assessment protocols	Possible use of stochastic models to assess range and probability of impacts.

5.4 Other factors

5.4.1 Patterns of burial on sloping ground

At larger cemeteries, shallow groundwater may be used to irrigate lawns and flower beds. Even in areas where the natural pedological/geological conditions are such that shallow groundwater would not normally be present, the disturbance of the ground to 2 or 3 metres depth which accompanies burial, may allow water to accumulate at burial level. If the proposed site is sloping and burial begins at an upslope position, polluted water from previous burials is likely to enter graves as they are dug down-gradient. It will then be necessary to pump out the water before interment can proceed, with the result that contaminated, and possibly offensive, water may be irrigated onto land within the burial ground, and may discharge to surface water by run-off.

5.4.2 Green burial sites

Comparison of the rate of release of potential groundwater contaminants by a green burial site with that from a lawn burial site in Table 3.8 is based on model sites, at which the rate of interment at the green site is three times that at the small lawn cemetery. Taking this into account, the rates of release of potential contaminants are directly comparable. The relatively shallow burial (1.3 metres depth) of a corpse at a green site will result in rapid, principally aerobic decay. This decay rate is encouraged by the use of coffins and shrouds made of readily degradable materials and the lack of embalming. The products of aerobic decay (carbon dioxide, water, nitrate, sulphate) are generally less polluting than those of anaerobic degradation and it is concluded green burial sites pose no more risk than traditional lawn burial grounds.

5.4.3 Pet cemeteries

These sites may have a lower, or equivalent, pollution potential as human burial grounds. The body mass of individual domestic animals is considerably less than that of a typical human, but burial density is greater than that in a typical human cemetery. The depth of burial (industry standard of 1 metre), use of readily degraded coffins and the lack of embalming encourage rapid decay processes. Pet cemeteries may require a Waste Management licence under the provisions of the Environmental Protection Act 1990. Appropriate operational safeguards and monitoring can therefore be employed through the use of certain Licence Conditions.

5.4.4 Mass burial sites

Mass burials of human and animal subjects are normally the result of a natural or man-made disaster and it may be a requirement, for reasons of public health, that the interments are not delayed. The infrequent and non-routine nature of these events make forward planning difficult, but essential if consequent environmental impact problems are to be avoided. It is recommended that liaison is established with county/regional Emergency Planning Teams (human mass burials), Local Authorities (Environmental Health, Planning, Legal, Social), Emergency Services and MAFF (animal emergencies), to establish broad criteria which can be acted on in the event of an incident. Routine review of the understandings is advised, to anticipate the potential problem of interrupted communication due to staff movements in all relevant organisations.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

There is an absence of recorded, recent examples of environmental pollution from burial grounds in the United Kingdom. Past examples from the United Kingdom took place many years ago, in response to crowded burial conditions which became typical of some urban burial grounds during Victorian times. Small numbers of examples of more recent pollution incidents have been reported from other parts of the world, almost inevitably in situations of high aquifer vulnerability and under climatic conditions which encourage rapid decay of bodies and leaching of contaminants to groundwater. However, the paucity of information from the United Kingdom may be a function of the lack of routine monitoring of groundwater and/or surface water at burial grounds, and a recommendation is made to improve the situation. It is understood that an investigation of groundwater at a cemetery in Nottingham has been carried out by the British Geological Survey on behalf of the Environment Agency. The results have not been seen and cannot be assessed.

It is concluded that the Planning laws of the United Kingdom, which have taken note of the pollution potential for some 150 years, have provided generally adequate protection to the environment from burial grounds. However, risk assessments based on hypothetical burial proposals suggest that certain combinations of environmental vulnerability and burial rates could pose significant threats, and recommendations are made for a staged assessment of proposals for burial grounds. The objective of the staged approach is to ensure that applications which pose no significant threat should be accepted with minimum delay and expenditure of effort (both by the Applicant and the Agency), whilst those which may impact significantly on the environment are subject to a rigorous risk assessment.

Guidance developed by the Ministry of Agriculture, Fisheries and Food for the burial of dead farm animals has been widely used to comment on human burial ground proposals by the regions of the Agency. The MAFF approach is consistent with the Agency's Policy and Practice for the Protection of Groundwater and there is no evidence that its application has given rise to problems.

6.2 Recommendations

6.2.1 Method of assessment

Risk assessment for burial site proposals should be in accordance with the staged methodology developed in this report, which has been designed to eliminate inconsistencies in the ways in which such developments are considered. However, no two proposals, nor sites, are identical and it is important that the specific factors relevant to the vulnerability of each site are taken fully into account.

6.2.2 Monitoring of cemeteries and burial grounds

Groundwater contamination by burial grounds appears similar to that attributable to other sources of degrading organic matter. If contamination from a burial ground is suspected, then it may be appropriate to undertake groundwater monitoring. Ideally, groundwater sampling should be carried out at one point up the hydraulic gradient from the site, and two points in the direction of groundwater flow from the burial ground. This is in order that the effects of the burial ground may be properly assessed.

If groundwater quality is poorly understood, background information should be collected by sampling and analysis from a well or borehole upgradient from the proposed site. The sampling should be carried out in accordance with the guidance given in Appendix C of Waste Management Paper No 4 (Department of the Environment, 1994). The frequency of measurements and lists of determinands should be as recommended for the site preparation phase of landfill development, as summarised in Table 6.1. Ideally, the information should be collected over not less than twelve months, to allow possible seasonal variations in quality and groundwater level to be assessed. It is recommended that the balance of cations and anions should be checked at each quarterly survey. The major cations and anions, expressed as milli-equivalents per litre, should balance to within about 5%. If the balance consistently fails then either the presence of significant concentrations of other ions (for example phosphate or volatile acids), or analytical errors, should be investigated.

Table 6.1 Determinands and sampling frequency for groundwater, where background information is inadequate

Frequency		**Determinands**
Monthly	- On-site instrumental measurements	Water level, pH, Temperature, Electrical Conductivity, Dissolved Oxygen.
	- Laboratory determinations	NH_4N, Cl.
Quarterly	- Laboratory determinations	as monthly, plus SO_4, NO_3, NO_2, Total Organic Carbon, Alkalinity, Na, K, Ca, Mg, Fe, Mn, Cd, Cr, Cu, Ni, Pb, Zn.

Once the groundwater quality in the area is well understood, an absolute minimum monitoring programme would consist of a single point immediately down-gradient from the burial area. Monitoring should take place at the frequency recommended for groundwaters at operational landfills in Table C.3 of Waste Management Paper No 4. The minimum suite of determinands should be:

- Ammoniacal nitrogen;
- Chloride;
- Sulphate;
- Sodium;
- Potassium;

If the values of these determinands depart consistently and progressively from the background levels, then it is recommended that the suite of determinands be increased to cover the range of quarterly analyses specified in Table 6.1.

If evidence of contamination is indicated by the inorganic determinands, sampling for bacterial indicators, in particular *Pseudomonas aeruginosa,* is recommended.

If monitoring demonstrates that groundwater pollution is taking place, burials at that site should be suspended whilst investigations determine the reason for the deterioration. Burial should be restarted only if appropriate measures can be put in place to prevent a recurrence of the pollution.

6.2.3 Further work

The two year long data base for groundwater quality and water level fluctuations at Branston in Lincolnshire has been described (Section 2.2.2 and in the Project Record P2/024/1). Routine monitoring of groundwater at this site should be continued, to provide a longer term data set on which to assess possible impact from the adjacent cemetery. Agency staff in a number of Regions suggested that evidence of the effect of cemeteries on groundwater or surface water could be gathered from a small number of other sites. The sites are identified in Table 6.2 and it is suggested that they should be investigated.

Table 6.2 Summary of possible sites for field monitoring of the potential impact of cemeteries on water quality.

Agency Region	Location	Potential source of data
Anglian	King's Cliffe, Northamptonshire	Private well in vicinity of proposed churchyard extension. Water to be tested regularly by Environmental Health
Southern	Not given. On Chalk covered by shallow gravel.	Borehole within 7 metres of nearest grave. Originally licensed to British Rail, later to ferry company.
South West	Combe Martin, Devon	Located at the confluence of two streams. Potential for upstream and downstream monitoring.
	Barnstaple, Devon	"Grey" water in stream below cemetery after rain.

If viable monitoring points are found to exist, the database on potential impacts could be expanded to a more representative level by initiating routine monitoring at these locations. The information accrued from an extended monitoring network should be reviewed critically, after not longer than two years, to assess its value.

REFERENCES

Anon (1990) *Water Well Journal* **44**(8), 8.

Beak Consultants Ltd (1992) Soil and Groundwater Quality Study of the Mount Pleasant Cemetery. Prepared for Commemorative Services of Ontario and Arbor Capital Inc.

Blakey, N.C. and Towler, P.A. (1988) The effect of unsaturated/saturated zone properties on the hydrogeochemical and microbiological processes involved in the migration and attenuation of landfill leachate components. *Water Science and Technology* **20**(3), 119-128.

Bouwer, H. (1978) Groundwater Hydrology. McGraw Hill Book Company. p 423-424.

Bradfield, J.B. (undated) Green Burial The d-i-y guide to law and practice. 2pp. The Natural Death Centre, 20 Heber Road, London, NW2 6AA.

Davies, Jonathan (1998) Midlands School of Embalming (01527 584 654) *pers telecomm*, 21.05.98.

Dent, B.B. and Knight, M.J. (1998) Cemeteries: A special kind of landfill. The context of their sustainable development. Groundwater: Sustainable Solutions Conference, Melbourne, Feb '98, IAH.

Department of the Environment 1993 Waste Management Paper No 26. Landfill Completion: A technical memorandum providing guidance on assessing the completion of licensed landfill sites. 48 pp. HMSO, London. ISBN 0 11 752807 2.

Department of the Environment (1994) Waste Management Paper No 4. Licensing of Waste Management Facilities - Guidance on the drafting, supervision and surrender of Waste Management Licences. 74 pp. HMSO, London. ISBN 0 11 752727 0.

Department of the Environment (1995) A guide to risk assessment and risk management for environmental protection. 92 pp. HMSO. ISBN 0 11 753091 3.

Environment Agency, Southern Region (1997) Agency submissions to Planning Appeal Inquiry APP/J2210A/96/268769. Application for installation of a sub-surface irrigation system for treating trade effluent at Thruxted Mill, Pennypot Lane, Waltham, Kent. Canterbury, February 1997.

Environment Agency (1998) Policy and practice for the protection of groundwater (Second Edition). 57 pp. 1 map. HMSO, London. ISBN 0-11-310145 7.

Forbes, G.B. (1987) Human Body Composition; Growth, Ageing, Nutrition and Activity. Springer-Verlag, New York, 380p.

Gerba, C.P. and Bitton, G (1994) Microbial pollutants: Their survival and transport pattern to groundwater. In: *Groundwater Pollution Microbiology* (Gerba and Bitton (eds.)), 65-88.

Holmes, B. (1896) The London Burial Grounds: Notes on their history from the earliest times to the present day. T. Fisher Unwin, London.

Jones, H. and Nedwell, D.B. (1989) Methane attenuation in granular growing media. Research Report CWM 003/89. 25 pp. Waste Technical Division, Department of the Environment.

Knight, M.J. and Dent, B.B. (1996) A Watery Grave - The Role of Hydrogeology in Cemetery Practice. Australian Cemeteries and Crematoria Association 1995, National Conference in Sydney. Reproduced in *Institute of Burial & Cremation Administration, Summer 1996.*

Knight, M.J. and Dent, B.B. (1998) Sustainability of waste and groundwater management systems. Groundwater: Sustainable Solutions Conference, Melbourne, Feb '98, IAH.

Lewin, K, Young, C.P., Sims, P., Blakey, N.C., Oakes, D.B., Reynolds, P. and Bradshaw, K. (1996) Long-term monitoring of non-contained landfills: Burntstump and Gorsethorpe on the Sherwood Sandstone. 101 pp. 9 Appendices. Report CWM 138/96. Waste Technical Division, Department of the Environment, London.

Ministry of Agriculture, Fisheries and Food (1991) Code of Good Agricultural Practice for the Protection of Water. 80 pp. MAFF Publications, London.

Ministry of Agriculture, Fisheries and Food (1998) The Water Code (Revised 1998) Code of Good Agricultural Practice for the Protection of Water. 97 pp. MAFF Publications, London.

Nash, George (1997) P*ers. comm.* 20 October 1997.

Pacheco, A., Mendes, J.M.B., Martins, T., Hassuda, S. and Kimmelman, A. (1991) Cemeteries - a potential risk to groundwater. *Water Science Technology.* **24** (11) 97-104.

Pedley, S. and Guy, H. (1996) The public health implications of microbiological contamination of groundwater. *Quarterly Journal of Engineering Geology.* **30**, 179-188.

Pentecost, A. (1997) The Last Word. *New Scientist* No 2098, p 97. 6 September 1997.

Pentecost, A. (1998) *Pers. comm.* 27 January 1998.

Polson, C.J. and Marshall, T.K. (1975) The Disposal of the Dead, 3rd edition. The English Universities Press Ltd. ISBN 0 340 16247 3.

Polytechnic of East London (1992) Theoretical estimates of methane yield from refuse. Report ETSU B 1318 Department of Trade and Industry.

Ricketts, Nick (1998) Chairman, Association of Private Pet Cemeteries and Crematoria. *Pers. telecomm.* 2 June 1998.

Robinson, H.D. (1995) A review of the composition of leachates from domestic wastes in landfill sites. Report CWM/072/95. 500 pp. Waste Technical Division - Department of the Environment.

Soo Chan, G., Scafe, M., Emani, S. (1992) Cemeteries and groundwater: An examination of the potential contamination of groundwater by preservatives containing formaldehyde. Water Resources Branch, Ontario Ministry of the Environment, February 1992. Queen's Printer for Ontario, ISBN 0-7729-9199-5.

Standing Committee of Analysts (1986) The sampling and initial preparation of sewage and waterworks sludges, soils, sediments, plant materials and contaminated wildlife prior to analysis (Second Edition). 29 pp. HMSO, London. ISBN 0 11 751885 9.

Statham, Chris (1998) Managing Director, Kenyon International Emergency Services. *Pers. telecomm.* 22 May 1998.

Suflita, J.M., Gerba, C.P., Ham, R.K., Palmisano, A.C., Rathje, W.L. and Robinson, J.A. (1992) The World's largest landfill. *Environmental, Science and Technology* **26**, 1486-1494.

Taylor, D.M., Woodgate, S.L. and Atkinson, M.J. (1995) Inactivation of the bovine spongiform encephalopathy agent by the rendering procedures. *Veterinary Record* **137**. 605-610.

United States Environmental Protection Agency (1988) Report to Congress: Solid Waste Disposal in the United States. Volume 1, EPA/530 - SW - 88 001B; Volume 2, EPA/530-86-007F, Washington DC, October 1988.

Water Supply (Water Quality) Regulations (1989).

van der Honing, H., Brinkman, F.J.J., van der Ende, P.J. and Hooimeijer, A. (1988) The quality of surface water, drainage water and groundwater near cemeteries.(in Dutch). *H_2O* **21**(12), 327-331.

van Haaren, F.W.J. (1951) Cemeteries as sources of groundwater contamination. *Water.* **35**(16), 167-172.

West, Kenneth (1998) Cemeteries Manager, Carlisle (01228 525 022) *Pers. telecomm*, 21.05.98.

APPENDIX A VULNERABILITY CLASS ASSESSMENT

In order to provide a means of comparing the relative risks associated with different hydrogeological situations, numerical values may be assigned to the categories listed in Table A.1.

Table A.1 Groundwater vulnerability ranking chart

Ranking	**Very low**	**Low**	**Moderate**	**High**	**Very high**
Drift type	Clay	Silt	Silty sand	Sand /gravel	Absent
Drift thickness	>5 m	>3 - 5m	3 m	0 - 3m	Absent
Depth to water table	>25 m	11 - 25m	10 m	5 - 9m	< 5m
Flow mechanism	Intergranular				Fissured
Aquifer	Non-aquifer		Minor aquifer		Major aquifer
Abstraction and SPZ	Outside Zone III	Within Zone III	Close to boundary of Zones II & III	Within Zone II	Within Zone I or <250 m from private source
Watercourses, springs	>100 m	>70 <100 m	>50 <70 m	>30 <50 m	<30m
Drains	>100 m	>40 <100 m	30 - 40 m	>10 <30 m	<10 m

In order to illustrate the use of numerical scores, assume two sites with the characteristics listed in Table A.2.

Table A.2 Characteristics of example sites

Factor	**Site 1**	**Site 2**
Drift type	Silty sand	No drift
Drift thickness	3 metres	Absent
Depth to water table	> 25 metres	5 metres
Flow mechanism	Fissure with intergranular storage	Fissure
Aquifer classification	Major Aquifer	Minor aquifer
Abstraction / SPZ	Zone III	Zone II
Watercourses, springs.	> 100 metres	80 metres
Drains	> 100 metres	20 metres.

A simple scoring scheme based on a scale of 1 to 10, is suggested, distributed thus:

- Very high vulnerability 10 - 9
- High vulnerability 8 - 7
- Moderate vulnerability 6 - 5
- Low vulnerability 4 - 3
- Very low vulnerability 2 -1

Entering the respective values into a simple score-sheet (Table A.3) Site 1 scores slightly below the potential average (40 points), suggesting that it is moderately vulnerable, whereas the score for Site 2 (56 - 64) indicates that it is of high vulnerability.

Table A.3 Vulnerability assessment - score sheet comparisons of Sites 1 and 2

Factor	Site 1	Site 2
Drift type	6 - 5	10 - 9
Drift thickness	6 - 5	10 - 9
Depth to water table	2 - 1	8 - 7
Flow mechanism	6 - 5	10 - 9
Aquifer	10 - 9	6 - 5
Abstractions and SPZ	4 - 3	8 - 7
Watercourses, springs	2 - 1	4 - 3
Drains	2 - 1	8 - 7
Total scores (range)	38 - 30	64 - 56

The positions of individual factors within a risk category are unlikely to be fixed and local knowledge should be applied to determine position within a class. Accumulation of local/ regional experience would refine and build confidence in the assessments.

APPENDIX B ESTIMATION OF POLLUTION LOAD FROM BURIALS

B1 Background data

A detailed elemental compositional breakdown for the human body has been given by Forbes (1987). In Table B1 this is compared with the composition of fresh domestic wastes (Polytechnic of East London, 1992) and with municipal solid waste which had been within a landfill for between 4 and 7 years (Lewin *et al.* 1996). The database for elemental composition of household/commercial/municipal wastes is sparse and incomplete, but comparison with Forbes (1987) information on the human body suggests a number of important differences and similarities:

- The "as delivered" water content of a human body is about twice that of domestic refuse. Lack of available moisture may inhibit both aerobic and anaerobic decay of wastes (Department of the Environment, 1995) and it would be expected that the high moisture content of human (and animal) bodies would encourage rapid decay processes.
- The C:N:P ratio in human cadavers (about 30:3:1) provides a good balance between the principal microbial nutrients; the ratio for municipal waste (about 2000:20:1) is extremely deficient in phosphorus.
- The proportion of the alkali earth metals Ca, Na and K are similar in corpses and municipal wastes, but municipal wastes contain significantly higher proportions of Mg and Fe.

Table B1 Comparison of the composition of a human body with municipal wastes (values % of wet weight)

Component	Human Body (1)	Fresh Domestic Waste (2)	4 - 7 Year Old Waste (3)
C	22.9	44.0	60.3
N	2.6	0.6	0.7
Ca	1.6		2.0
Mg	0.03		0.4
Na	0.1		0.1
K	0.2		0.2
P	0.7		0.03
S	0.2		0.1
Cl	0.1		0.1
Fe	0.006		1.4
Heavy metals	Trace		1.1
Water	71.6	34	33.6

Notes:
(1) Data from Forbes (1987) based on a 70 kg cadaver
(2) Data from Figure 2 and Table 18, Polytechnic of East London (1992)
(3) Values recalculated to wet weight from Appendices D1 and D3, Lewin *et al.* (1996)

The proportion of carbon in household wastes estimated by Environment and Industry Research Unit, Polytechnic of East London (1992) includes carbon rich materials which are either non-degradable or only slowly degraded (such as plastic and cardboard). In comparison, some 70% of the as received weight (including water) of a human corpse comprises rapidly degradable protein, carbohydrates and lipids, with some 30% comprising resistant bone, enamel (teeth) and keratin (nails and hair). Allowing for a 70 kg corpse, buried in a 10 kg chipboard coffin, the relative rate of degradation compared with fresh household waste is given in Table B2.

Table B2 Comparison of readily to slowly degraded matter of a coffined human corpse with fresh household waste

Component	Category %			
	Readily degradable	Moderately degradable	Slowly degradable	Inert (non-degradable)
Human corpse	60	15	20*	5*
Fresh household waste	18	12	31	39

Note * Assumes mineral salts (ashes) represent final stable residue; slowly degradable component of bones may be considered essentially inert for practical purposes.

The proportions of potential contaminants in a corpse, and the amounts of pollution which may be released, are made on the basis of the individual corpse. The volume of ground occupied by remains, and the relative weights of bodies and soil in a filled burial ground, are estimated below.

Assumptions:

Burials, 1976 per hectare (800 per acre), each burial 80 kg (70 kg corpse, 10 kg coffin)
Grave dimensions 2.1 x 1.2 x 1.8 m (7 feet long, 4 feet wide, 6 feet deep)
Depth of coffin - lid to base - 0.4 m (16 inches)
Density of soil 2.0 tonnes per m^3

Volume comparison:-

Soil , 1 hectare to 1.8 m = 18 000 m^3
Burials, 2.1 x 1.2 x 0.4 x 1976 = 1992 m^3.
1992 / 18 000 = 11% total volume (i.e. eight times as much soil as coffin, by volume).

Weight comparison :

Volume of soil 1 hectare to 1.8 m , less coffin volume (18 000 - 1976) = 16024 m^3
Weight of soil (16024 x 2.0) = 32048 tonnes
Weight of burials (1976 x 0.08) = 158 tonnes
Burials represent 158 / (32048 + 158) = 0.5% of total mass (i.e. soil comprises over 99% of total weight).

B2 Amounts of pollution released by human burial

Taking the elemental proportions for a corpse given in Table B1, and assuming that 75% of the carbonaceous matter is moderately or readily degradable (Table B2), then theoretical annual releases, for a 70 kg corpse, may be assessed (Table B3).

Table B3 Annual potential release (kg) of contaminants from a single 70 kg burial

Year	TOC	NH_4	Ca	Mg	Na	K	P	SO_4	Cl	Fe
1	6.0	0.87	0.56	0.01	0.05	0.07	0.25	0.21	0.048	0.02
2	3.0	0.44	0.28	0.005	0.025	0.035	0.125	0.11	0.024	0.01
3	1.5	0.22	0.14	0.003	0.013	0.018	0.063	0.054	0.012	0.005
4	0.75	0.11	0.07	0.001	0.006	0.009	0.032	0.027	0.006	0.003
5	0.37	0.05	0.03	<0.001	0.003	0.004	0.016	0.012	0.003	0.001
6	0.19	0.03	0.02	<0.001	0.002	0.002	0.008	0.006	0.002	<0.001
7	0.10	0.01	0.01	<0.001	0.001	0.001	0.004	0.003	<0.001	<0.001
8	0.05	<0.01	<0.01	<0.001	<0.001	<0.001	0.002	0.001	<0.001	<0.001
9	0.02	<0.01	<0.01	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
10	0.01	<0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

B3 Estimation of flux of water

Assuming a mean annual rainfall of 650 mm (typical of much of central and southern lowland England) typical annual evapotranspirative losses and infiltration values would be:

Surface type	Evapotranspiration ($mm\ yr^{-1}$)	Infiltration ($mm\ yr^{-1}$)
Chippings	350	300
Grass	450	200
Trees / shrubs	550	100

The superficial dimensions of a standard grave are 1.2 by 2.1 metres (2.5 m^2), so that in one year the volume of infiltrating water would be (based on the hypothetical rainfall example given above) :

Surface type	Annual volume, litres
Chippings	750
Grass	500
Trees/shrubs	250

Application of such infiltration estimates to, for example, the releases of ammonia and chloride predicted from consideration of the composition of the human body, suggests initial concentrations of the order of 900 to 2700 mg l^{-1} of ammonia and 25 to 70 mg l^{-1} of chloride in effluent, the former being comparable to the concentrations reported from landfill leachate derived from fresh domestic waste.

However, lateral flows and dispersion within the unsaturated zone is likely to mix the products of decay with water infiltrating through the areas separating individual graves. A grave density of 2740 per hectare (1000 per acre) is commonly assumed, but in practical terms, making allowance for driveways, paths etc., the overall density in municipal cemeteries is closer to 1976 per hectare (800 per acre), so that each grave may be considered to be centred in an area of about 12.5 m^2. Grave density at green burial sites is about 80% of that at typical lawn (municipal) cemeteries, that is about 1580 per hectare (640 per acre), each with a contributing area of close to 15.5 m^2. The annual infiltration volume for each grave area may then be estimated (again using the model rainfall conditions stated above, and assuming that the areas between graves are grass covered):

Surface type	Infiltration from grass surrounds	Infiltration for surface	Total annual infiltration (litres)
Chippings	2000	750	2750
Grass	2000	500	2500
Trees/shrubs (Green burial)	2600	250	2850

These approximations may then be used to estimate the possible average composition of effluent reaching the water table beneath a burial ground. Three scenarios are examined, based on the assumptions with respect to timing and rate of contaminant release (Table B3) and for the model values of rainfall and evapotranspiration employed above. The scenarios are:

1. Small churchyard, serving community of 3000 - 4000, 10 burials per year, grass cover;
2. Large municipal cemetery, serving Metropolitan/County Borough of 100 000, 350 burials per year, half grass cover, half chippings;
3. Green (woodland) burial site, 30 burials per year.

It should be noted that the assumptions regarding the rate and duration of release of potential contaminants imply that after ten years, at a constant annual burial rate, the annual release of contaminants will reach equilibrium. However, because the area of burials will continue to expand, the predicted concentrations of contaminants in effluent **averaged over the whole burial ground** will continue to decrease.

Country churchyard

The predicted area occupied by burials, annual volume of effluent produced and predicted concentrations for ammonia and chloride in the effluent for a burial ground accepting 10 per year are listed in Table B4.

Table B4 Example of estimates of effluent concentrations, small burial ground

Year	Cumulative area of burials (m^2)	Annual effluent production (litres)	Average concentration NH_4 (mg l^{-1})	Average concentration Cl (mg l^{-1})
1	125	25 000	348	19
2	250	50 000	262	14
3	375	75 000	204	11
4	500	100 000	164	9.0
5	625	125 000	135	7.4
6	750	150 000	114	6.3
7	875	175 000	98	5.4
8	1000	200 000	87	4.8
9	1125	225 000	77	4.2
10	1250	250 000	69	3.8

Large municipal cemetery

The predicted areas, volumes and concentrations for a municipal cemetery receiving 350 burials per year are shown in Table B5.

Table B5 Example of estimates of effluent concentrations, large municipal cemetery

Year	Cumulative area of burials (m^2)	Annual effluent production (litres)	Average concentration NH_4 (mg l^{-1})	Average concentration Cl (mg l^{-1})
1	4 375	918 750	331	18
2	8 750	1 837 500	249	14
3	13 125	2 756 250	194	11
4	17 500	3 675 000	156	8.6
5	21 875	4 593 750	129	7.1
6	26 250	5 512 500	109	6.0
7	30 625	6 431 250	94	5.2
8	35 000	7 350 000	82	4.5
9	39 375	8 268 750	73	4.0
10	43 750	9 187 500	66	3.6

Estimation of the possible release of formaldehyde from embalming can be made: assuming an average of 9 litres of 2% formalin solution per body (Davies, 1998) is used and that 50% of the formaldehyde is broken down by the putrefaction process (Soo Chan *et al*, 1992), then the potential release per embalmed body is 0.1 litres formaldehyde (9 x 0.5 x 0.02). If all were leached within one year and infiltration conditions were as discussed for the model cemeteries discussed above, it would produce an effluent of about 40 mg l^{-1}. If the release were to follow the pattern postulated for other potential contaminants, then a maximum concentration of 20 mg l^{-1} would be predicted, with a ten year averaged value of less than 5 mg l^{-1}.

Green (woodland) burial ground

The predicted areas, volumes and concentrations for a green burial ground receiving 30 burials per year are shown in Table B6.

Table B6 Example of estimates of effluent concentrations, green (woodland) burial ground

Year	Cumulative area of burials (m^2)	Annual effluent production (litres)	Average concentration NH_4 (mg l^{-1})	Average concentration Cl (mg l^{-1})
1	465	85 500	305	16
2	930	171 000	230	13
3	1395	265 500	173	9.5
4	1860	342 000	144	7.9
5	2325	427 500	119	6.5
6	2790	513 000	100	5.6
7	3255	598 500	86	4.8
8	3720	684 000	76	4.2
9	4185	769 500	67	3.7
10	4650	855 000	61	3.3

B4 Estimation of pollutant load from mass burial of animals

The body weights of farm stock and the size of typical herds are listed in Table B7, where they are combined with relative body weight factors to estimate the total pollution load (as kg N) which could be imposed. In making the estimates it is assumed that a herd is composed of 70% adults and 30% juveniles.

Examination of the table suggests that the greatest threat may come, not from the slaughter of herds of cattle, but from the disposal of culled poultry, in particular turkeys, which by virtue of the very large size of commercial flocks may impose a high aggregate pollution load. Nevertheless, significant loadings may arise from cattle culls, particularly if a "convenient" quarry or pit is employed for the disposal of carcasses from several farms. An example of the latter occurred at a location between Ripon and Harrogate during the early days of the BSE crisis, where up to 1400 carcasses are reputed to have been buried in an unlined quarry.

Table B7 Estimates of potential contaminant loads from mass burial of animals, based on liveweights and group sizes

Class of animal	Typical juvenile weight (kg)	Typical adult weight (kg)	Flock / herd size	Potential pollution load (kg N)
CATTLE				
Milker	35 (birth)	500 (24 months)	70	616
Beef	35 (birth)	600 (below 30 months)	70	736
Sheep	8 (6 weeks)	80	700 (but even distribution between 300 and 2000)	1 000
PIGS	25 (piglet)	90	250	430
POULTRY				
Chickens		3	50% of flocks >20 000	1 470
Turkeys		5 - 14	92% >100 000 <1% below 5000	24 400
Ducks		3	1000	73
Geese		10	1000	244